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At Edmund Optics® (EO), we specialize in creating cost effective solutions that meet our customer's specifications and timelines. Our goal is for each of your projects to be as successful as possible, and for you to have the very best experience along the way – whether you are in the early stages of development or ready for OEM production, we are here to answer your questions and help solve your applications.



Over the last few years, higher performance imaging and rapid sensor technology developments have greatly impacted our lives through advancements in industrial automation, medical testing, autonomous vehicles, and virtual reality. As the imaging industry continues to advance and possibilities for new and improved systems and devices continues to evolve, we face new technological challenges, but EO will continue to innovate and develop products to push forward into new creative solution spaces. We believe customer success is understanding and have therefore included over 52 pages of technical material, with three new sections on Pixel Size and Optics, Lens Spacers and Shims, and Ruggedization of Imaging Lenses.

We look forward to hearing from you – whatever the need – and hope to continue to be your partner in imaging optics.

Warm regards,
Greg Hollows &
the EO Imaging Team

PHONE & ONLINE CHAT

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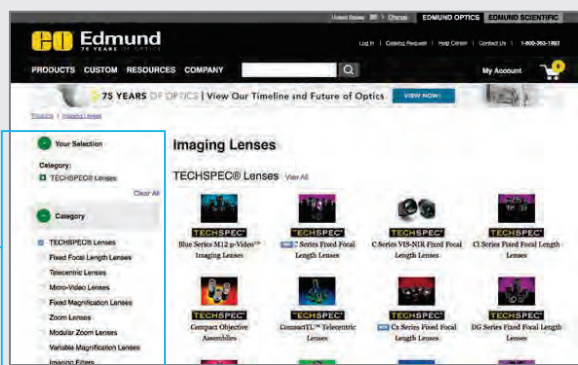
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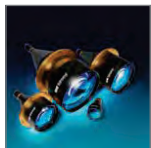


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Imaging Resource Guide



Whether your application is in machine vision, life sciences, security, or traffic solutions, understanding the fundamentals of imaging technology significantly eases the development and deployment of sophisticated imaging systems. While advancements in sensor and illumination technologies suggest limitless system capabilities, there are physical limitations in the design and manufacture of these technologies. Optical components are not an exception to such limitations, and optics can often be the limiting factor in a system's performance. The content provided in this guide is designed to help you specify an imaging system, maximize your system's performance, and minimize cost.

Section 1: Getting Started

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Section 1.1: 11 Best Practices for Better Imaging

We have compiled a number of best practices for creating sophisticated, cost-effective imaging systems that are applicable for most applications. While the following list is nearly exhaustive and should be considered when designing any imaging system, every application is unique and additional considerations may be required.

► EO Best Practice #1: Bigger, in many cases, is better. Allow ample room for the imaging system.

Understanding a system's space requirements before building is especially true for high resolution and high magnification requirements. While recent advancements in consumer camera technology have yielded strong results in a small package, they still do not approach the capabilities required for even intermediate-level industrial imaging systems – partially because of their size limitations. Many applications can require complex light geometries, large diameter and long length lenses, and large cameras, in addition to the cabling and power sources required to operate some of the equipment. Avoid having to make sacrifices to system performance just because the system's space requirements were not considered. It is often advantageous to specify the vision portion of a system first, as it is typically easier to arrange the electronics and mechanics around the vision portion rather than the other way around. It is also important to remember that the illumination scheme is part of the vision system, and the geometry of the object under inspection can often necessitate the use of a large light source such as a diffuse dome (see *EO Best Practice #4*).

► EO Best Practice #2: Don't believe your eyes.

The human eye and brain work together to form an extremely advanced imaging and analysis system that is capable of filling in information that is not necessarily there. Additionally, humans see and process contrast differently than imaging systems. Software analysis should be used to ensure image quality and performance requirements are met. Images that look good to a human viewer may not be usable with an algorithm.

► EO Best Practice #3: Danger! Don't get too close.

Due to the constraints of physics, attempting to look at fields of view that are too large relative to a lens's working distance places excessive demands on the design of the optical component and can decrease system performance. It is recommended that a lens be chosen such that the working distance is roughly two to four times as long as the desired field of view is wide, in order to maximize performance while minimizing cost and complexity. Remember *EO Best Practice #1* and

Best Practice #1 and #3: If a 100mm field of view is required, it is recommended that the system's working distance be 200 - 400mm. It may be possible that the system's performance requirements can be met at WD to FOV ratios approaching or exceeding 1 to 1, however, potentially significant cost and performance tradeoffs may be necessary.

Figure 1.1a

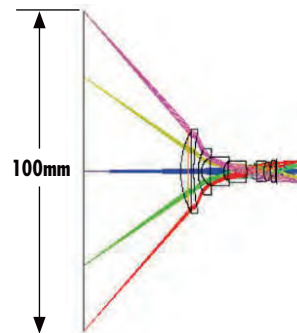


Figure 1.1b



Figure 1.1: Two lens designs, 1.1a and 1.1b, with the same field of view and very different working distances.

Both lenses in *Figure 1.1a* and *Figure 1.1b* are imaging the same field of view onto the same sensor, but the lens in *a* has a working distance of half of its field of view, while the lens in *b* has a working distance of 3X its field of view. The light passes through the lens in *a* at extreme angles and the light on the edges of the field of view (magenta/red) have a much longer distance to travel than the light in the center of the field of view (blue). In contrast, the lens in *b* achieves the same field of view at shallower angles with a smaller path length difference. As a result, the lens in *b* features a much less complex lens design and provides superior performance at a lower cost.

consider the imaging system's space requirement before building the system.

This practice also applies to the relationship between sensor size and focal length. It is best to have focal length to sensor diagonal ratios of two to four to maximize performance.

► **EO Best Practice #4: Light up your life.**
It really does matter.

While it can seem like an art form, selecting the appropriate lighting geometry is highly scientific. In order for a lens and sensor to effectively work together, strong contrast must be produced by properly lighting the object. The characteristics of the object under inspection and the nature of any defects must be understood so that the proper illumination geometry is used. Keep in mind that sometimes these lights can be very large (see *EO Best Practice #1*).

Learn more about illumination geometries on pages 152-155.

► **EO Best Practice #5: Color matters.**

The wavelength (color) selected for the illumination can have an enormous impact on improving or reducing system performance. For instance, in an application using both high quality optics and a top-of-the-line sensor, switching from broadband to monochromatic illumination, or between specific wavelengths, can improve performance by a significant amount. As with *EO Best Practice #4*, the proper choice of wavelength can make the difference between high contrast and no contrast. Depending on whether the wavelength is correctly chosen or not, the color of illumination can determine the success or failure of a system.

Learn how proper filtering techniques can have an impact on system performance on Pages 120-122.

► **EO Best Practice #6: There can be only one; high resolution and large depths of field struggle to co-exist.**

As shown in *Section 2.4*, maximizing resolution and depth of field requires the same variable, the lens's $f/\#$, to move in opposite directions. Essentially, it is impossible to have very high resolution over a large depth of field. Physics dictates that this cannot be done and compromises will need to be made or more elaborate solutions, such as using multiple imaging systems, will need to be employed.

► **EO Best Practice #7: There is no universal solution; a single lens that can do everything does not exist.**

As resolution requirements increase, the ability to decrease aberrations (attributes of optical design that adversely affect performance) becomes increasingly difficult over a wide range of working distances and fields of view. Even without budget constraints, there are limitations. For this reason a wide range of lens solutions for similar applications are required. More details are in *Section 3, pages 14-17* on Designing for Performance.

► **EO Best Practice #8: Be self-aware. Thoroughly understand the object to be inspected.**

The foundation of imaging is the ability to produce the highest level of contrast possible on the object under inspection, so an understanding of the object's properties, such as its materials or finishes, is critical to the application's success. Additionally, it is not enough to just know what parts are considered good or bad. Rather, to guarantee high levels of reliability and repeatability, the range of details that will be inspected and the margins for good and bad must be understood.

► **EO Best Practice #9: Be a control freak.**

The ability to control the environment into which the imaging system is deployed can significantly affect the reliability and consistency of results. Additionally, it also reduces the likelihood of unintended problems. Whether using filters to increase contrast, baffles to eliminate unwanted light from entering the system, or measurement devices to monitor light sources for spectral stability, controlling the environment will reduce unforeseen difficulties in the future. Some of these techniques are extremely low cost ways to protect and increase the performance of an expensive imaging system.

► **EO Best Practice #10: Be the squeaky wheel.**

Do not be afraid to ask why something will or will not work. Suppliers should be able to explain why different components in the system are or are not capable of achieving the desired result. The answer will not always be the same; sometimes the issues are laws of physics limitations and sometimes they are deficiencies related to the design or fabrication of the component. Optical manufacturing is a science, and the designers and manufacturers should be capable of explaining why things are happening.

► **EO Best Practice #11: Make a list; understand and define the fundamental parameters of the imaging systems.**

By narrowing down the specific parameters required for the imaging system, the wide range of available lenses and sensors can be reduced to a manageable selection of components. Fundamental parameters of an imaging systems are a great place to start and are detailed in the next section.

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Section 1.2: Fundamental Parameters of an Imaging System

The following parameters are the most basic concepts of imaging and will be referenced throughout the remainder of this guide.

Field of View (FOV): The viewable area of the object under inspection. This is the portion of the object that fills the camera's sensor.

Working Distance (WD): The distance from the front of the lens to the object under inspection.

Resolution: The minimum feature size of the object that can be distinguished by the imaging system. Learn more in *Section 2.1*.

Depth of Field (DOF): The maximum object depth that can be maintained entirely in acceptable focus. DOF is also the amount of object movement (in and out of best focus) allowable while maintaining focus. Learn more in *Section 4.4, page 26*.

Sensor Size: The size of a camera sensor's active area, typically specified in the horizontal dimension. This parameter is important in determining the proper lens magnification required to obtain a desired field of view.

PMAG: The **P**rimarily **M**agnification of the lens is defined as the ratio between the sensor size and the FOV. Although sensor size and field of view are fundamental parameters, it is important to realize that PMAG is not.

$$\text{PMAG} = \frac{\text{sensor size (mm)}}{\text{field of view (mm)}}$$

1.1

Note: Typically, only horizontal values are used.

Figure 1.2

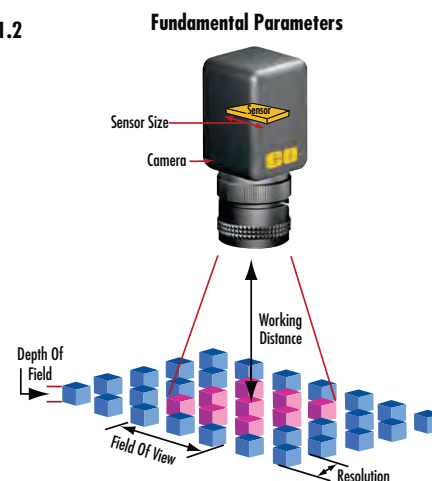


Figure 1.2: Illustration of fundamental parameters of an imaging system.

Section 1.3: Understanding Focal Length and Field of View

Fixed Focal Length Lenses

A **Fixed Focal Length Lens**, also known as a conventional or entocentric lens, is a lens with a fixed **Angular Field of View (AFOV)**. By focusing the lens for different working distances, differently sized Fields of View (FOV) can be obtained, though the viewing angle is held constant. AFOV is typically specified as the full angle (in degrees) associated with the horizontal dimension (width) of the sensor that the lens is to be used with.

Note: Fixed Focal Length Lenses should not be confused with **Fixed Focus Lenses**. Fixed Focal Length Lenses have the ability to be focused for different distances; Fixed Focus Lenses are intended for use at a single, specific working distance. Examples of Fixed Focus Lenses are many Telecentric Lenses and Microscope Objectives.

The focal length of a lens defines the lens's angular field of view. For a given sensor size, the shorter the focal length, the wider the angular field of the lens. Additionally, the shorter the focal length of the lens, the shorter the distance needed to obtain the same FOV compared to a longer focal length lens. For a simple, thin convex lens, the focal length is the distance from the back of the lens to the plane of the image formed of an object placed infinitely far in front of the lens. From this definition, it can be shown that the angular field of view of a lens is related to the focal length (*Equation 1.2*), where f is the focal length in millimeters and h is the horizontal dimension of the sensor in millimeters (*Figure 1.3*).

$$\text{AFOV}(\text{°}) = 2 \times \tan^{-1} \left(\frac{h}{2f} \right) \quad 1.2$$

In general, however, the focal length is measured from the lens's rear **principal plane**, which is rarely located at the mechanical back of an imaging lens; this is one of the reasons that working distances calculated using **paraxial** equations are only approximations and the mechanical

design of a system should only be laid out using data produced by computer simulation or data taken from lens specification tables. Paraxial calculations, as from lens calculators, are a good starting point to speed the lens selection process, but the numerical values produced should be used with caution.

When using Fixed Focal Length Lenses, there are three ways to change the field of view of the system (camera and lens). The first and often easiest option is to change the working distance from the lens to the object; moving the lens farther away from the object plane increases the field of view. The second option is to swap out the lens that is being used with one of a different focal length. The third option is to change the size of the sensor that is being used; a larger sensor will yield a larger field of view for the same working distance, as defined in *Equation 1.2*.

While it may often be convenient to have a very wide angular field of view, there are some negatives to consider. First, the level of distortion that is associated with some short focal length lenses can greatly influence the actual AFOV and can cause variations in the angle with respect to Working Distance (WD) due to the varying magnitude of the distortion. Next, short focal length lenses generally struggle to obtain the highest level of performance when compared against longer focal length options (see Best Practice #3 in *Section 1.1, page 4*). Additionally, short focal length lenses can have difficulties covering medium to large sensor sizes, which can limit their usability, as discussed in *Section 4.2, pages 20-23*.

Another way to change the field of view of a system is to use either a **Varifocal Lens** or a **Zoom Lens**; these types of lenses allow for the adjustment of their focal lengths and thus have variable angular fields of view. Varifocal and Zoom Lenses often have drawbacks in terms of size and cost in comparison to Fixed Focal Length Lenses, and often cannot offer the same level of performance as Fixed Focal Length Lenses.

Figure 1.3

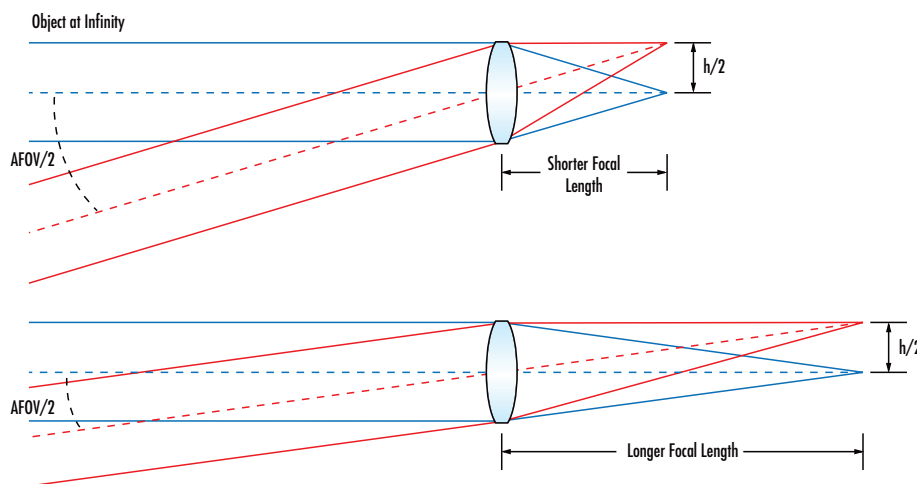


Figure 1.3: For a given sensor size, h , shorter focal lengths produce wider AFOV's.

Using WD and FOV to Determine Focal Length

In many applications, the required distance from an object and the desired field of view (typically the size of the object with additional buffer space) are known quantities. This information can be used to directly determine the required angular field of view via the formulas shown in *Equation 1.3*, where WD is the Working Distance from the lens and AFOV is the Angular Field of View. *Equation 1.3* is the equivalent of

finding the vertex angle of a triangle with its height equal to the working distance and its base equal to the horizontal field of view, as shown in *Figure 1.4*. **Note:** In practice, the vertex of this triangle is rarely located at the mechanical front of the lens, from which working distance is measured, and should only be used as an approximation unless the entrance pupil location is known.

$$\text{AFOV}(\text{°}) = 2 \times \tan^{-1} \left(\frac{\text{Horizontal FOV (mm)}}{2 \times \text{WD (mm)}} \right) \quad \text{or} \quad \text{Horizontal FOV (mm)} = 2 \times \text{WD (mm)} \times \tan \left(\frac{\text{AFOV}(\text{°})}{2} \right) \quad 1.3$$

Once the required AFOV has been determined, the focal length can be approximated using *Equation 1.2* and the proper lens can be chosen from a lens specification table or datasheet by finding the closest available focal length with the necessary angular field of view for the sensor being used.

The 14.25° derived in Example 1 (see white box below) can be used to determine the lens that is needed, but the sensor size must also be chosen. As the sensor size is increased or decreased it will change how much of the lens's image is utilized; this will alter the AFOV of the system and thus the overall FOV. The larger the sensor, the larger the obtainable AFOV for the same focal length. For example, a 25mm lens could be used with a ½" (6.4mm horizontal) sensor or a 35mm lens could be used with a ⅔" (8.8mm horizontal) sensor as they would both approximately produce a 14.5° angular FOV on their respective sensors.

Alternatively if the sensor has already been chosen, the focal length can be determined directly from the FOV and WD by substituting *Equation 1.2* in *Equation 1.3*, as shown in *Equation 1.4*,

$$FL = \frac{(h \times WD)}{\text{Horizontal FOV}} \quad 1.4$$

where, h is the horizontal sensor dimension (number of horizontal pixels multiplied by the pixel size) and FL is the focal length of the lens, both in millimeters; the FOV and WD must be measured in the same unit system. As previously stated, some amount of flexibility to the system's working distance should be factored in, as the above examples are only first-order approximations and they also do not take distortion into account.

Calculating FOV Using a Lens with a Fixed Magnification

Generally, lenses that have fixed magnifications have fixed or limited working distance ranges. While using a Telecentric or other Fixed Magnification Lens can be more constraining, as they do not allow for different fields of view by varying the working distance, the calculations for them are very direct, as shown in *Equation 1.5*.

$$\text{Horizontal FOV (mm)} = \frac{\text{Horizontal Sensor Size (mm)}}{\text{PMAG}} \quad 1.5$$

Since the desired FOV and sensor are often known, the lens selection process can be simplified by restructuring *Equation 1.5* into *Equation 1.6*.

$$\text{PMAG} = \frac{\text{Horizontal Sensor Size (mm)}}{\text{Horizontal FOV (mm)}} \quad 1.6$$

If the required magnification is already known and the working distance is constrained, *Equation 1.4* can be rearranged (replacing h/FOV with magnification) and used to determine an appropriate fixed focal length lens, as shown in *Equation 1.7*.

$$\text{PMAG} = \frac{FL}{WD} \quad 1.7$$

Be aware that *Equation 1.7* is an approximation and will rapidly deteriorate for magnifications greater than 0.1 or for short working distances. For magnifications beyond 0.1, either a Fixed Magnification Lens or computer simulations (e.g. Zemax) with the appropriate lens model should be used. For the same reasons, lens calculators commonly found on the internet should only be used for reference. When in doubt, consult a lens specification table.

Note: Horizontal FOV is typically used in discussions of FOV as a matter of convenience, but the sensor aspect ratio (ratio of a sensor's width to its height) must be taken into account to ensure that the entire object fits into the image where the aspect ratio is used as a fraction (e.g. 4:3 = ⅔), *Equation 1.8*.

$$\text{Horizontal FOV} = \text{Vertical FOV} \times \text{Aspect Ratio} \quad 1.8$$

Figure 1.4

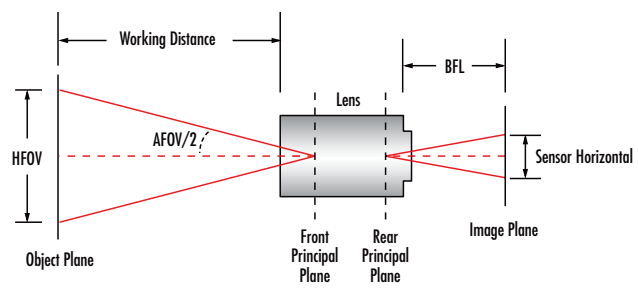


Figure 1.4: Relationship between HFOV, sensor size, and WD for a given angular FOV.

LENS FOCAL LENGTH EXAMPLES

Using WD and FOV to Determine Focal Length

Example 1: For a system with a desired working distance of 200mm and a horizontal FOV of 50mm, what is the Angular Field of View (AFOV)?

$$2 \times \tan^{-1} \left(\frac{50\text{mm}}{2 \times 200\text{mm}} \right) = \text{AFOV}(\text{°})$$

$$\text{AFOV} = 14.25\text{°}$$

Calculating FOV Using a Lens with a Fixed Magnification

Example 2: For an application using a ½" sensor, which has a horizontal sensor size of 6.4mm, a horizontal FOV of 25mm is desired.

$$\text{PMAG} = \frac{6.4\text{mm}}{25\text{mm}} \quad \text{PMAG} = 0.256\text{X}$$

By reviewing a list of Fixed Magnification or Telecentric Lenses, a proper magnification can be selected. **Note:** As the magnification increases, the size of the field of view will decrease; a magnification that is lower than what is calculated is usually desirable so that the full field of view can be visualized. In the case of *Example 2*, a 0.25X lens is the closest common option, which yields a 25.6mm FOV on the same sensor.

While most sensors are 4:3, 5:4 and 1:1 are also quite common. This distinction in aspect ratio also leads to varying dimensions of sensors of the same **sensor format**. All of the equations used in this section can also be used for vertical FOV as long as the sensor's vertical dimension is substituted in for the horizontal dimension specified in the equations.

Section 2: Understanding Lens Specifications



Understanding a manufacturer's specifications for a lens can greatly simplify the research and purchasing processes. In order to know how a lens works, it is critical to understand resolution, magnification, contrast, f/#, and how to read common performance curves including Modulation Transfer Function (MTF), Depth of Field (DOF), Relative Illumination, and distortion.

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Section 2.1: Resolution

Resolution is a measurement of an imaging system's ability to reproduce object detail and can be influenced by factors such as the type of lighting used, the pixel size of the sensor, or the capabilities of the optics. The smaller the object detail, the higher the required resolution.

Dividing the number of horizontal or vertical pixels on a sensor into the size of the object one wishes to observe will indicate how much space each pixel covers on the object and can be used to estimate resolution. However, this does not truly determine if the information on the pixel is distinguishable from the information on any other pixel.

As a starting point, it is important to understand what can actually limit system resolution. An example can be shown in *Figure 2.1*: a pair of squares on a white background. If the squares are imaged onto neighboring pixels on the camera sensor, then they will appear to be one larger rectangle in the image (a) rather than two separate squares (b). In order to distinguish the squares, at least one pixel needs to be between them. This minimum distance is the limiting resolution of the system. The absolute limitation is defined by the size of the pixels on the sensor as well as the number of pixels on the sensor.

The Line Pair and Sensor Limitations

The relationship between alternating black and white squares is often described as a **line pair**. Typically, the resolution is defined by the frequency measured in line pairs per millimeter (lp/mm). A lens's resolution is unfortunately not an absolute number (learn more in *Section 3*). At a given resolution, the ability to see the two squares as separate entities will be dependent on grey scale level. The bigger the separation in the grey scale between the squares and space between them (*Figure 2.1b*), the more robust is the ability to resolve the squares. This grey scale separation is known as contrast (at a specified frequency). The spatial frequency is given in lp/mm. For this reason, calculating resolution in terms of lp/mm is extremely useful when comparing lenses and for determining the best choice for given sensors and applications. Contrast is explained in more detail in *Section 2.3*.

The sensor is where the system resolution calculation begins. By starting with the sensor, it is easier to determine what lens performance is required to match the sensor or other application requirements. The highest frequency which can be resolved by a sensor, the **Nyquist frequency**, is effectively two pixels or one line pair. *Table 2.1* shows the Nyquist limit associated with pixel sizes found on some highly used sensors. The resolution of the sensor, also referred to as the image space resolution for the system, can be calculated by multiplying the pixel size in μm by 2 (to create a pair), and dividing that into 1000 to convert to mm:

$$\text{sensor resolution in lp/mm} = \frac{\text{image space resolution in lp/mm}}{2 \times \text{pixel size } (\mu\text{m})} = \frac{1000\mu\text{m/mm}}{2 \times \text{pixel size } (\mu\text{m})} \quad 2.1$$

Sensors with larger pixels will have lower limiting resolutions. Sensors with smaller pixels will have higher limiting resolutions. How this information is used to determine necessary lens performance can be found in *Section 3*.

With this information, the limiting resolution on the object to be viewed can be calculated. In order to do so, the relationships between the sensor size, the field of view, and the number of pixels on the sensor need to be understood.

Figure 2.1

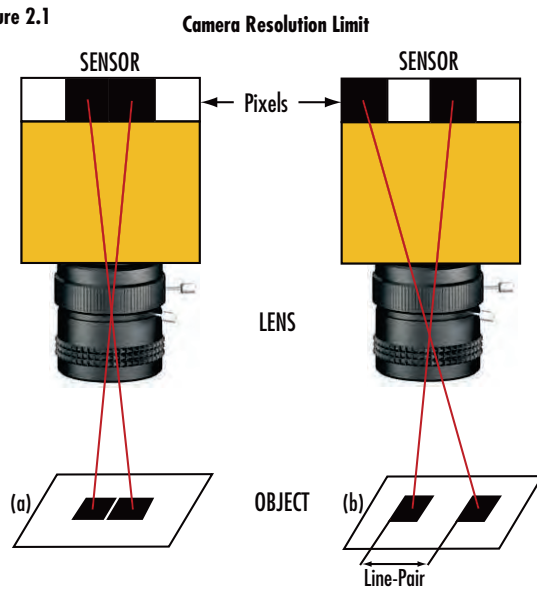


Figure 2.1: Resolving two squares. If the space between the squares is too small (a) the camera sensor will be unable to resolve them as separate objects.

Sensor size refers to the size of a camera sensor's active area, typically specified by the **sensor format** size (*Page 143*). However, the exact sensor proportions will vary depending on the aspect ratio, and the nominal sensor formats should be used only as a guideline, especially for telecentric lenses and high magnification objectives. The sensor size can be directly calculated from the pixel size and the number of active pixels on the sensor.

$$\text{Horizontal sensor dimension in mm} = \frac{(\text{Horizontal pixel size in } \mu\text{m}) \times (\# \text{ of active horizontal pixels})}{1000\mu\text{m/mm}} \quad 2.2$$

$$\text{Vertical sensor dimension in mm} = \frac{(\text{Vertical pixel size in } \mu\text{m}) \times (\# \text{ of active vertical pixels})}{1000\mu\text{m/mm}} \quad 2.3$$

Pixel Size (μm)	Associated Nyquist Limit (lp/mm)
1.67	299.4
2.2	227.3
3.45	144.9
4.54	110.1
5.5	90.9

Table 2.1: As pixel sizes get smaller the associated Nyquist limit in lp/mm rises proportionally.

Section 2.2: Object Space Resolution

In order to determine the absolute minimum resolvable spot that can be seen on the object, the ratio of the field of view to the sensor size needs to be calculated. This is also known as the Primary Magnification (PMAG) of the system.

$$\text{PMAG} = \frac{\text{sensor size (mm)}}{\text{field of view (mm)}} \quad 2.4$$

The ratio associated with system PMAG allows for the scaling of the imaging space resolution which tells us the resolution of the object.

$$\text{object space resolution in (lp/mm)} = \text{image space resolution (lp/mm)} \times \text{PMAG} \quad 2.5$$

Generally when developing an application, a system's resolution requirement is not given in lp/mm, but rather in microns (μm) or fractions of an inch.

There are two ways to make this conversion:

$$\text{object space resolution } (\mu\text{m}) = \frac{1000\mu\text{m/mm}}{2 \times \text{object space resolution in (lp/mm)}} \quad 2.6$$

Or

$$\text{object space resolution } (\mu\text{m}) = \frac{\text{pixel size } (\mu\text{m})}{\text{PMAG of the system}} \quad 2.7$$

While one can quickly jump to the limiting resolution on the object by using the last formula, it is very helpful to determine the imaging space resolution and PMAG to simplify lens selection. It is also important to keep in mind that there are many additional factors involved, and this limitation is often much lower than what can be easily calculated using the equations. Learn more about lenses and contrast limitations in *Sections 2.3 and 3*.

Section 2.3: Contrast

Contrast describes how well black can be distinguished from white at a given resolution on an object. For an image to appear well defined, the black details need to appear black and the white details must appear white (See *Figure 2.2*). The more the black and white information trend into the intermediate greys, the lower the contrast at that frequency. The greater the difference in intensity between a light and dark line, the better the contrast. While this may appear obvious, it is critically important.

The contrast at a given frequency can be calculated in *Equation 2.8*, where I_{max} is the maximum intensity (usually in pixel greyscale values, if a camera is being used) and I_{min} is the minimum intensity:

$$\% \text{ Contrast} = \frac{(I_{\text{max}} - I_{\text{min}})}{(I_{\text{max}} + I_{\text{min}})} \times 100 \quad 2.8$$

The lens, sensor, and illumination all play key roles in determining the resulting image contrast. Each one can detract from the overall contrast of a system at a given resolution if not applied correctly and in concert with one another.

(Continued on page 10)

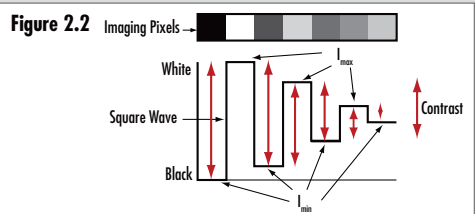


Figure 2.2: Understanding contrast. Transition from black to white is high contrast while intermediate greys indicate lower contrast.



RESOLUTION AND MAGNIFICATION CALCULATION EXAMPLES USING A SONY ICX 625 SENSOR

Known Parameters:

Pixel Size = $3.45 \times 3.45\mu\text{m}$

Number of Pixels (H x V) = 2448×2050

Desired FOV (Horizontal) = 100mm

Limiting Sensor Resolution:

$$\text{image space resolution in lp/mm} = \frac{1000\mu\text{m/mm}}{2 \times \text{pixel size } (\mu\text{m})}$$

$$\text{image space resolution in lp/mm} = \frac{1000\mu\text{m/mm}}{2 \times 3.45\mu\text{m}} \approx 145 \text{ lp/mm}$$

Sensor Dimensions:

$$\text{horizontal sensor dimension in mm} = \frac{(3.45\mu\text{m}) \times (2448)}{1000\mu\text{m/mm}} = 8.45\text{mm}$$

$$\text{vertical sensor dimension in mm} = \frac{(3.45\mu\text{m}) \times (2050)}{1000\mu\text{m/mm}} = 7.07\text{mm}$$

PMAG:

$$\text{PMAG} = \frac{8.45\text{mm}}{100\text{mm}} = 0.0845X$$

Resolution:

$$\text{object space resolution} = 145 \text{ lp/mm} \times 0.0845 = 12.25 \text{ lp/mm} \approx 41\mu\text{m}$$

CONTRAST EXAMPLE

The ability to resolve detail is directly related to both a lens's ability to reproduce contrast and the number of pixels utilized. The images below are of the same test target, but taken by two different lenses using the same number of pixels on the sensor. Both images are cropped from the center of the sensor. Each lens's ability to reproduce contrast is the determining factor in the performance of the system.

Lens 1 yields a contrast level of 22.6%, while Lens 2 produces a contrast level of 12.7%. This is a 78% difference in performance between the two lenses, even though the systems look somewhat equivalent to the human eye.

It must also be understood that a lens will not necessarily produce the same contrast at the same frequency across the entire FOV. Additionally, contrast levels will change as a lens's f/# is adjusted. More detail on this can be found in *Sections 2.4 and 2.5*.



Lens 1



Lens 2

(Continued from page 9)

Lenses and Contrast Limitations

Lens contrast is typically defined in terms of the percentage of the object contrast that is reproduced when assuming ideal illumination. Resolution is actually somewhat meaningless unless defined at a specific contrast. In *Section 2.1*, the example assumed perfect reproduction on the object, including sharp transitions at the edge of the object on the pixel. However, in reality this is never the case. Because of the nature of light, even a perfectly designed and manufactured lens cannot fully reproduce an object's resolution and contrast. Even when the lens is operating at the diffraction limit (described in *Section 3.1*), the edges of the dots in *Figure 2.3* will be blurred in the image. This is where calculating a system's resolution by simply counting pixels loses accuracy, and can even become completely ineffective.

Consider two dots close to each other being imaged through a lens, as in *Figure 2.3*. When the spots are far apart (in other words, at a low frequency), the dots are distinct, though both somewhat blurry at the edges. As they approach each other, the blurs overlap until the dots can no longer be distinguished as separate entities. The system's actual resolving power depends on the imaging system's ability to detect the space between the dots. Even if there are ample pixels between the spots, if the spots blend together due to lack of contrast, they will not easily be resolved as two separate details. Therefore, the resolution of the system depends on many things, including blur caused by diffraction and other optical errors, the dot spacing, and the sensors ability to detect contrast.

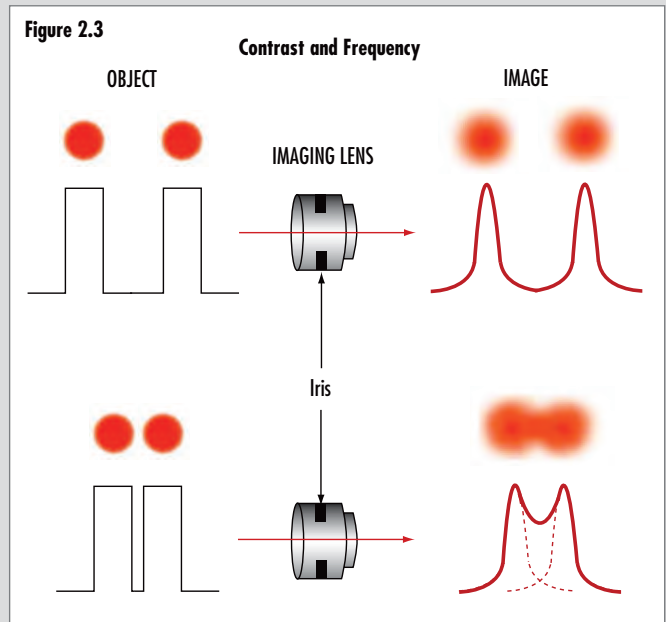


Figure 2.3: Two spots being imaged by the same lens. The top lens is imaging objects at a low frequency, the bottom lens is imaging objects at a higher frequency.

Section 2.4: f/# (Lens Iris/Aperture Setting)

The f/# setting on a lens controls many of the lens's parameters: overall light throughput, depth of field, and the ability to produce contrast at a given resolution. Fundamentally, f/# is the ratio of the effective focal length (EFL) of the lens to the effective aperture diameter (D_{EP}):

$$f/\# = \frac{EFL}{D_{EP}} \quad (\text{See Figure 2.4a}) \quad 2.9$$

In most lenses, the f/# is set by the turning the iris adjusting ring, thereby opening and closing the iris diaphragm inside. The numbers labeling the ring denote light throughput with its associated aperture diameter. The numbers usually increase by multiples of $\sqrt{2}$. Increasing the f/# by a factor of $\sqrt{2}$ will halve the area of the aperture, effectively decreasing the light throughput of the lens by a factor of 2. Lenses with lower f/#s are considered fast and allow more light to pass through the system, while lenses of higher f/#s are considered slow and feature reduced light throughput.

Table 2.2 shows an example of f/#, aperture diameters, and effective opening size for a 25mm focal length lens. Notice that from the setting of f/1 to f/2, and again for f/4 to f/8, the lens aperture is reduced by half and the effective area is reduced by a factor of 4 at each interval. This illustrates the reduction in throughput associated with increasing a lens's f/#.

f/#	Lens Aperture Diameter (mm)	Aperture Opening Area (mm ²)
1	25.0	490.8
1.4	17.9	251.6
2	12.5	122.7
2.8	8.9	62.2
4	6.3	31.2
5.6	4.5	15.9
8	3.1	7.5

Table 2.2: The relationship between f/# and effective area for a 25mm singlet lens. As the f/# increases, the area decreases, leading to a slower system with less light throughput.

► f/# and Effects on a Lens's Theoretical Resolution, Contrast, and DOF:

The f/# impacts more than just light throughput. Specifically, f/# is directly related to the theoretical resolution and contrast limits and the Depth of Field (DOF) and depth of focus of the lens. Additionally, it will influence the aberrations of a specific lens design.

As pixels continue to decrease in size, f/# becomes one of the most important limiting factors of a system's performance because its effects on DOF and resolution move in opposite directions. As shown in *Table 2.3*, the requirements are often in direct conflict and compromises must be made.

f/#	Diffraction Limited Resolution	Depth of Field	Light Throughput	Numerical Aperture
▲ ▼	▼ ▲	▲ ▼	▼ ▲	▼ ▲

Table 2.3: Lens performance changes as the f/# varies.

f/# Changes with Working Distance Change: – ADVANCED

The definition of f/# in *Equation 2.9* is limited in the sense that it is defined at an infinite working distance where the magnification is effectively zero. Most often in machine vision applications, the object is located much closer to the lens than an infinite distance away, and f/# is more accurately represented by the working f/#, *Equation 2.10*.

$$(f/\#)_w \approx (1 + |m|) \times f/\# \quad 2.10$$

In the equation for **working f/#**, *m* represents the paraxial magnification (ratio of image to object height) of the objective. Note that as *m* approaches zero (as the object approaches infinity), the working f/# is equal to the infinite f/#. It is especially important to keep working f/# in mind at smaller working distances. For example, an f/2.8, 25mm focal length lens operating with a magnification of -0.5X will have an effective working f/# of f/4.2. This impacts image quality as well as the lens's ability to collect light.



f/# and Numerical Aperture (NA) – ADVANCED

It can often be easier to talk about overall light throughput in a lens in terms of the cone angle, or the numerical aperture (NA), of a lens. The **numerical aperture** of a lens is defined as the sine of the marginal ray angle in image space, and is shown in *Figure 2.4*.

Figure 2.4a

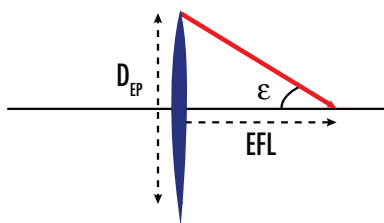


Figure 2.4b

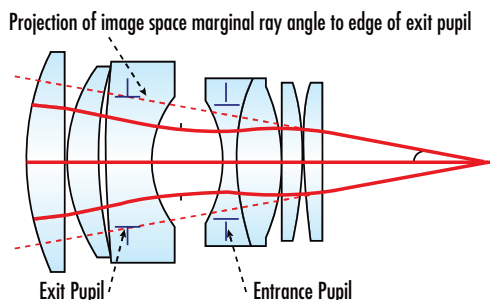


Figure 2.4: Visual representation of f/#, both for a simple lens (a) and a real-world system (b).

It is important to remember that f/# and NA are inversely related.

$$NA = \frac{1}{2(f/\#)} \quad 2.11$$

Table 2.4 shows both a typical f/# layout on a lens (each successive figure increasing by a factor of $\sqrt{2}$) along with its relationship with numerical aperture.

f/#	1.4	2	2.8	4	5.6	8	11	16
NA	0.36	0.25	0.18	0.13	0.09	0.06	0.05	0.03

Table 2.4: Relationship between f/# and numerical aperture.

Notation in terms of numerical aperture as opposed to f/# is especially common in microscopy, but it is important to keep in mind that the NA values that are specified for microscope objectives are specified in object space, since light collection is often more easily thought of there. The other interesting parallel is that infinite conjugate microscope objectives can be thought of as machine vision objectives (focused at infinity) in reverse.

More on f/# effects on resolution can be found in the sections on MTF, the Diffraction Limit, and the Airy Disk. Details on f/# and DOF can be found *Section 4.4*.

f/# greatly impacts all of the following sections and is a very important concept to understand.

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Section 2.5 Limitations on Resolution and Contrast: The Airy Disk – ADVANCED

When light passes through any size aperture (every lens has a finite aperture), diffraction occurs. The resulting diffraction pattern, a bright region in the center together with a series of concentric rings of decreasing intensity around it, is called the **Airy Disk** (see *Figure 2.5*).

The diameter of this pattern is related to the wavelength (λ) of the illuminating light and the size of the circular aperture, which is important since the Airy Disk is the smallest point to which a beam of light can be focused. As focused Airy patterns from different details on the object come close together, they begin to overlap (refer to *Section 2.3* for more information on contrast). When the overlapping patterns create enough constructive interference to reduce contrast, as in *Figure 2.3*, they eventually become indistinguishable from each other. *Figure 2.5* shows the difference in spot sizes between a lens set at f/2.8 and a lens set at f/8.

As pixels continue to reduce in size, this effect becomes more of an issue and eventually is very difficult to overcome. The Airy Disk, or minimum spot size can be calculated using the f/# and wavelength in μm :

$$\text{minimum spot size (Airy Disk diameter) in } \mu\text{m} = 2.44 \times \lambda (\mu\text{m}) \times f/\# \quad 2.12$$

Table 2.5 shows the calculated Airy Disk diameter for different f/#s using green light (520nm or 0.520 μm). The smallest achievable spot size can quickly exceed the size of small pixels. This leads to difficulties when trying to yield the full resolution capacities of a sensor with any usable level of contrast. Additionally, this does not take into account any lens design limitations and manufacturing errors associated with the fabrication of lens elements and optical assemblies, which can lead to reductions in the ability to produce the smallest physically achievable spot and thus reduced levels of resolution and contrast. **Note:** This is all theoretical and is the starting point for limitations in an optical system.

Figure 2.5

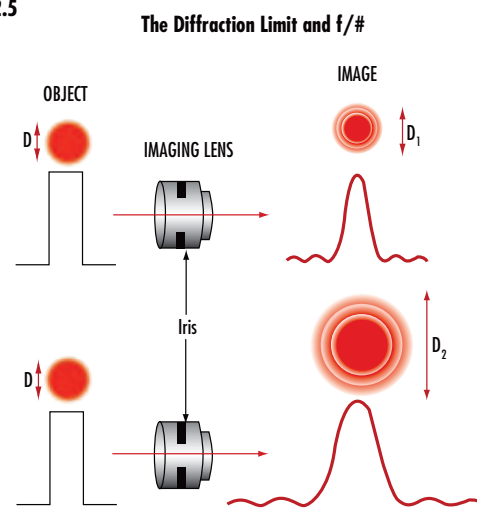


Figure 2.5: Diffraction increases as the imaging lens iris is closed (f/# increases).

f/#	Airy Disk Diameter (μm) at a Wavelength of 520nm
1.4	1.78
2	2.54
2.8	3.55
4	5.08
5.6	7.11
8	10.15
11	13.96
16	20.30

Table 2.5: The minimum spot size, or Airy Disk, increases with f/# and can quickly surpass pixel size. See *Table 2.1* for sample pixel sizes.

Section 2.6: Lens Performance Curves

Understanding and calculating a lens's performance can be a difficult task. There are many variables that will affect a lens's performance, including the laws of physics, design criteria and philosophy, and manufacturing tolerances and errors. In order to obtain optimal system performance, both optical designers and the end users have access to several metrics that can be used to measure a lens's performance. These curves are often provided to help specify the correct lens.

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to **download comprehensive datasheets**
for all TECHSPEC® imaging lenses which
feature these performance curves.



Modulation Transfer Function (MTF)

The Modulation Transfer Function (MTF) curve is an information-dense metric that reflects how a lens reproduces contrast as spatial frequency (resolution) varies. These curves offer a composite view of how optical aberrations affect performance at a particular set of fundamental parameters dictated by the application's need. It is important to understand that changing almost any setting on a vision system, including the fundamental parameters, will change the performance characteristics of the curve. How MTF is calculated and the limits of MTF are detailed in *Section 3.2*; Fundamental parameters are defined in *Section 1.2*.

Figure 2.6 shows a common type of MTF curve, which describes the modulus of the optical transfer function (contrast) vs. frequency (resolution). How frequency is determined is covered in *Section 2.1*. This curve provides a broad overview of a lens's performance at a specific working distance, $f/\#$, sensor size, and wavelength range.

In regards to our presentation, there are multiple colored curves (black, blue, green, and red) that are displayed. The solid black line at the top is the diffraction limit of the lens, and represents the absolute limit of the lens performance. No matter how advanced the lens performance becomes, it will never rise above this line. The additional

colored lines on the curve that are below the diffraction limit represent the MTF performance of the lens. They correspond to different field heights (positions across the sensor) that are to be used. In this case, there are three different field heights represented: on-axis (blue), which represents the center of the image circle; 70% of the diameter of the image circle (green), which represents about half the image area; and the full image circle (red), which is the corner of the image sensor that is in use. Note that some curves will contain more field points for analysis.

The other noteworthy feature within the curves is the difference between solid and dashed lines, represented on the curve by the letters T and S, which represent the **tangential** (T: yz) and **sagittal**, or "radial" (S: xz) planes of focus, respectively. These fields are different due to aberrations that are caused by asymmetry, such as astigmatism, which is why there is not a separate curve for tangential and sagittal on-axis. If element tilts or decenters existed, the asymmetry would cause there to be different T and S curves on-axis, as well.

The MTF curve is a map of contrast vs. frequency. Interpretation of an MTF curve is highly application dependant.

Figure 2.6

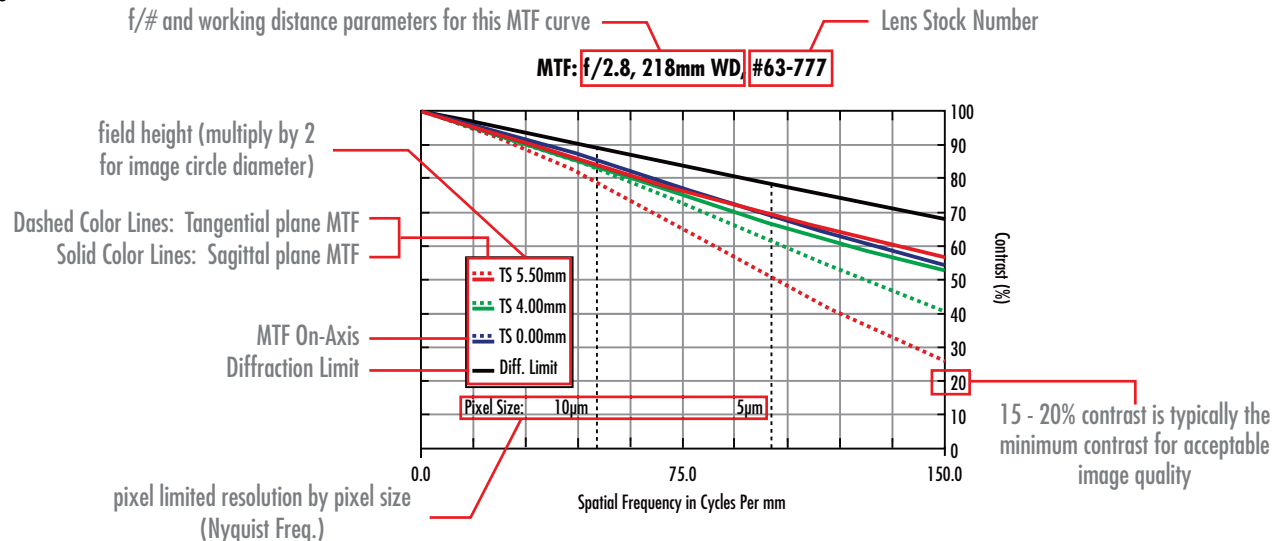


Figure 2.6: An MTF performance curve illustrates contrast vs. frequency.

Depth of Field (DOF)

The Depth of Field (DOF) plot displays how the MTF changes as details of a specific size (resolution, given as a frequency) move closer to, or farther away from, the lens without refocusing. In other words, how the contrast changes above and below the specified working distance. Figure 2.7 shows the type of DOF curve provided in TECHSPEC® lens datasheets.

The depth of field plot shows the differences in MTF based on constant field heights (the different colors of the individual curves) for a

fixed spacial frequency on the image side, with the diffraction limit left out. As the MTF is sampled at different positions along the optical axis, defocus is introduced into the system. In general, as defocus is introduced, the contrast will decrease. The horizontal line toward the bottom of the curve represents the depth of field at a specific contrast level (in this case, 20%). The generally accepted minimum contrast for a machine vision system to maintain accurate results is 20%.

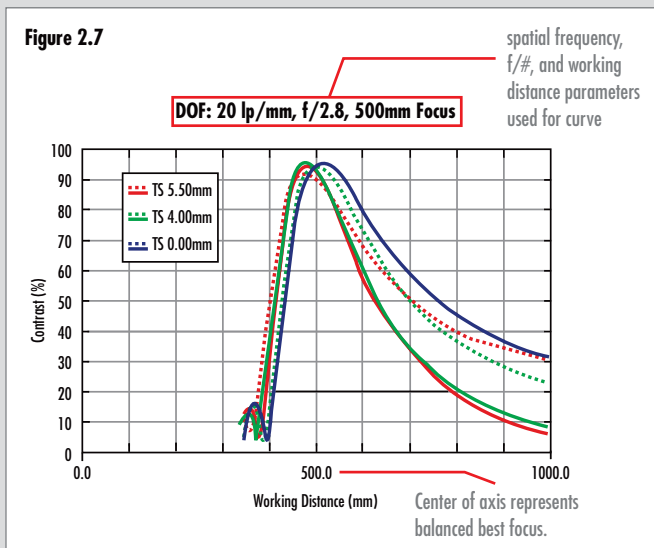


Figure 2.7: Depth of field performance curve shows how contrast changes with working distance.

Relative Illumination

The Relative Illumination curve is used to quantify changes in the illumination level across the sensor. Changes in illumination can have undesired effects on the final image when it comes to analysis. Details on what causes RI changes can be found in *Section 4.2* on Relative Illumination. The curve in *Figure 2.8a* shows a typical relative illumination curve, with the relative brightness (relative to the brightest point in the image) vs. field height.

The different individual curves represent the relative illumination performance based on f/#. Note that as the f/# increases, relative illumination generally increases. Be careful not to confuse this with absolute brightness, as higher f/#s will still cause an overall brightness decrease. Learn more about f/# in *Section 2.4*.

The x-axis represents the distance from the center of the sensor to the corner of the sensor. The y-axis indicates how much illumination exists at any position in the field relative to the point of highest illumination, typically the center of the field, set equal to 100%. In order to clarify how the lens's relative illumination will perform across different sensors, dotted lines representing different sensor diagonals have been included in the plots. *Figure 2.8b* is a projection of how the relative illumination in *Figure 2.8a* will look at f/1.4 in a real world image. Learn more about relative illumination in *Section 4.2, page 20*.

Distortion

In an imaging system, distortion causes apparent magnification changes with respect to field position. There are many ways to represent distortion, but *Figure 2.9* shows field height vs. geometric distortion percentage, which is a typical plot that lens designers and engineers utilize to characterize distortion. Learn more about distortion in *Section 4.5, pages 29-30*.

The plot in *Figure 2.9* shows distortion as the percentage of magnification shift (x-axis) moving from the center of the image to the corner of the image (y-axis). The larger the absolute percentage of distortion, the larger the difference between the ideal image map and the distorted one.

Our curves are shown for one point in space and performance will vary at other points. Please contact **EO Technical Support** for details relating to your application.
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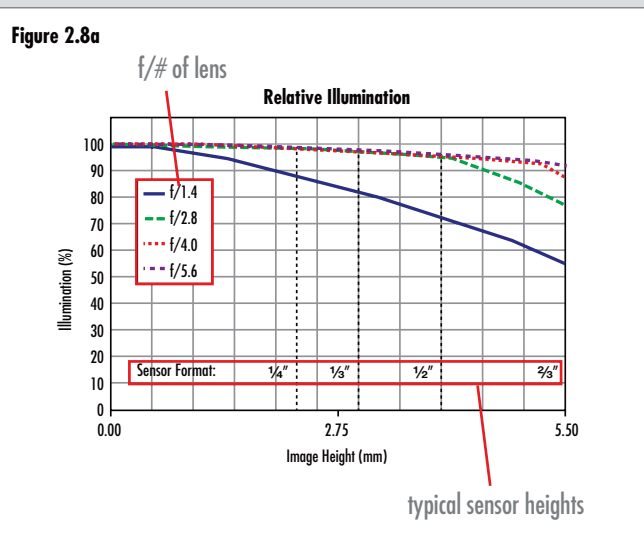


Figure 2.8a: A relative illumination curve shows the relative brightness vs. field height at various f/#s.

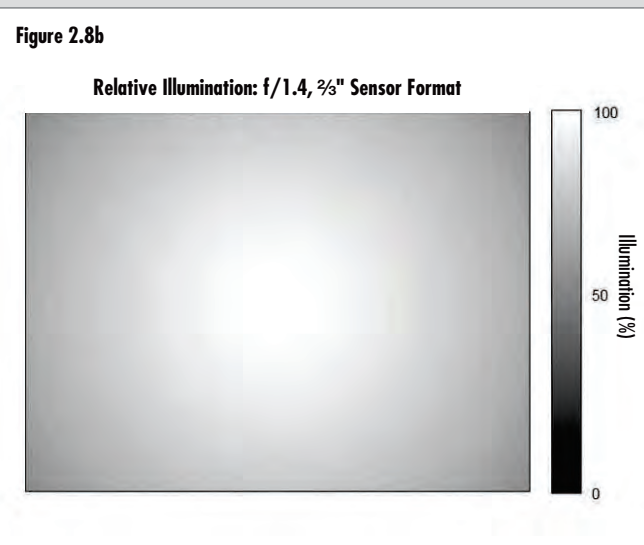


Figure 2.8b: This plot shows how the f/1.4 curve blue in 2.8a will appear across a 2/3" image sensor.

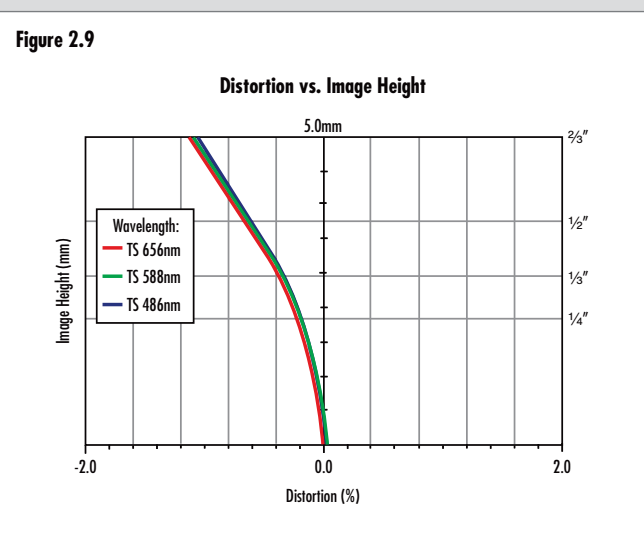


Figure 2.9: A distortion curve illustrates the magnification shift from the center of the image to the edge.

Section 3: Understanding Lens Design Limitations

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Section 3.1: Diffraction Limit:

Every lens has an absolute upper performance limit dictated by the laws of physics. This limitation is controlled by the working $f/\#$ of the lens and the wavelength(s) of light that pass through the lens. Known as the **Diffraction Limit**, this limitation is given in line pairs/mm and determines the theoretical maximum resolving power of the lens. Even a perfect lens that is not limited by design will be diffraction limited. This limit is the point where two Airy patterns (*Section 2.5*) are no longer distinguishable from each other. To calculate the diffraction limit, a simple formula that relates it to the $f/\#$ of the lens and the wavelength of light can be used. Learn more about $f/\#$ in *Section 2.4*.

$$\text{Diffraction Limit (lp/mm)} = \frac{1000\mu\text{m/mm}}{f/\# \times \text{wavelength (in } \mu\text{m)}} \quad 3.1$$

After the diffraction limit is reached, the lens becomes incapable of resolving greater frequencies. The diffraction limit detailed in *Table 3.1* shows contrast at 0% for given frequencies. These numbers may appear rather high, but are strictly theoretical – a number of other practical factors must also be considered. First, as a general rule, imaging sensors cannot reproduce information at or near 0% contrast. Due to inherent noise, contrast generally needs to be above 10% to be reliably detected on standard imaging sensors. To avoid imaging complications, it is recommended to target 20% contrast or higher at the application's critical lp/mm resolution. Additionally, lens aberrations and variations associated with manufacturing tolerances also reduce performance. **Modulation Transfer Function (MTF)** curves are used to determine whether a lens will effectively utilize a sensor's capabilities and fulfill the desired application's requirements.



$f/\#$	0% Contrast Limit (lp/mm) @ 0.520 μm
1.4	1374
2	962
2.8	687
4	481
5.6	343
8	240
11	175
16	120

Table 3.1: The diffraction limit calculated at different $f/\#$ s for 0.520 μm light (green light).

Section 3.2: Modulation Transfer Function (MTF) and MTF Curves:

MTF curves show resolution and contrast information simultaneously allowing a lens to be evaluated based on the requirements for a specific application and can be used to compare the performance of multiple lenses. Used correctly, MTF curves can help determine if an application is actually feasible. For information on how to read an MTF curve, see *Section 2.6*.

Figure 3.1 is an example of an MTF curve for a 12mm lens used on the Sony ICX625 sensor, which has a sensor format of $\frac{2}{3}"$ and 3.45 μm pixels. Sensor format is described in the camera section on *Pages 142-145*. The curve shows lens contrast over a frequency range from 0 lp/mm to 150 lp/mm (the sensor's limiting resolution is 145 lp/mm). Additionally, this lens has its $f/\#$ set at 2.8 and is set at a PMAG of 0.05X, which yields a FOV of approximately 170mm for 20X the horizontal dimensions of the sensor. This FOV/PMAG will be used for all examples in this section. White light is used for the simulated light source.

This curve provides a variety of information. The first thing to note is that the diffraction limit is represented by the black line. The black line indicates that the maximum theoretically possible contrast that can be achieved is almost 70% at the 150 lp/mm frequency, and that no lens design, no matter how good, can perform higher than this. Additionally, there are three colored lines: blue, green, and red. These lines correspond to how this lens performs across the sensor in the center (blue), the 0.7 position at 70% of the full field on the sensor (green), and the corner of the sensor (red), respectively. It is clearly shown that at lower and higher frequencies contrast reproduction is not the same across the entire sensor and, thus, not the same over the FOV.

Additionally, it can be seen that there are two green and two red lines.

Figure 3.1

MTF: $f/2.8$, 150mm WD, 12mm FL

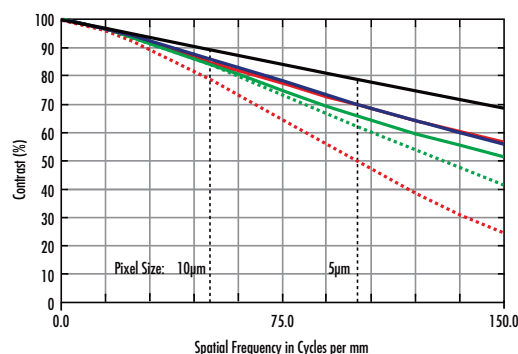


Figure 3.1: MTF curve for a 12mm lens used on the Sony ICX625 sensor.

These lines represent the tangential and sagittal contrast components associated with detail reproduction that is not in the center of the FOV. Due to aberrational effects (*Section 6, pages 36-38*), a lens will produce spots that are not completely round and will therefore have different sizes in the horizontal and vertical orientation. This size variation leads to spots blending together more quickly in one direction than the other, and produces different contrast levels in different axes at the same frequency. It is very important to consider the implications of the lower of these two values when evaluating a lens for a given application. It is generally advantageous to maximize the contrast level across the entire sensor to gain the highest levels of performance in a system.

Comparing Lens Designs and Configurations

► Example 1: Comparison of two different lens designs with the same focal length (FL), 12mm, at f/2.8

Figure 3.2 examines two different lenses of the same focal length that have the same FOV, sensor, and f/#. These lenses will produce systems that are the same size but differ in performance. In analysis, the horizontal light blue line at 30% contrast on Figure 3.2a demonstrates that at least 30% contrast is achievable essentially everywhere within the FOV, which will allow for the entire capability of the sensor to be well-utilized. For Figure 3.2b, nearly all of the field is below 30% contrast. This means that better image quality will only be achievable over a small portion of the sensor. Also to note, the orange box on both curves represents the intercept frequency of the lower performance lens in Figure 3.2b with 70% contrast. When that same box is placed on Figure 3.2a, a tremendous performance difference can be seen even at lower frequencies between the two lenses.

The difference between these lenses is the cost associated with overcoming both design constraints and fabrication variations; Figure 3.2a is associated with a much more complex design and tighter manufacturing tolerances. Figure 3.2a will excel in both lower resolution and demanding resolution applications where relatively short working distances for larger field of view are required. Figure 3.2b will work best where more pixels are needed to enhance the fidelity of image processing algorithms and where lower cost is required. Both lenses have situations where they are the correct choice, depending on the application.

► Example 2: Two different high resolution lens designs with different focal lengths: 12mm and 16mm at f/2.8

Figure 3.3 examines two different high resolution lenses with focal lengths of 12mm and 16mm that have the same FOV, sensor, and f/#. By looking at the lens's contrast at the Nyquist limit of Figure 3.3b (light blue line), a distinct performance increase can be seen when compared to Figure 3.3a. While the absolute difference is only about 10 - 12% contrast, the relative difference is closer to 33% considering the change from approximately 30% contrast to 42%. Another orange box has been placed on this graph, this time where Figure 3.3a hits 70% contrast. Note that the difference at this level is not as extreme as in the previous example. The tradeoff between these lenses is that the working distance for the lens in Figure 3.3b has an increase of about 33% but with a decent increase in performance. This follows the general guidelines outlined in the Best Practices Section 1.1.

► Example 3: Comparison of MTF for different f/#s of the same 35mm lens design

Figure 3.4 features the MTF for a 35mm lens design using white light at f/4 (a) and f/2 (b). The yellow line shows the diffraction-limited contrast at the Nyquist limit for Figure 3.4a on both graphs while the blue line denotes the lowest actual performance at the Nyquist limit of the same lens at f/4 in Figure 3.4a. While the theoretical limit of Figure 3.4b is far higher, the performance is much lower. This is an example of how a higher f/# can reduce the aberrational effects, greatly increasing performance of a lens, even though the theoretical performance limit is greatly reduced. The primary tradeoff besides resolution is less light throughput at the higher f/#.

(Continued on page 16)

Figure 3.2a

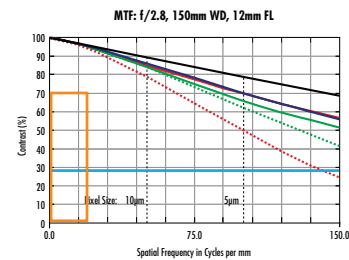


Figure 3.2b

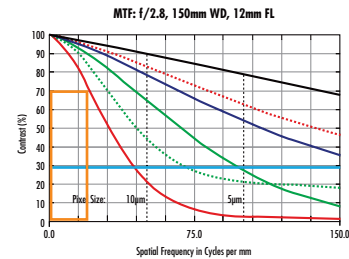


Figure 3.2: MTF curves for two lens designs (a and b) with the same focal length, f/#, and system parameters.

Figure 3.3a

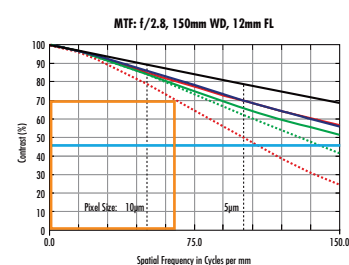


Figure 3.3b

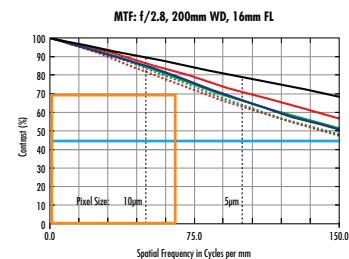


Figure 3.3: Two different high resolution lens designs with different focal lengths at the same f/# and system parameters.

Figure 3.4a

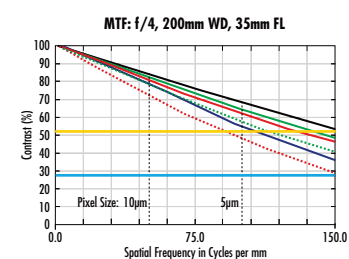


Figure 3.4b

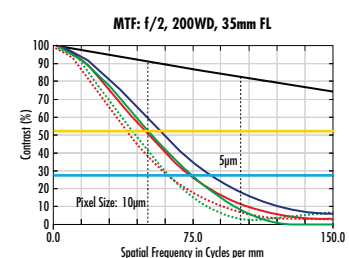


Figure 3.4: MTF curves for a 35mm lens at the same WD and different f/#s: f/4 (a) and f/2 (b).

Comparing Lens Designs and Configurations

► Example 4: The Effect of Changing Working Distance on MTF

For Figure 3.5, working distances of 200mm (a) and 450mm (b) are examined for the same 35mm lens design at f/2. A large performance difference can be seen, which is directly related to the ability to balance aberrational content in lens design over a range of working distances. Changing working distance, even with refocusing, will lead to variations or reductions in performance as the lens moves away from its designed range. These effects are most profound at lower f/#s. More details on these effects can be found in the section Designing to Balance Aberrations and the section on Aberrations in Section 6.1, page 36 and Section 6.2, page 37 respectively.

Visit WWW.EDMUNDOPTICS.COM/IMAGING
to download comprehensive datasheets
for all TECHSPEC® imaging lenses which
feature these MTF curves.



Figure 3.5a

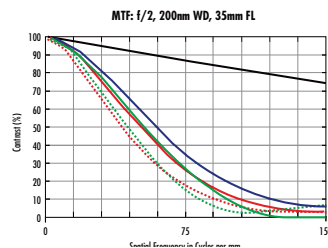


Figure 3.5b

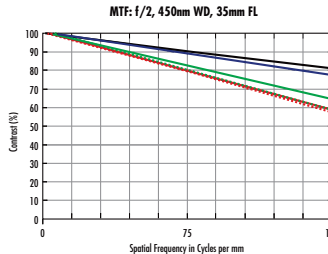


Figure 3.5: MTF curves for a 35mm focal length lens at f/2 with different working distances.

Section 3.3: Wavelength Effects on Performance

Different wavelengths bend at different angles as light passes through a medium (glass, water, air, etc.). This is commonly observed when sunlight passes through a prism and creates a rainbow effect; shorter wavelengths are bent more than longer ones. This same effect creates problems when trying to resolve details and gain information in imaging systems. To avoid this issue, imaging and machine vision systems commonly use monochromatic illumination, which involves only single wavelengths or narrow bands of the spectrum. Monochromatic illumination, e.g. from a 660nm LED, practically eliminates what are known as chromatic aberrations in an imaging system.

Chromatic Aberrations

Chromatic aberrations exist in two fundamental forms: lateral color shift (Figure 3.6) and chromatic focal shift (Figure 3.7).

Figure 3.6

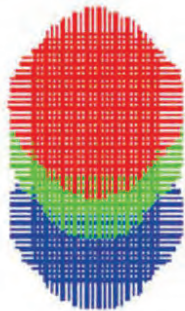


Figure 3.6: Lateral Color Shift.

Lateral color shift. Figure 3.6, can be seen as you move from the center of the image towards the edge of the image. In the center, the spots for different wavelengths of light are concentric. Moving towards the corner of the image, wavelengths tend to separate and produce a rainbow effect. As a result of this color separation, a given point on the object is imaged over a larger area, resulting in reduced contrast. On sensors with smaller pixels, this result is even more pronounced, as the blurring spreads over more pixels. In depth details on lateral color can be found in Section 6.2 on aberrations.

Chromatic focal shift. Figure 3.7, relates to the ability of a lens to focus all wavelengths at the same distance away from the lens. Different wavelengths will have different planes of best focus. This shift in focus with respect to wavelength results in reduced contrast, since the different wavelengths create different spot sizes at the image plane where the camera sensor is located. In the image plane of Figure 3.7 a small spot size in the red wavelengths, a larger spot size in green, and the largest spot size in blue is shown. Not all colors will be in focus all at once. Advanced details can be found in Section 6.2 on Aberrations.

Figure 3.7

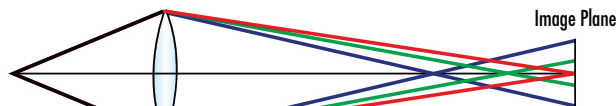


Figure 3.7: Chromatic Focal Shift.

Choosing the Optimal Wavelength

Monochromatic illumination enhances contrast by eliminating both chromatic focal shift and lateral chromatic aberration. It is readily available in the form of LED illumination, lasers, and through the use of filters. However, different wavelengths can have different MTF effects in a system. The diffraction limit defines the smallest theoretical spot which can be created by a perfect lens, as defined by the Airy Disk diameter, which has a wavelength (η) dependence. See Section 2.5 for more details on the Airy Disk and diffraction limit. Using the Equation 3.2, one can analyze the change in spot size for both different wavelengths and different f/#s.

$$\text{Minimum spot size (Airy Disk diameter) in } \mu\text{m} = 2.44 \times \eta (\mu\text{m}) \times f/\# \quad 3.2$$

Table 3.2 features the calculated Airy disk diameter for wavelengths ranging from Violet (405nm) to Near-Infrared (880nm) at various f/#s. This data clearly shows that lens systems have better theoretical resolution and performance when they are utilized with shorter wavelengths. The benefits to understanding this are multi-fold. First, shorter wavelengths allow for better utilization of the sensor's pixels regardless of size due to the smaller achievable spot size. This is especially pronounced on sensors with very small pixels. Second, it allows for more flexibility to use higher f/#s, which will allow for greater depth of field. For example, a red LED could be used at f/2.8 to generate a spot size of 4.51 μ m or a blue LED could be used to generate almost the same spot size at f/4. If both options yield acceptable levels of performance at best focus, the system set at f/4 using blue light will produce better depth of field, which could be a critical requirement. Advanced details may be found in Section 4.4, pages 26-28 on f/# and DOF.

► Example 1: Improvement with Wavelength

Both images in Figure 3.8 are taken with the same lenses and camera producing the same field of view, thus presenting the same spatial resolution on the object in lp/mm. The camera utilizes 3.45 μ m pixels. The illumination used in Figure 3.8a is set at 660nm and 3.8b at 470nm. The high resolution lens was set to higher f/# to greatly reduce any aberrational effects. This allows diffraction to be the primary limitation in the system. The blue circles are representative of the limiting resolution in Figure 3.8a. Note that Figure 3.8b has a significant increase in resolvable detail (approximately 50% finer detail). Even at the lower frequencies (wider lines), there is a higher level of contrast with 470nm illumination in Figure 3.8b.

► Example 2: White Light vs. Monochromatic MTF

In Figure 3.9, the same lens is used at the same working distance and f/#. Figure 3.9a is using white light, and Figure 3.9b is using 470nm illumination. In Figure 3.9a, all of the performance is at 50% or below at the Nyquist limit. For Figure 3.9b, all of the performance at the Nyquist limit is higher than Figure 3.9a. Additionally, performance in the center of the system in Figure 3.9b is above the diffraction limit of Figure 3.9a. The reason for this increase in performance is twofold: using monochromatic light eliminates chromatic aberrations in the system which generally allows for much smaller spots to be created, and 470nm illumination is one of the shortest wavelengths of light that is used in visible range imaging. As detailed in the sections on diffraction limit and Airy Disk, shorter wavelengths allow for higher levels of resolution.

Wavelength Considerations

A few issues can arise with changing wavelength that need to be understood. From a lens design perspective, the further into the blue portion of the spectrum, as wavelengths become shorter, the more a lens design can struggle regardless of how narrow the waveband that is used. Essentially, glass materials tend to not perform well at shorter wavelengths. Designs do exist in this region of the spectrum, but they are often limited in their capabilities, and the exotic materials that may be required to build the lens can be costly. The best theoretical performance seen in Table 3.2 is at the violet wavelength of 405nm, but most system designs cannot perform well in this area. It's very important to evaluate what a lens can realistically do at such short wavelengths using lens performance curves.

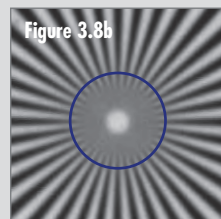
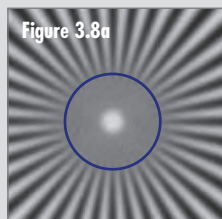
► Example 3: Theoretical Limitations

Figure 3.10 compares a 35mm lens at f/2 with blue (470nm) and violet (405nm) wavelengths (3.10a and 3.10b respectively). While Figure 3.10a has a lower diffraction limit, it also shows that the 470nm wavelength yields higher performance at all field positions. The effect here is increased when the lens is used at the extremes of its design capabilities for f/# and WD (detailed in Section 3.2 on MTF).

Another wavelength issue that can greatly affect performance is related to chromatic focal shift. As the application's wavelength range increases, the lens's ability to maintain high levels of performance will be compromised. Section 6.2 on Aberrations goes into more detail on the phenomenon.

Color	Wavelength (nm)	Aperture (f/#)				
		f/1.4	f/2.8	f/4	f/8	f/16
NIR (Near-Infrared)	880	3.01	6.01	8.59	17.18	34.36
Red	660	2.25	4.51	6.44	12.88	25.77
Green	520	1.78	3.55	5.08	10.15	20.30
Blue	470	1.61	3.21	4.59	9.17	18.35
Violet	405	1.38	2.77	3.95	7.91	15.81

Table 3.2: Theoretical Airy Disk diameter spot size (in μ m) for various wavelengths and f/#s.



Each image is from the center of the field of view of a multi element star target. The elements of a star target allow for the visualization of changing resolution produced by a lens and camera system in all directions. Higher resolutions are observed closer to the center of the star where the lines become narrower, producing higher frequencies.

Figure 3.8: Images of a star target taken with the same lens, at the same f/#, with the same sensor. The wavelength is varied from 660nm (a) to 470nm (b).

Figure 3.9a

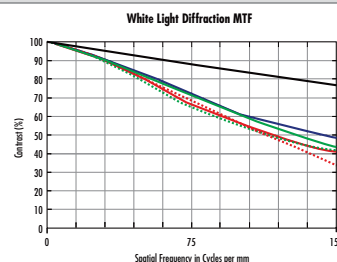


Figure 3.9b

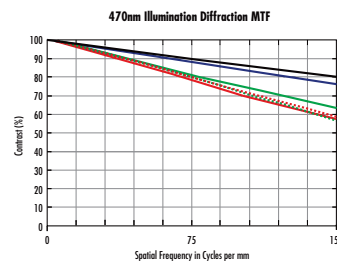


Figure 3.9: MTF curves for the same lens at f/2 using different wavelengths; white light (a) and 470nm (b).

Figure 3.10a

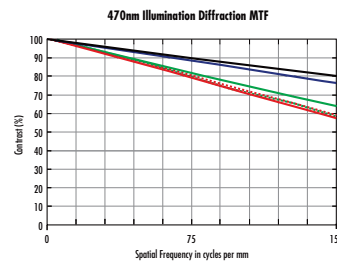


Figure 3.10b

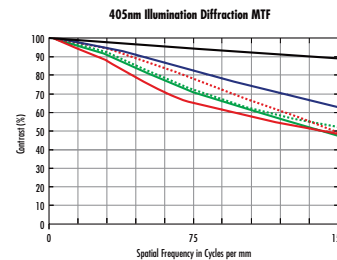


Figure 3.10: MTF curves for a 35mm lens at f/2 with 470nm (a) and 405nm (b) wavelength illumination.

Section 4: Real World Performance



Section 4.1: From Lens to Sensor: Limitations on Collecting Information

In an effort to better understand the differences that can occur between theoretical and as-manufactured performance, *Examples 1-3* show what happens at the sensor level, and how output from the sensor would be visualized with different wavelengths and $f/\#$ s. Figures transition from theoretical to real world examples that include aberration and lens fabrication errors.

As will be noted, the shorter the wavelength, the theoretically greater the performance of the imaging system. In recent years, blue LEDs have become very dependable for increasing the performance of small pixel-equipped sensors. Remember EO Best Practice #5, (page 5) *Color Matters*. Understanding the physical capabilities and limitations of a lens at different $f/\#$ s and wavelengths helps the user optimize the utility of high resolution imagers and enables solutions to once difficult applications.

► Example 1: Variation in Spot Sizes and Pixel Outputs with Wavelength at Low $f/\#$ (Theoretical)

Figures 4.1a and 4.1b demonstrate four different wavelengths being perfectly imaged, with the exception of blur caused by diffraction (Section 3.1), in the center of a sensor containing $3.45\mu\text{m}$ pixels and at $f/2.8$. This is considered a small pixel size, and it is associated with a very popular 5 megapixel sensor utilized by many camera companies. Figure 4.1a shows the difference in spot size when stepping up from 470nm (Blue) to 880nm (NIR) wavelengths. Figure 4.1b shows pixel outputs for each of the images created by the lens in Figure 4.1a; notice the smaller spots associated with the shorter wavelengths.

Figure 4.1a: An Illustration of how spot size changes by wavelength from 470nm (blue) to 880nm (NIR) at $f/2.8$.

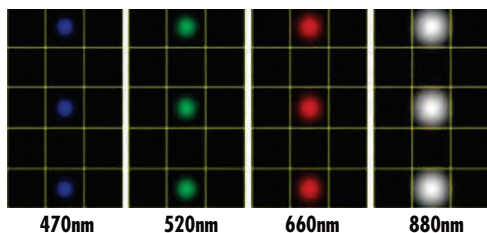


Figure 4.1b: How the pixels of a sensor interpret the spot sizes in figure 4.1a.

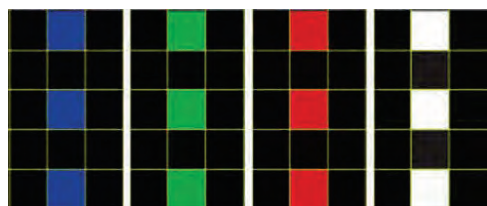


Figure 4.1: Variation in spot sizes and pixel outputs with wavelength at low $f/\#$.

► Example 2: Variation in Spot Sizes and Pixel Outputs with Wavelength at High $f/\#$ s (Theoretical)

The images in Figure 4.2 are similar to Figure 4.1, but the aperture setting has been changed to $f/8$. At this setting, Figure 4.2a shows that all of the spots, regardless of wavelength, exceed the size of a single pixel, which causes energy to spill into adjacent pixels. Figure 4.2b shows a noticeable blurring in the pixel outputs at the longer wavelengths with spots at 880nm no longer able to be separated. This demonstrates the physical ramifications associated with changing the $f/\#$, even in a theoretically perfect system.

Figure 4.2a: An Illustration of how spot size changes by wavelength from 470nm (blue) to 880nm (NIR) at $f/8$.

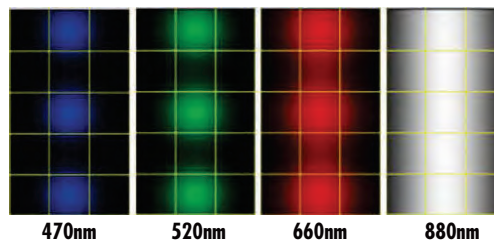


Figure 4.2b: How the pixels of a sensor interpret the spot sizes in figure 4.2a.

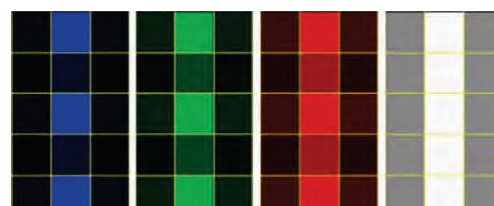


Figure 4.2: Variation in spot sizes and pixel outputs with wavelength at high $f/\#$.

► Example 3: Variation in Spot Sizes and Pixel Outputs with Wavelength in Real Lenses That Include Aberrations

In this example, a more realistic representation of the center and corner of a true lens design is shown at $f/2.8$. These figures now include aberrations that are inherent in even the highest quality lens designs, as well as issues associated with manufacturing tolerances. Aberrations misplace information and alter the shape of the spots that are created, leading to shapes that are no longer rotationally symmetric; the sum of all

aberrations involved determine this shape. Please note, aberrations tend to be more pronounced at the corner of an image than compared to the center. A great difference can be seen between the spots shown in *Figures 4.1a and 4.1b* versus *Figures 4.3a and 4.3b*; *Figure 4.1* is a theoretical demonstration, while *Figure 4.3* uses a real lens. Notice how aberrations influence the spot shapes image shown in *Figure 4.3c* and *4.3d*.

Figure 4.3a: An Illustration of spot sizes for a real lens with aberrations in the center of the image at $f/2.8$.

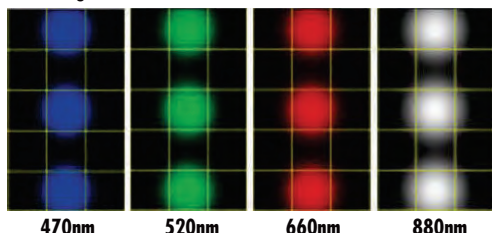


Figure 4.3b: How the pixels of a sensor interpret the spot sizes in figure 4.3a.

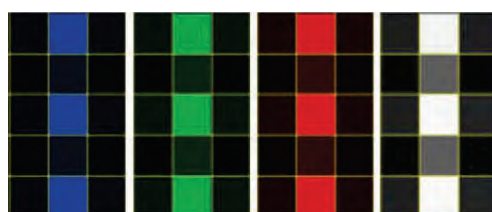


Figure 4.3c: An Illustration of spot sizes for a real lens with triangular shaped aberrations in the image corner at $f/2.8$.

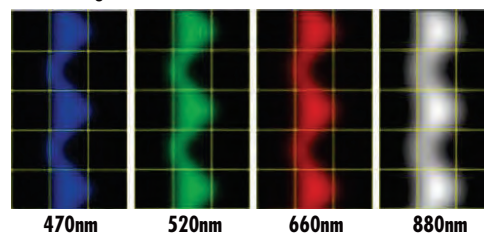


Figure 4.3d: How the pixels of a sensor interpret the spot sizes in figure 4.3c.

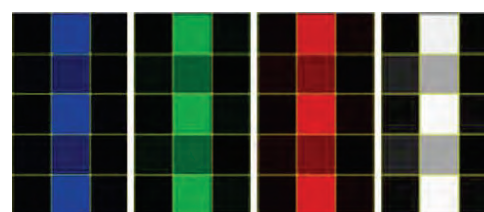


Figure 4.3: Variation in spot sizes and pixel outputs with wavelength in real lenses that include aberrations.

► Example 4: Real-World Lens Performance. Looking at Actual Images.

Figure 4.4 is an application image that shows the difference in real-world performance of two lenses with the same focal length (16mm), $f/\#$ (2.8), and field of view (100mm horizontally) coverage. These images demonstrate all of the concepts detailed in the sections on MTF, $f/\#$, and wavelength (*Sections 3.2, 2.4, 3.3, and 4.1* respectively). The target is a multi-element Star Target (#58-835) that allows the concurrent visualization of a wide range of frequencies (resolutions) in all areas of the FOV and in all directions. More details on this and other targets for benchmarking a systems performance can be found on *pages 164-173*.

The differences in lens performance can be seen by examining close-up sections of the field of view (full resolution images available online). *Figure 4.4* shows the complete star target; the highlighted areas located in the center, bottom middle, and the corner of the target will be compared between the two different lenses. A Sony ICX 625 monochrome sensor with $3.45\mu\text{m}$ pixels and a total resolution of 5 megapixels and a white light back light illuminator are used in this example.

The comparisons shown in *Figure 4.4* demonstrate *Lens A's* superior performance. Specifically, the corner of the image shows a large difference in contrast, as it is noticeably more difficult to differentiate the blacks and whites in the *Lens B* example. Additionally, the directionality of different aberrations (mainly astigmatism) are prominent; more detail can be seen associated with lines propagating in the radial direction.

The close up of the corner of the image in *Figure 4.4* (yellow and red boxes) presents an additional concern, where each black and white line pair covers approximately 10 pixels total. Compared to the resolvable portion at the center of the image, the corner has effectively reduced spatial resolution (due to the blur circle covering multiple pixels) from 5 megapixels (2448×2050) near the center to approximately 500×400 pixels in the corner, which is below what a VGA sensor (640×480 pixels) can reproduce. Even at reduced sensor resolution, some lenses will still struggle greatly due to design constraints and manufacturing tolerances, which is demonstrated by the different contrast levels from each lens. For instance, the contrast level in the yellow box for *Lens A* is 45% and 7% in the red box for *Lens B*.

Figure 4.4

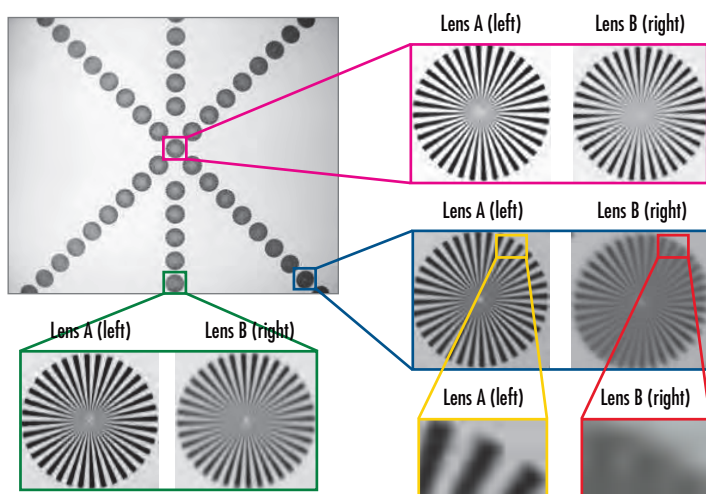


Figure 4.4: A star target is imaged with two lenses (A and B) with the same focal length, $f/\#$, field of view, and sensor. The superiority of *Lens A* is apparent in all areas but is most pronounced along the edge and in the corner of the image.

Section 4.2: Sensor Relative Illumination, Roll-Off, and Vignetting

In order to evaluate and understand issues that can be associated with vignetting (the blocking of rays that pass through the outer edges of an imaging lens), roll-off and relative illumination, sensor sizes, and formats need to be considered. In addition to the following overview, more information on sensors and formats can be found on pages 142-145.

Matching Sensors with Lenses

One issue that often arises is the ability of an imaging lens to support certain sensor sizes. If the sensor is too large for the lens design, the resulting image may appear to fade away and degrade towards the edges; this effect is caused by vignetting. As the resolution demands of a system increase, one of two things needs to happen: pixels need to get smaller or sensors need to get bigger. As is detailed in the sections on MTF and diffraction limit (Sections 3.2 and 3.1), continuous reduction in pixel size produces significant issues regarding the optics' ability to resolve true detail. This concern, combined with the signal to noise and sensitivity issues associated with current sensor technology, results in sensors having to grow in size; such growth causes these issues regarding vignetting and roll-off, unless the proper lens is used.

Relative Illumination

Relative Illumination is a way of representing the combined effect of vignetting and roll-off in an imaging lens, and is generally given as a percentage of illumination at any point on the sensor normalized to the position in the field with maximum illumination. Vignetting and roll-off are two separate components of relative illumination. An example of RI is shown in Figure 4.5. More details on how to read this curve can be found in Section 2.6.

The curve in Figure 4.5 shows that at its lowest aperture setting ($f/1.4$ – the blue line), this lens has an RI of 57% of the illumination level of the image center at the corner of a $\frac{2}{3}$ " sensor. Under the same conditions, the lens has an RI of 72% in the corner of a $\frac{1}{2}$ " sensor. As the sensor gets smaller, the RI improves. Also note that the RI improves as the $f/\#$ is increased; this occurs until there is no more vignetting in the lens, at which point all higher $f/\#$ settings will have the same illumination profile. Increasing the $f/\#$ generally does not increase the image circle size much, in that a lens designed for a particular sensor size will not perform well on a larger sensor even with the $f/\#$ stopped down.

Roll-off will still occur when the lens is stopped down, as that is related to the angle of the rays and not the number of rays that pass through the lens. Many lenses will have an illumination profile that is highest in the middle of the field and is either flat or declines to some lower percentage as it approaches the edge. There are rare cases where the RI increases slightly across the image circle, but this is related to pupil compression and will not be covered in this text.

Vignetting Within a Lens – ADVANCED

Vignetting is the result of light rays not making it through the entire lens system to the sensor, due to being blocked by the edges of individual lens elements or mechanical stops. This clipping of rays can be intentional or unintentional, and in some case is unavoidable. Vignetting is most often seen at or in lower $f/\#$ s, short focal length lenses, or lenses where higher resolutions need to be achieved at a lower cost.

Figure 4.6 demonstrates clipping as it may occur for the same 16mm lens at different $f/\#$ s ($f/1.8$ and $f/4$). Note the clipping of rays in Figure 4.6a, as indicated with red circles; these rays are not able to pass through all of the optics in the lens. Figure 4.6b, on the other hand, demonstrates an example without vignetting. The vignetting in Figure 4.6a could have several causes, including diameter limitations of the optics or a need to eliminate the rays to block stray light. Vignetting is sometimes purposely included in a lens design to improve overall lens performance or reduce cost.

Sensor Roll-Off

Roll-off is the decrease in relative illumination with respect to field that is not caused by vignetting, but by radiometric laws.

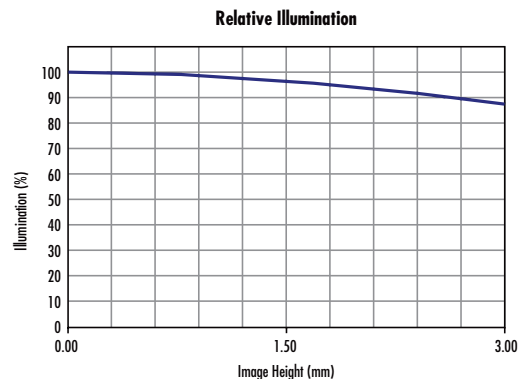


Figure 4.5

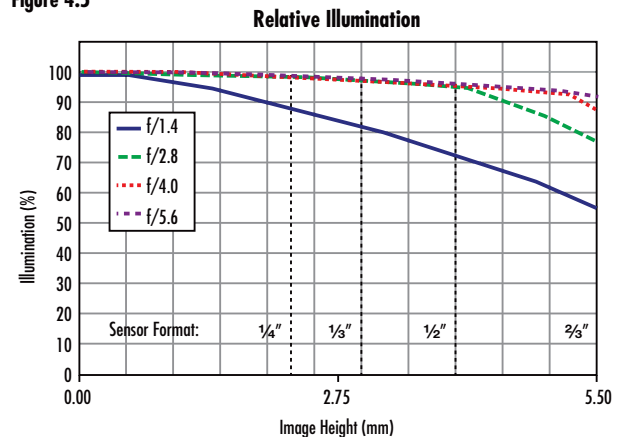


Figure 4.5: A relative illumination curve showing relevant image sensor formats on the x-axis.

Figure 4.6a

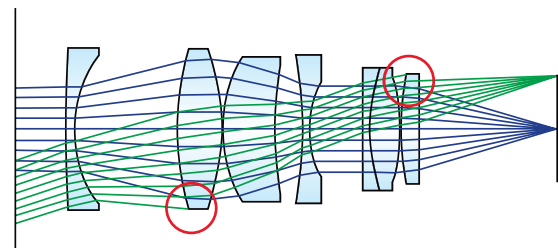


Figure 4.6b

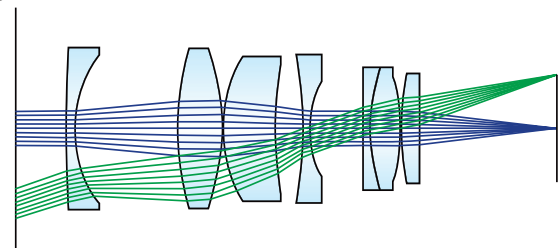


Figure 4.6: A 16mm lens design at $f/1.8$ (a) and $f/4$ (b). At $f/1.8$ vignetting occurs where light rays are clipped by the edges of the lens.

Vignetting to Gain Performance (Selective Vignetting)

– ADVANCED

Vignetting is often used to maximize the resolution of a lens design across the entire image circle. Since it is more difficult to direct the rays that create the edge of an image to the desired location on a sensor, higher resolution objects are generally more difficult to reproduce at the edge of the image than at the center. Rays that end up on the wrong pixel will degrade the image at that location; one way to manage this is to eliminate these rays from the system. If the undesired rays do not make it to the sensor, they cannot degrade the image. Removing these mis-directed rays, however, reduces relative illumination.

Effects of Vignetting at the Pixel Level: Large Pixels

Figure 4.7 illustrates light rays incident on a pixel in the corner of a sensor at $f/1.4$ (a) and $f/2$ (b). In Figure 4.7a, some light spills onto the adjacent pixel creating image and contrast degradation. Increasing the $f/\#$ (Figure 4.7b) essentially creates vignetting which clips those extraneous rays. Figure 4.8 illustrates this same vignetting effect at the center of the sensor. However, with these large pixels, the change in $f/\#$ has little effect on the overall image quality.

Vignetting can also be purposefully designed into lenses in scenarios in which the effects from manufacturing tolerances adversely affect the

control of rays, causing image degradation. The looser the tolerances on the lens, the more adverse these degrading effects can become, and tightening the tolerances is often not practical due to the increase in manufacturing cost. Often, a balance must be struck between reducing manufacturing cost and maintaining image quality. In cases where cost is a primary factor, vignetting must be utilized in an attempt maintain resolution across the field of view. Doing such will have an adverse effect on the illumination profile. Designing vignetting into a lens can be accomplished in a couple different ways: by purposefully designing the clear apertures of the individual lens elements such that they vignette severely off-axis rays, or by introducing mechanical apertures to block aberrated rays, as shown in Figure 4.11a.

Effects of Vignetting at the Pixel Level: Small Pixels

In Figures 4.9 and 4.10, the pixels have been reduced to half the size, yielding a 4X resolution increase. In this example, vignetting by increasing $f/\#$ greatly improves performance across the entire sensor, as opposed to the first example which only slightly improved the imaging performance in the corner of the image. All of these Figures (4.7 - 4.10) exhibit nominal design capabilities and do not account for reduced performance that results from manufacturing tolerances. With tolerances included, the need for vignetting can be even more pronounced, especially in cases where cost is a driving factor. (Continued on page 22)

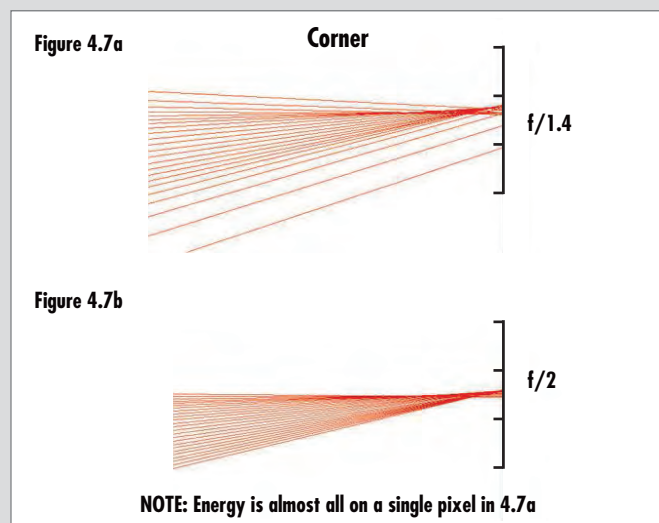


Figure 4.7: Light rays incident on pixels in the corner of a sensor at $f/1.4$ (a) and $f/2$ (b). Increasing the $f/\#$ creates vignetting which clips the extraneous rays spilling onto the adjacent pixel in 4.7a.

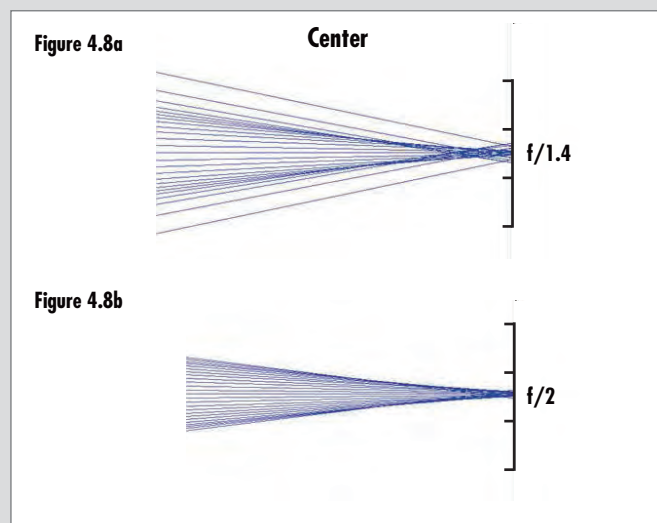


Figure 4.8: Light rays incident on pixels in the center of an image at $f/1.4$ (a) and $f/2$ (b). Increasing the $f/\#$ has no significant effect on image quality as all rays were contained in the desired pixel for each example.

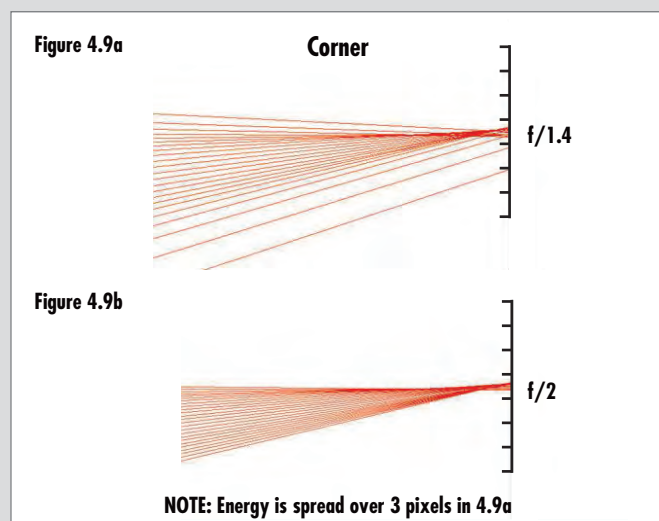


Figure 4.9: Light rays incident on pixels in the corner of a sensor at $f/1.4$ (a) and $f/2$ (b). Increasing the $f/\#$ creates vignetting which clips the extraneous rays spilling adjacent pixels.

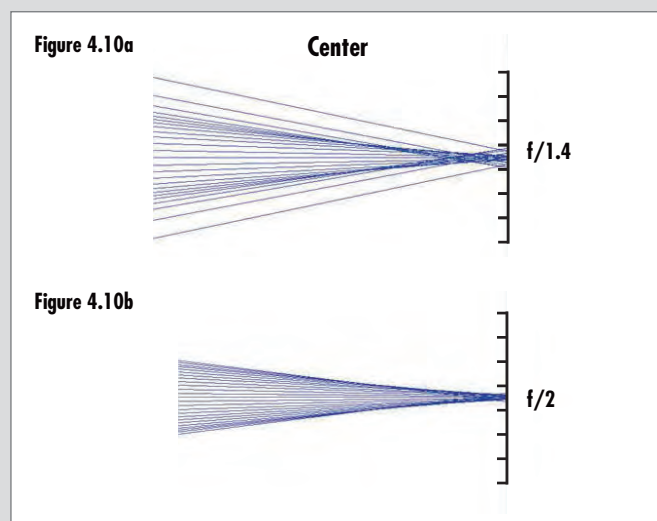


Figure 4.10: Light rays incident on pixels in the center of an image at $f/1.4$ (a) and $f/2$ (b). Increasing the $f/\#$ creates vignetting which prevents the extraneous rays from spilling onto nearby pixels.

Demonstration of Vignetting in Different Lens Designs – ADVANCED

Figure 4.11 features a standard 12mm lens design layout, along with both its relative illumination and MTF curves. Note the size difference of the ray bundles in 4.11a at the center (blue lines) and corner (green lines); the size difference demonstrates a large amount of selective vignetting. The vignetting leads to lower illumination at the edges of the image than in the center (4.11b). This is done in an effort to minimize the costs associated with materials and manufacturing tolerances, while maintaining reasonable performance at a lower price.

Figure 4.11a

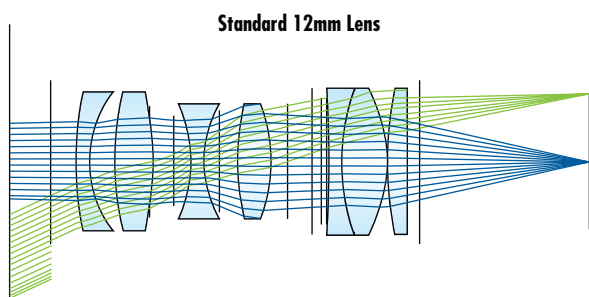


Figure 4.11b

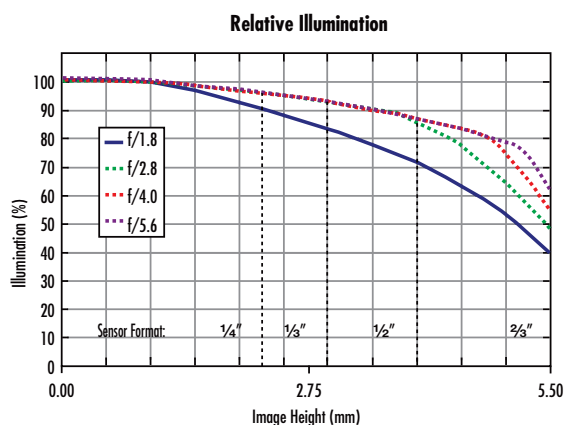


Figure 4.11c

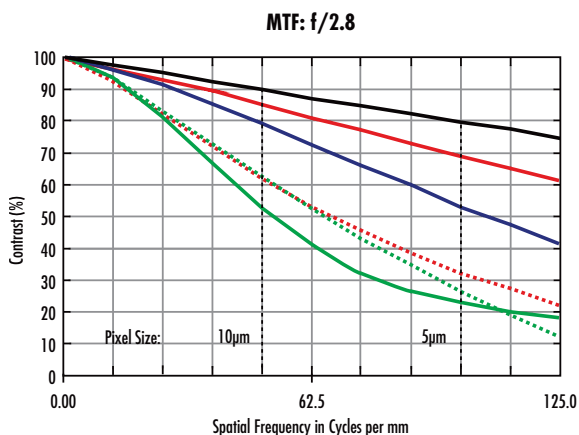


Figure 4.11: A standard 12mm lens ray path (a), relative illumination curve (b), and MTF curve (c).

The lens in Figure 4.12, an ultra-high resolution 12mm lens design, has a much more evenly sized ray bundles across the field (4.12a) due to a low level of vignetting. This translates to much more even relative illumination across the entire sensor (4.12b). The lens in this example is designed using more costly materials at tighter tolerances, which allows it to maintain high levels of performance across the image, without the need to introduce vignetting to improve its performance. The trade off in using such a lens is that the ultra-high resolution lens is more expensive than the standard design.

Figure 4.12a

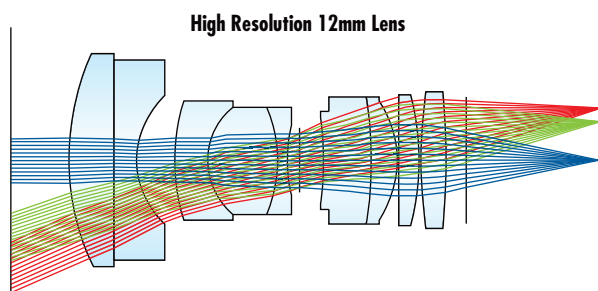


Figure 4.12b

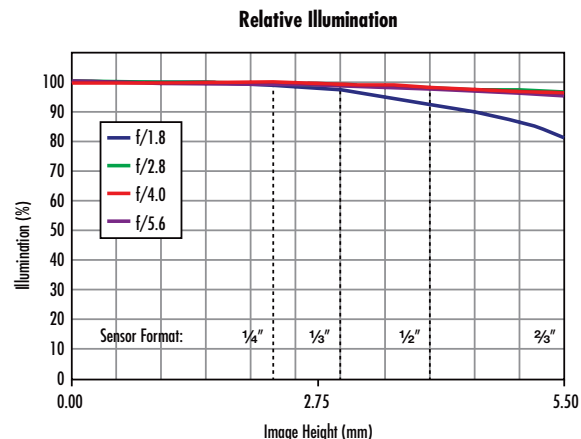


Figure 4.12c

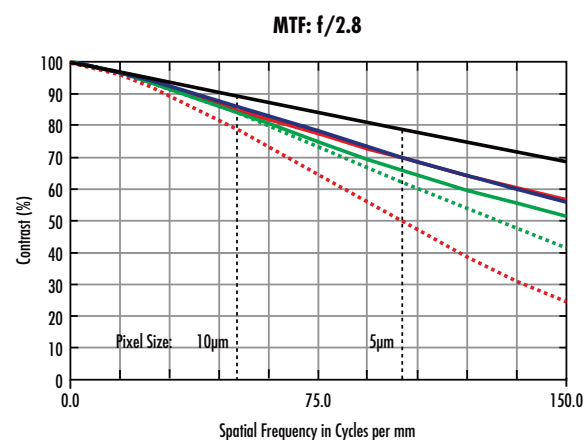


Figure 4.12: A ultra-high resolution 12mm lens ray path (a), relative illumination curve (b), and MTF curve (c).

Illumination Roll-Off – ADVANCED

In its simplest form, the maximum brightness of a lens for some given image circle with no vignetting is limited by the fourth power of the cosine of the chief ray angle in image space. This is known as $\cos^4\epsilon$ roll-off. Figure 4.13 shows the chief rays for the center and the corner of the image (highlighted in red).

In many applications, roll-off is not an issue, but it can be problematic when the chief ray angle becomes quite steep. This is especially true in applications utilizing large sensors, line-scan applications, and wide angular FOV (short focal length) applications. Table 4.1 shows how roll-off increases with angle. Notice that for an angle of 15° , there is a reduction in relative illumination of about 13% from the center to the corner, but by doubling the angle, the roll-off increases to nearly a 44% reduction of RI.

Roll-off must be considered in applications with short working distances and large fields of view. This can produce large chief ray angles in image space, regardless of sensor size.

One way to correct for roll-off is by designing the lens to be image space telecentric. In doing this, the difference in the angle of the chief rays will be 0° , which produces even illumination. Another way to offset roll-off is to create unbalanced illumination on the object under inspection. By mounting additional lights closer to the edges of the object under inspection or by adding an apodizing neutral density filter onto the lens, roll off-can be mitigated.

Difference in Chief Ray Angle	Maximum Relative Illumination Level Center to Corner
5°	98.5%
10°	94.0%
15°	87.1%
30°	56.3%
45°	25.0%
60°	6.3%

Table 4.1: Relation between chief ray angle and relative illumination at the corner of an image, assuming 100% relative illumination at the center.

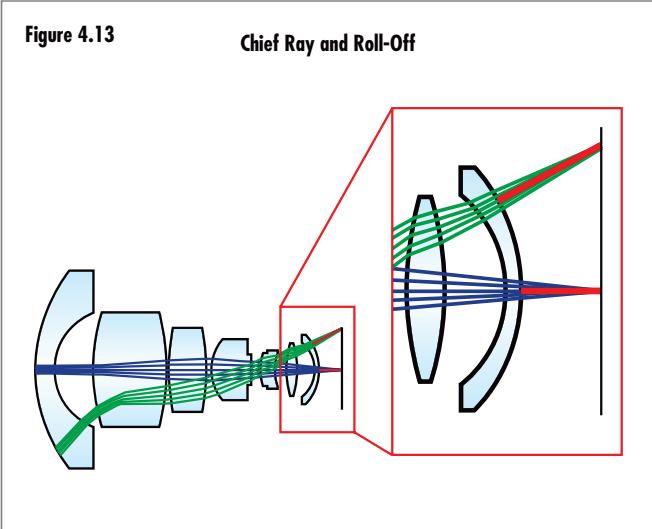


Figure 4.13: Imaging lens layout, highlighting the chief rays of the ray bundles belonging to the center (blue lines) and the corner (green lines) of the image. These define the angle which is used to approximate roll-off.

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Roll-Off and Micro Lenses – ADVANCED

Micro lenses are utilized on many sensors in an effort to increase the amount of light making it to the active pixel area. Like all other lenses, micro lenses have an angular acceptance in which they operate most efficiently. As the angle of incidence increases, the amount of light that makes it to the active area of the pixel is reduced. Most lens designs attempt to keep their image space chief ray angles below 5 to 7° in order to reduce these effects. Figure 4.14a shows a micro lens

over the pixel. Figures 4.14b and 4.14c show how light is focused at normal incidence and at an oblique incidence to the micro lens, respectively. Normal incidence would represent the center pixel on the sensor. At this position all rays are focused onto the active area of the pixel. At oblique angles, not all rays make it to the active pixel area. This results in additional reduced relative illumination beyond what is specified in a lens's relative illumination curve.

Figure 4.14a Microlens

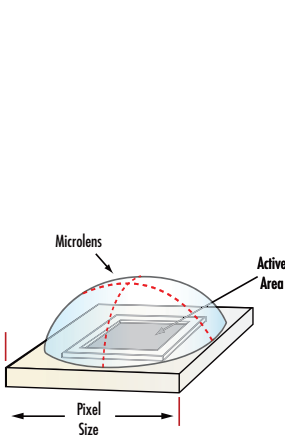


Figure 4.14b Normal Angle of Incidence

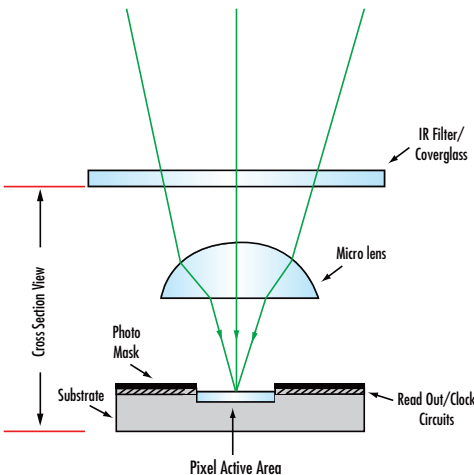
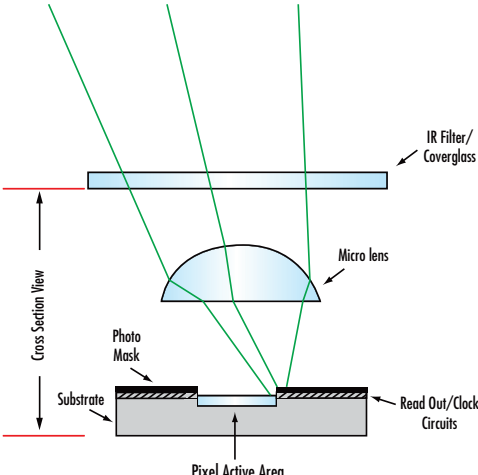


Figure 4.14c Increased / Oblique Angle of Incidence



Section 4.3: Pixel Sizes and Optics

– ADVANCED

Understanding the interplay between camera sensors and imaging lenses is a vital part of designing and implementing a machine vision system. The optimization of this relationship is often overlooked, and the impact that it can have on the overall resolution of the system is large. An improperly paired camera/lens combination could lead to wasted money on the imaging system. Unfortunately, determining which lens and camera to use in any application is not always an easy task: more camera sensors (and as a direct result, more lenses) continue to be designed and manufactured to take advantage of new manufacturing capabilities and drive performance up. These new sensors present a number of challenges for lenses to overcome, and make the correct camera to lens pairing less obvious.

The first challenge is that pixels continue to get smaller. While smaller pixels typically mean higher system-level resolution, this is not always the case once the optics utilized are taken into account. In a perfect world, with no diffraction or optical errors in a system, resolution would be based simply upon the size of a pixel and the size of the object that is being viewed (see *Section 2.1* for further explanation). To briefly summarize, as pixel size decreases, the resolution increases. This increase occurs as smaller objects can be fit onto smaller pixels and still be able to resolve the spacing between the objects, even as that spacing decreases. This is an oversimplified model of how a camera sensor detects objects, not taking noise or other parameters into account.

Lenses also have resolution specifications, but the basics are not quite as easy to understand as sensors since there is nothing quite as concrete as a pixel. However, there are two factors that ultimately determine the contrast reproduction (modulation transfer function, or MTF) of a particular object feature onto a pixel when imaged through a lens: diffraction and aberrational content. Diffraction will occur anytime light passes through an aperture, causing contrast reduction (more details in *Section 2.5*). Aberrations are errors that occur in every imaging lens that either blur or misplace image information depending on the type of aberration (more information on individual optical aberrations can be found in *Section 6.2*). With a fast lens ($\leq f/4$), optical aberrations are most often the cause for a system departing from “perfect” as would be dictated by the diffraction limit; in most cases, lenses simply do not function at their theoretical cutoff frequency (ϕ_{cutoff}), as dictated by *Equation 4.1*

$$\phi_{\text{cutoff}} = \frac{1}{\eta(f/\#)} \quad 4.1$$

To relate this equation back to a camera sensor, as the frequency of pixels increases (pixel size goes down), contrast goes down - every lens will always follow this trend. However, this does not account for the real world hardware performance of a lens. How tightly a lens is tolerated and manufactured will also have an impact on the aberrational content of a lens and the real-world performance will differ from the nominal, as-designed performance. It can be difficult to approximate how a real world lens will perform based on nominal data, but tests in a lab can help determine if a particular lens and camera sensor are compatible.

One way to understand how a lens will perform with a certain sensor is to test its resolution with a USAF 1951 bar target. Bar targets are better for determining lens/sensor compatibility than star targets, as their features line up better with square (and rectangular) pixels. The following examples show test images taken with the same high resolution 50mm focal length lens and the same lighting conditions on three different camera sensors. Each image is then compared to the lens's nominal, on-axis MTF curve (blue curve). Only the on-axis curve is used in this case because the region of interest where contrast was measured only covered a small portion of the center of the sensor.

Figure 4.15 shows the performance of the 50mm lens when paired with a 1/2.5" ON Semiconductor MT9P031 with 2.2µm pixels, when at a magnification of 0.177X. Using *Equation 2.1* from *Section 2* (see page 8), the sensor's Nyquist resolution is 227.7 lp/mm,

$$\text{Sensor Resolution} = \frac{1000}{2 \cdot (2.2\mu\text{m})} = 227.7 \text{ lp/mm}$$

meaning that the smallest object that the system could theoretically image when at a magnification of 0.177X is 12.4µm (using an alternate form of *Equation 2.7*).

$$\text{Object Space Resolution} = \text{Sensor Resolution} \cdot \text{PMAG} = 227.7 \cdot 0.177 = 40.3 \text{ lp/mm} \quad 12.4\mu\text{m}$$

Keep in mind that these calculations have no contrast value associated with them. The left side of *Figure 4.15* shows the images of two elements on a USAF 1951 target; the top image shows two pixels per feature, and the bottom image shows one pixel per feature. At the Nyquist frequency of the sensor (227 lp/mm), the system images the target with 8.8% contrast, which is below the recommended 20% minimum contrast for a reliable imaging system. Note that by increasing the feature size by a factor of two to 24.8µm, the contrast is increased by nearly a factor of three. In a practical sense, the imaging system would be much more reliable at half the Nyquist frequency.

Figure 4.15

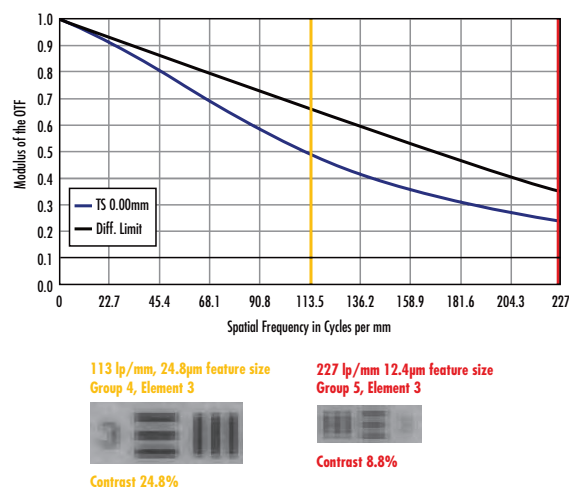


Figure 4.15: Comparison nominal lens performance vs. real-world performance for a high resolution 50mm lens on the ON Semiconductor MT9P031 with 2.2µm pixels. The red line shows the Nyquist limit of the sensor and the yellow line shows half of the Nyquist limit.

The conclusion that the imaging system could not reliably image an object feature that is 12.4µm in size is in direct opposition to what equations 2.1 and 2.7 show, as mathematically the objects fall within the capabilities of the system. This contradiction highlights that first order calculations and approximations are not enough to determine whether or not an imaging system can achieve a particular resolution. Additionally, a Nyquist frequency calculation is not a solid metric on which to lay the foundation of the resolution capabilities of a system, and should only be used as a guideline of the limitations that a system will have. A contrast of 8.8% is too low to be considered accurate since minor fluctuations in conditions could easily drive contrast down to unresolvable levels.

Figures 4.16 and 4.17 show similar images to those in *Figure 4.15* though the sensors used were the Sony ICX655 (3.45µm pixels) and ON Semiconductor KAI-4021 (7.4µm pixels). The top images in each figure show two pixels per feature and the bottom images show one pixel per feature. The major difference between the three Figures is that all of the image contrasts for *Figures 4.16 and 4.17* are above 20%, meaning (at first glance) that they would be reliable at resolving features of that size. Of course, the minimum sized objects they can resolve are larger when compared to the 2.2µm pixels in *Figure 4.15*. However, imaging at the Nyquist frequency is still ill-advised as slight movements in the object could shift the desired feature between two pixels, making the object unresolvable. Note that as the pixel sizes increase from 2.2µm, to 3.45µm, to 7.4µm, the respective increases in contrast from one pixel per feature to two pixels per feature are less impactful. On the ICX655 (3.45µm pixels), the contrast changes by just under a factor of 2; this effect is further diminished with the KAI-4021 (7.4µm pixels).

Figure 4.16

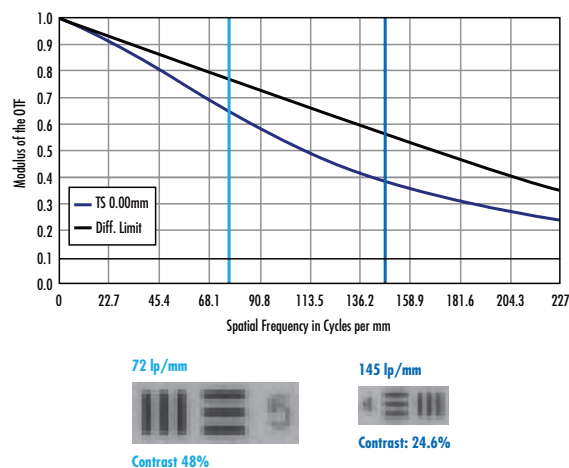


Figure 4.16: Comparison nominal lens performance vs. real-world performance for a high resolution 50mm lens on the Sony ICX655 with 3.45µm pixels. The dark blue line shows the Nyquist limit of the sensor, and the light blue line shows half of the Nyquist limit.

Figure 4.17

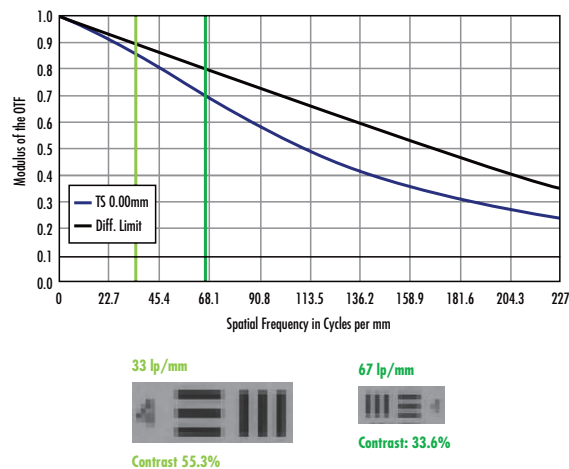


Figure 4.17: Comparison nominal lens performance vs. real-world performance for a high resolution 50mm lens on the ON Semiconductor KAI-4021 with 7.4µm pixels. The dark green line shows the Nyquist limit of the sensor, and the light green line shows half of the Nyquist limit.

An important discrepancy in *Figures 4.15, 4.16, and 4.17* is the difference between the nominal lens MTF and the real-world contrast in an actual image. The MTF curve of the lens on the right side of *Figure 4.15* shows that the lens should achieve approximately 24% contrast at the frequency of 227 lp/mm, when the contrast value produced was 8.8%. There are two main contributors to this difference: sensor MTF and lens tolerances. Most sensor companies do not publish MTF curves for their sensors, but they have the same general shape that the lens has. Since system-level MTF is a product of the MTFs of all of the components of a system, the lens and the sensor MTFs must be multiplied together to provide a more accurate conclusion of the overall resolution capabilities of a system. As mentioned above, a toleranced MTF of a lens is also a departure from the nominal. All of these factors combine to change the expected resolution of a system, and on its own, a lens MTF curve is not an accurate representation of system-level resolution.

As seen in the images in *Figure 4.18*, the best system-level contrast is in the images taken with the larger pixels. As the pixel size decreases, the contrast drops considerably. A good best practice is to use 20% as a minimum contrast in a machine vision system, as any contrast value below that is too susceptible to fluctuations in noise coming from temperature variations or crosstalk in illumination. The image taken with the

50mm lens and the 2.2µm pixel in *Figure 4.15* has a contrast of 8.8% and is too low to rely on the image data for object feature sizes corresponding to the 2.2µm pixel size because the lens is on the brink of becoming the limiting factor in the system. Sensors with pixels much smaller than 2.2µm certainly exist and are quite popular, but much below that size becomes nearly impossible for optics to resolve down to the individual pixel level. This means that the equations described in *Section 2* become functionally meaningless for helping to determine system-level resolution, and images similar to those taken in the aforementioned figures would be impossible to capture. However, these tiny pixels still have a use - just because optics cannot resolve the entire pixel does not render them useless. For certain algorithms, such as blob analysis or optical character recognition (OCR), it is less about whether the lens can actually resolve down to the individual pixel level and more about how many pixels can be placed over a particular feature. With smaller pixels subpixel interpolation can be avoided, which will add to the accuracy of any measurement done with it. Additionally, there is less of a penalty in terms of resolution loss when switching to a color camera with a Bayer pattern filter.

Figure 4.18

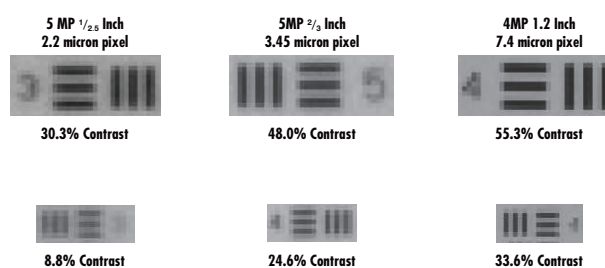


Figure 4.18: Images taken with the same lens and lighting conditions on three different camera sensors with three different pixel sizes. The top images are taken with four pixels per feature, and the bottom images are taken with two pixels per feature.

Another important point to remember is that jumping from one pixel per feature to two pixels per feature gives a substantial amount of contrast back, particularly on the smaller pixels. Although by halving the frequency, the minimum resolvable object effectively doubles in size. If it is absolutely necessary to view down to the single pixel level, it is often better to double the optics' magnification and halve the field of view. This will cause the feature size to cover twice as many pixels and the contrast will be much higher. The downside to this solution is that less of the overall field will be visible. From the image sensor perspective, the best thing to do is to maintain the pixel size and double the format size of the image sensor. For example, an imaging system with a 1X magnification using a 1/2" sensor with a 2.2µm pixel will have the same field of view and spatial resolution as a 2X magnification system using a 1" sensor with a 2.2µm pixel, but with the 2X system, the contrast is theoretically doubled.

Unfortunately, doubling the sensor size creates additional problems for lenses. One of the major cost drivers of an imaging lens is the format size for which it was designed. Designing an objective lens for a larger format sensor takes more individual optical components; those components need to be larger and the tolerancing of the system needs to be tighter. Continuing from the example above, a lens designed for a 1" sensor may cost five times as much as a lens designed for a 1/2" sensor, even if it cannot hit the same pixel limited resolution specifications.



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Section 4.4: Depth of Field and Depth of Focus



Due to similarities in name and nature, depth of field and depth of focus are commonly confused concepts. To simplify the definitions for our purposes, depth of field concerns the image quality of a stationary lens as an object is repositioned, whereas depth of focus concerns a stationary object and a sensor's ability to maintain focus for different sensor positions, including tilt.

Depth of Field

The Depth of Field (DOF) of a lens is its ability to maintain a desired amount of image quality (spatial frequency at a specified contrast), without refocusing, if the object is positioned closer to and farther from best focus. DOF also applies to objects with complex geometries or features of different heights. As an object is placed closer or farther than the set focus distance of a lens, the object blurs and both resolution and contrast suffer. Because of this, DOF only makes sense if it is defined with an associated resolution and contrast. A number of targets can be used to directly measure and benchmark an imaging systems DOF; these targets are detailed on pages 164-167.

DOF Requires a Resolution

"Does this lens have good depth of field?" Although a common question, it is difficult to quantify without using a specific object detail size or image space frequency. The smaller the detail, the higher the spatial frequency that needs to be resolved, and the smaller the DOF the lens can produce. A DOF curve can be used to see how a lens actually performs over a given depth at a specific detail's size (Section 2.6). These graphs not only take into account the theoretical limitations associated with the $f/\#$ setting, but also the aberrational effects of the lens design itself.

In Figure 4.19, the contrast levels (y-axis) that can be seen over a working distance range (x-axis) at a fixed frequency of 20 lp/mm (image detail) are shown. Note the difference in DOF between Figure 4.19a, which is set at $f/2.8$, and Figure 4.19b, which is set at $f/4$. Something else to note is that there is more usable DOF beyond the best focus than between the best focus and the lens, due to magnification decreasing. The graphs themselves contain different color lines denoting different positions where the image will fall on the sensor.

Figure 4.20 features the same lens as Figure 4.19a but at a different working distance. Note an increase in DOF occurs at longer working distances. Eventually, as the lens focuses towards infinitely far away objects, the hyperfocal condition occurs. This condition is reached at the distance in which everything appears in equal focus.

How $f/\#$ Affects Depth of Field, Conceptual

Changing the $f/\#$ of a lens will change the DOF, as shown in Figure 4.21. For each configuration shown in Figure 4.21 there are two bundles of rays. The bundle represented by dotted black lines shows how information spreads as it moves from the object toward the lens system. As an object moves away from the best focus position (where the dotted lines cross), object details move into a wider area of the cone. The wider the spread of the cone, the more the information from that distance from the lens is blurred into all of the other information around it. The $f/\#$ of the lens controls how fast the cone expands and, thus, how much information or detail is actually blurred together at a given distance.

There is also a red cone in the figure, which is an angular representation of the resolution of the system. Where the lines of the two cones intersect defines the total range of the depth of field. The lower the $f/\#$, the faster the black dotted lines expand, and the lower the depth of field.

As details get smaller, the bundles in Figure 4.21a and 4.21b move closer together, accelerating the effect. Eventually, increasing the $f/\#$ too much causes smaller details to blur due to the diffraction limit of the lens being reached, since the limiting resolution of the lens is inversely proportional to the $f/\#$. This limitation means that while increasing the $f/\#$ will always increase the depth of field, the feature size that is resolvable (even at best focus) gets larger. For more information on the diffraction limit and its relationship to $f/\#$, see Section 3.1. Utilizing short wavelengths does allow for forgiveness in this area, and in many ways

Figure 4.19a

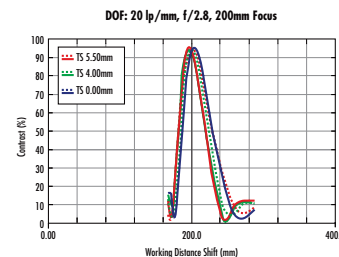


Figure 4.19b

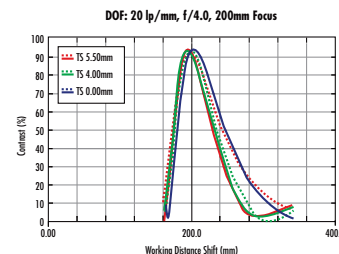


Figure 4.19: Depth of field curves for a lens at $f/2.8$ (a) and $f/4$ (b).

Figure 4.20a

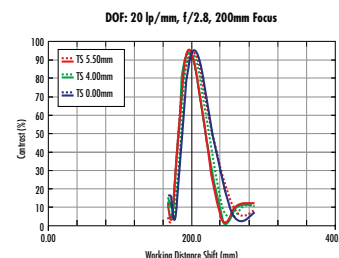


Figure 4.20b

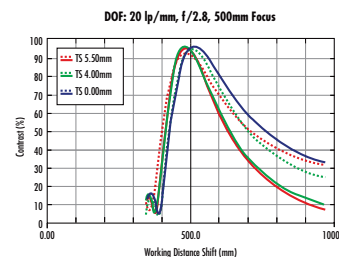


Figure 4.20: Depth of field curves for a lens at $f/2.8$ at 200mm WD (a) and at 500mm WD (b). Note (b) has a much larger scale.

Figure 4.21a

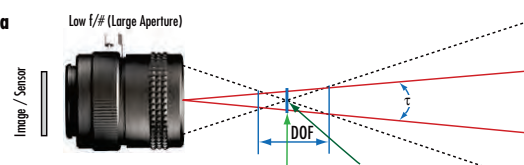


Figure 4.21b

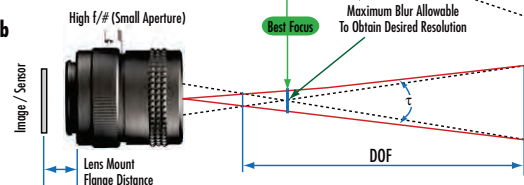


Figure 4.21: Geometric representation of DOF for high and low $f/\#$ lenses.

some of this lost resolution can be salvaged. Learn more about changing wavelength can affect system performance in Section 3.3.

In general, when lenses are focused at short working distances, the large cone angles cause the cones to diverge very quickly on either side of best focus, leading to limited depth of field. For objects that are in focus at longer working distances, the rate of transition of the bundles decreases and DOF will increase.

► Example: f/# Effects at the Object Level, a Close Up View

Figure 4.22 illustrates the ray bundle at the center of an object under inspection at f/2.8 (a) and f/8 (b). The vertical lines represent 2mm increments of movement away from best focus and closer to the lens. On each vertical line, there is a square that represents a single pixel of detail. Figure 4.22a demonstrates that the desired amount of detail quickly becomes a limited part of each bundle as the width of the bundle exceeds the feature size. In Figure 4.22b, the bundle expands far more slowly and the detail is larger than the bundle diameter for all distances shown, allowing it to be the dominant signal contributor and thus more distinguishable.

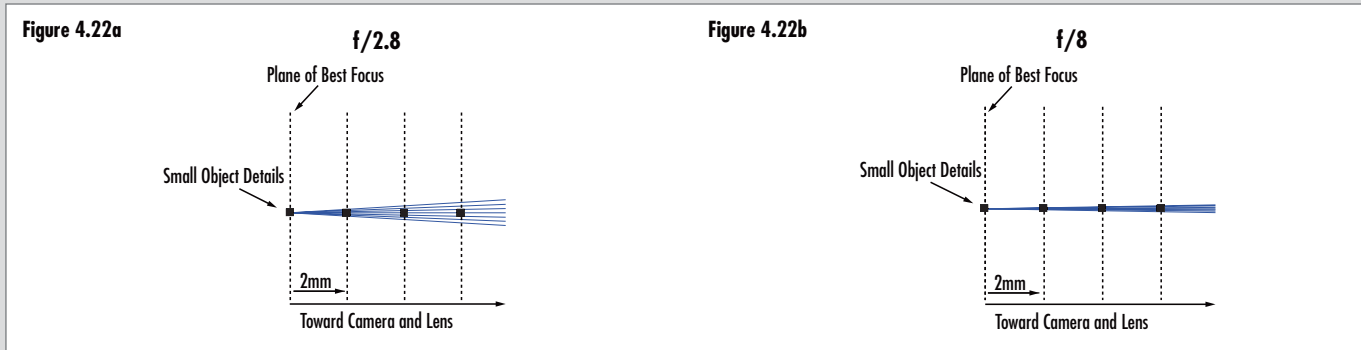


Figure 4.22: An illustration of the ray bundle at the center of an object under inspection at f/2.8 (a) and f/8 (b).

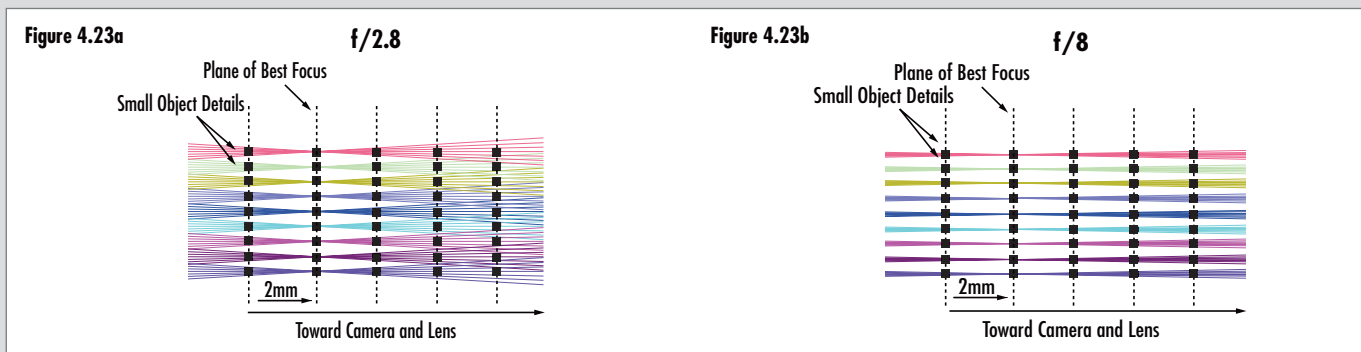


Figure 4.23: An illustration of ray bundles across a portion of the center of the field of view at f/2.8 (a) and f/8 (b).

Depth of Focus – ADVANCED

Depth of focus is the image-space complement of depth of field and is related to how the quality of focus changes on the sensor side of the lens as the sensor is moved while the object remains in the same position. Depth of focus dictates how much tip and tilt can be tolerated between the image plane of the lens and the sensor plane itself. The lower the f/#, the more the depth of focus is reduced and the more impact tilt has on achieving best focus across the sensor.

It needs to be understood that without active adjustment there will always be some degree of variation in the orthogonality between the sensor and the lens that is used; Figure 4.24 shows how this issue arises. It is generally assumed that problems involving depth of focus only occur with large sensors, however, this issue is actually independent of sensor size. As the derivation in Figure 4.24 shows, depth of focus is heavily dependent on the number of pixels and has little to do with array or pixel size. As sensors increase in pixel count, this issue is only amplified. Particularly in many line scan applications, the large arrays and low f/#s emphasize the need for careful alignment between the object, lens, and sensor.

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Figure 4.24

Sensor Tilt and Depth of Focus

Definitions:

- = Sensor Tilt
- z = Axial Shift due to "—"
- s = Pixel Size
- p = Number of Pixels on sensor
- h = Half Sensor Size
- Δ = Depth of Focus
- (f/#)_w = Working F-number

$$\Delta = 2 * (f/\#)_w * s$$

$$z = (s * p * \tan(_)) / 2$$

$$\Delta / 2 > z$$

$$(f/\#)_w > (p * \tan(_)) / 2$$

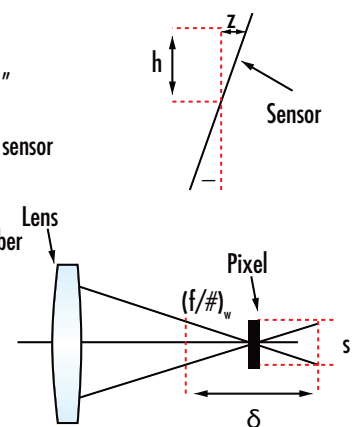


Figure 4.24: How sensor tilt with respect to the optical axis affects depth of focus.

Effects of Sensor Tilt – ADVANCED

Figure 4.25 shows a 35mm lens using 470nm illumination. Figure 4.25a is set to f/2.8 and Figure 4.25b is set to f/5.6. Both graphs go out to 150 lp/mm, which is roughly the Nyquist limit of a sensor using 3.45µm pixels. It is easy to see that the performance of Figure 4.25a is far better than Figure 4.25b, using this lens at a setting of f/2.8 would provide the highest level of imaging quality in a given object plane. However, as discussed in the previous section, tilt in relation to the sensor will negatively impact the actual image quality that the system produces: the higher the number of pixels, the more profound the effects.

In Figure 4.26, depth of focus for f/2.8 and f/5.6 of the 35mm lens featured in Figure 4.25 are analyzed. In both figures, the far right vertical line represents best focus for the entire image. Each semi-vertical line to the left of best focus represents a position 12.5µm closer to the back of the lens. These simulate the positions of the pixels assuming a tip/tilt of 12.5µm and 25µm respectively from the center to the corner of the sensor. The blue ray bundle is for the center of the image and the yellow and red bundles are for the corner of the image. The yellow and red bundles represent one line pair cycle on the sensor assuming 3.45µm pixels. Notice in Figure 4.26a, f/2.8, that there is already bleed-over between the yellow and red ray bundles at the shift to the 12.5µm tilt position. Moving out to 25µm, the red bundle now covers two full pixels and about half the yellow bundle as well, causing significant blurring. In Figure 4.26b, f/5.6, we see that the yellow and red ray bundles stay within one pixel over the full 25µm tilt range. Note that the blue pixel's position does not change, as the tip/tilt is centered on this pixel.

Figure 4.25a

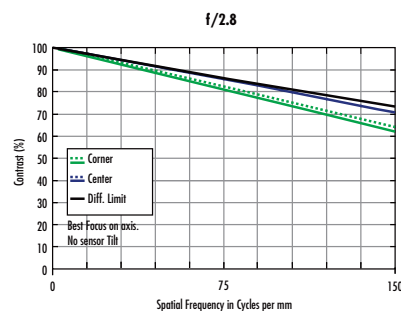


Figure 4.25b

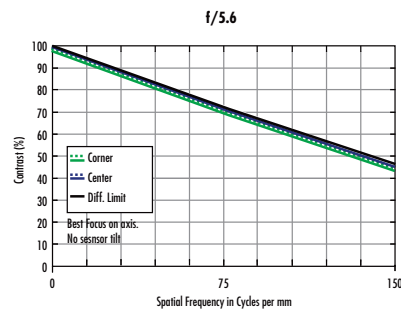


Figure 4.25: MTF performance of a 35mm lens at f/2.8 (a) and f/5.6 (b). Note that in each case, the diffraction limited resolution is nearly obtained.

Figure 4.26a

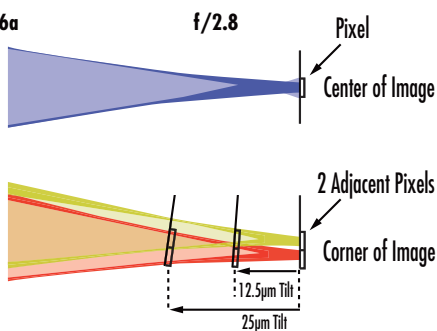


Figure 4.26b

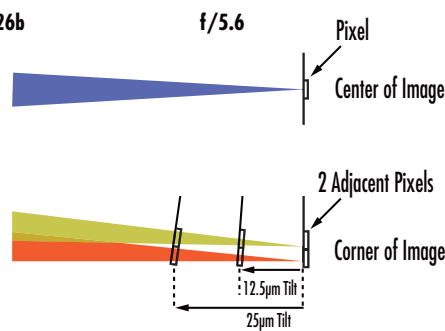


Figure 4.26: Ray bundles in image space of the same 35mm focal length lens at f/2.8 (a) and f/5.6 (b). The blue ray bundle is in the center of the image; the red and yellow bundles are at the corner of the image.

Figure 4.27 illustrates the change in MTF performance in the corner of the image for this 35mm lens assuming 25µm of tilt as seen in Figure 4.26. Figure 4.27a shows the new performance of the lens at f/2.8, note the significant reduction in performance from Figure 4.27a. Figure 4.27b shows the performance shift at f/5.6 which is minor in relation to 4.27b. Most importantly this lens at f/5.6 will now significantly outperform the f/2.8 setting. The drawback to running systems at f/5.6 is three times less light; this could be problematic in high speed and line scan applications. Finally, assuming that the sensor is tilted about the center of the sensor, reduced performance will occur at both the top and bottom of the sensor (and their corresponding points in the field of view) due to the tilt, since the ray bundles expand after best focus. No two camera and lens combinations are exactly the same. When building multiple systems this issue can present itself at varying degrees of magnitude.

In order to overcome these issues, cameras and lenses with higher tolerance control should be utilized. Additionally, for sensors, some lenses have tip/tilt control mechanisms to actively overcome this effect. It is also important to note that some line scan sensors can have swale, which means that they are not completely flat; this cannot be mitigated or removed via tip/tilt control.

Figure 4.27a

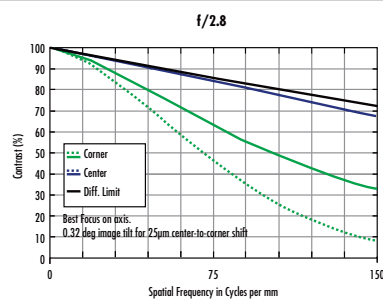


Figure 4.27b

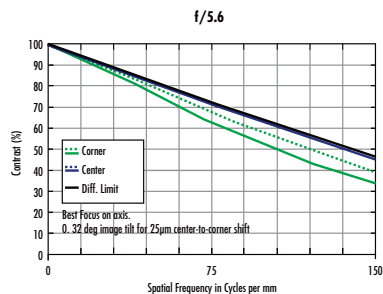


Figure 4.27: MTF performance of a 35mm lens at f/2.8 (a) and f/5.6(b), and with 25µm of z-axis shift caused by image plane tilt.

Section 4.5: Distortion

The term distortion is often applied interchangeably with reduced image quality. Distortion is an individual aberration that does not technically reduce the information in the image; while most aberrations actually mix information together to create image blur, distortion simply misplaces information geometrically. This means that distortion can actually be calculated or mapped out of an image, whereas information from other aberrations is essentially lost in the image and cannot easily be recreated. More details on other aberrations can be found in *Section 6*. Please note that in extreme high distortion environments, some information and detail can be lost due to resolution change with magnification or because of too much information being crowded onto a single pixel.

Distortion is a monochromatic optical aberration that describes how the magnification in an image changes across the field of view at a fixed working distance; this is critically important in precision machine vision and gauging applications. Distortion is distinct from parallax, which is a change in magnification (field of view) with working distance (more on parallax is provided in the section on telecentricity in *Section 5.1*). It is important to keep in mind that distortion varies with wavelength, as shown in *Figure 4.28*, and that when calibrating distortion out of a machine vision system the wavelength of the illumination needs to be taken into account. Curves like the one in *Figure 4.28* are very helpful in determining how to calibrate out distortion.

As with other aberrations, distortion is determined by the optical design of the lens. Lenses with larger fields of view will generally exhibit greater amounts of distortion because of its cubic field dependence. Distortion is a third-order aberration that, for simple lenses, increases with the third power of the field height; this means that larger fields of view (a result of low magnification or short focal length) are more susceptible to distortion than smaller fields of view (high magnification or long focal length). The wide fields of view achieved by short focal length lenses should be weighed against aberrations introduced in the system (such as distortion). On the other hand, telecentric lenses typically have very little distortion: a consequence of the way that they function. It is also important to note that when designing a lens to have minimal distortion, the maximum achievable resolution can be decreased. In order to minimize distortion while maintaining high resolution, the complexity of the system must be increased by adding elements to the design or by utilizing more complex optical glasses.

How is Distortion Specified?

Distortion is typically specified as a percentage of the field height. Typically, ± 2 to 3% distortion is unnoticed in a vision system if measurement algorithms are not in use. In simple lenses, there are two main types of distortion: positive, barrel distortion, where points in the field of view appear too close to the center; and negative, pincushion distortion, where the points are too far away. Barrel and pincushion refer to the shape a rectangular field will take when subjected to the two distortion types, as shown in *Figure 4.29*.

Distortion can be calculated simply by relating the Actual Distance (AD) to the Predicted Distance (PD) of the image using *Equation 4.2*. This is done by using a pattern such as dot target shown in *Figure 4.30*.

$$\text{Distortion (\%)} = \frac{\text{AD} - \text{PD}}{\text{PD}} \times 100 \quad 4.2$$

It is important to note that while distortion generally runs negative or positive in a lens, it is not necessarily linear in its manifestation across the image for a multi-element assembly. Additionally, as wavelength changes, so does the level of distortion. Finally, distortion can change with changes in working distance. Ultimately, it is important to individually consider each lens that will be used for a specific application in order to guarantee the highest level of accuracy when looking to remove distortion from a system.

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(Continued on page 30)

Figure 4.28

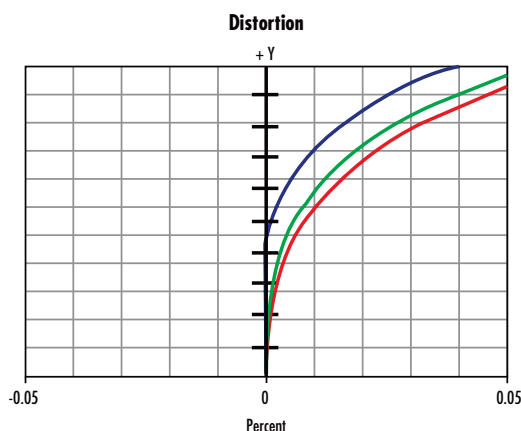


Figure 4.28: Distortion plot showing the variance of distortion with respect to wavelength.

Figure 4.29

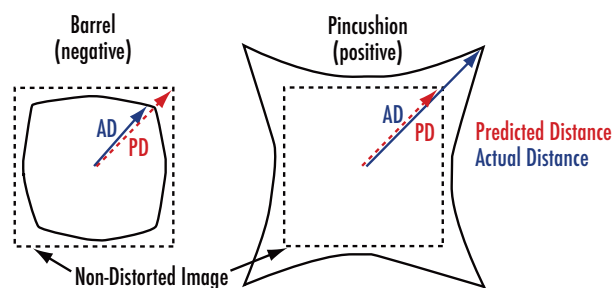


Figure 4.29: An illustration of positive and negative distortion.

Figure 4.30

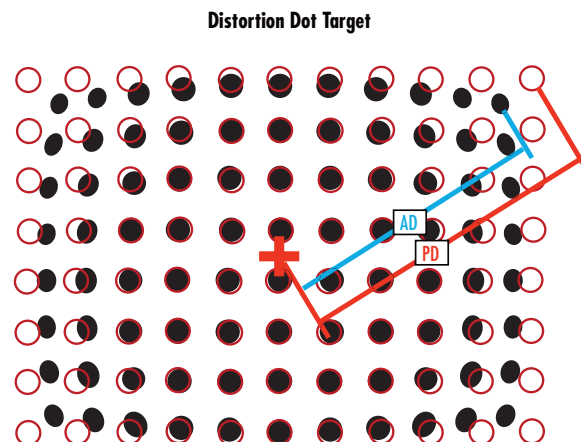


Figure 4.30: Calibrated target (red circles) vs. imaged (black dots) dot distortion pattern.

Example of Distortion Curves

Figure 4.31 shows negative, or barrel, distortion in a 35mm lens system. In this specific example, all of the wavelengths analyzed carry almost identical levels of distortion, thus wavelength-related issues are not present. In Figure 4.32, an interesting set of distortion characteristics can be seen: first, there is separation in the level of distortion for the different wavelengths, and second, both negative and positive distortion is present in this lens. Distortion of this nature is referred to as wave, or moustache, distortion. This is often seen in lenses that are designed for very low levels of distortion, such as those designed for measurement and gauging applications. In this scenario, calibrating the system so that distortion is removed can require special consideration for applications where different wavelengths are used.

Geometric Distortion vs TV Distortion: An Important Difference

In lens datasheets, distortion is usually specified in one of two ways: radial, geometric distortion or RIAA TV distortion. Geometric distortion describes the distance between where points appear in the distorted image and where they would be in a perfect system. In practice, this can be measured using a distortion dot target. The difference between the distance from the center of the target to any dot in the field of view and the distance from the center of the image to the same, now misplaced dot (shown in Figure 4.30), provides the radial distortion percentage calculated with Equation 4.2.

The measurement of TV distortion is specified by an RIAA imaging standard, and is determined by imaging a square target that fills the vertical field of view. The difference in height between the corners and the center edge of the square is used to calculate the TV distortion with Equation 4.3; this describes the apparent straightness of a line which appears at the edge of the image, which is essentially the geometric distortion at a single field point. By only specifying distortion at one point in the field, it is possible to misrepresent a non-zero distortion lens as having 0% distortion. In Figure 4.32, a 0% intercept can be found for any of the wavelengths shown. However, when the full image circle is considered, it is obvious that the lens has non-zero distortion. An example of how TV distortion can be found is shown in Figure 4.33.

$$D_{TV} = \frac{\Delta H}{H} \times 100 \quad 4.3$$

As shown in Figure 4.32, in real world, compound imaging lens assemblies, distortion is not necessarily monotonic and can change signs across the field of view, which is why a radial distortion plot is preferable to the single RIAA value. Due to the way it is specified, the TV distortion value can be much lower than the maximum geometric distortion value of the same lens, thus it is important to be aware of what type of distortion is being specified when choosing the most appropriate lens for an application.

Keystone Distortion

In addition to the previous distortion types mentioned, which are inherent to the optical design of a lens, improper system alignment can also result in keystone distortion, which is a manifestation of parallax (shown in Figure 4.34a and 4.34b).

When calibrating an imaging system against distortion, keystone distortion should be considered in addition to radial geometric distortion. Although distortion is often thought of as a cosmetic aberration, it should be carefully considered against other system specifications when choosing the right lens. In addition to the potential for a loss in image information, algorithmic distortion correction takes additional processing time and power, which may not be acceptable in high speed or embedded applications.



Did you know telecentric lenses typically feature very low levels of distortion? See **pages 82-109** for our **complete selection of TECHSPEC® telecentric lenses.**

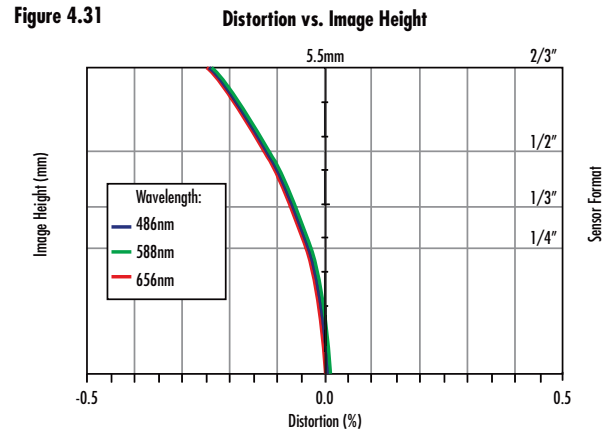


Figure 4.31: Negative, or barrel, distortion in a lens.

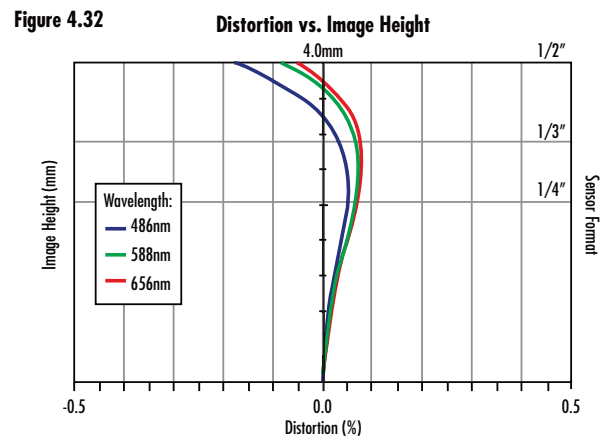


Figure 4.32: Wave, or moustache, distortion in a lens.

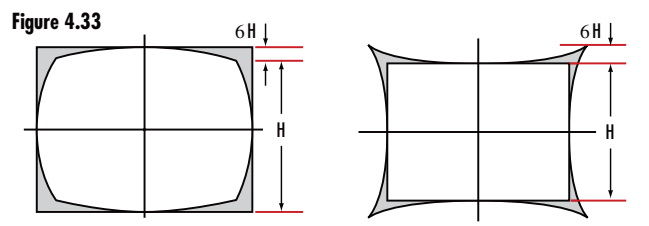


Figure 4.33: TV distortion with both barrel and pincushion distortion.

Figure 4.34a: Lens layout showing keystone distortion.

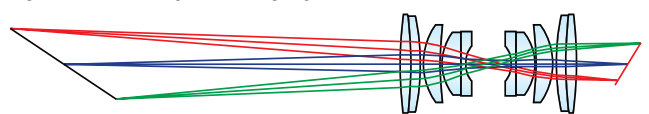


Figure 4.34b: Manifestation of keystone distortion.

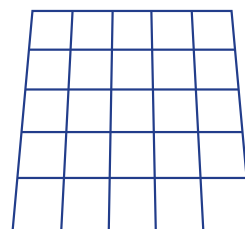


Figure 4.34: Examples of keystone distortion.

Section 5: Telecentricity and Perspective Error

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The ability to quickly perform repeatable, high accuracy measurements is critical to maximize the performance of many machine vision systems. For such systems, a telecentric lens allows the highest possible accuracy to be obtained. This section discusses the unique performance characteristics of Telecentric Lenses and how telecentricity can impact system performance.

TECHSPEC® Telecentric Lenses can be found on **pages 82-109**
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Section 5.1: The Advantages of Telecentricity

Zero Angular Field of View: Parallax Error Elimination

Conventional lenses have angular fields of view such that as the distance between the lens and object increases, the magnification decreases. This is how the human vision behaves, and contributes to our depth perception. This angular field of view results in **parallax**, also known as perspective error, which decreases accuracy, as the observed measurement of the vision system will change if the object is moved (even when remaining within the depth of field) due to the magnification change. Telecentric Lenses eliminate the parallax error characteristic of standard lenses by having a constant, non-angular field of view; at any distance from the lens, a Telecentric Lens will always have the same field of view. See *Figure 5.1* for the difference between a non-telecentric and a telecentric field of view.

A Telecentric Lens's constant field of view has both benefits and constraints for gauging applications. The primary advantage of a Telecentric Lens is that its magnification does not change in respect to depth. *Figure 5.2* shows two different objects at different working distances, both imaged by a Fixed Focal Length (non-telecentric) Lens (center) and a

Telecentric Lens (right). Note that in the image taken with a Telecentric Lens, it is impossible to tell which object is in front of the other. With the Fixed Focal Length Lens, it is quite obvious that the object that appears smaller is positioned farther from the lens.

While *Figure 5.2* is drastic in terms of a working distance shift, it illustrates the importance of minimizing parallax error. Many automated inspection tasks are imaging objects that move through the field of view of an imaging system, and the position of parts is rarely perfectly repeatable. If the working distance is not identical for each object that the lens is imaging, the measurement of each object will vary due to the magnification shift (see *Section 2.2* on magnification and how it is defined, *page 9*). A machine vision system that outputs different results based on a magnification calibration error (which is unavoidable with a Fixed Focal Length Lens) is a non-reliable solution and cannot be used when high precision is necessary. Telecentric Lenses eliminate the concern about measurement errors that would otherwise occur due to factors such as a vibrating conveyor or inexact part locations.

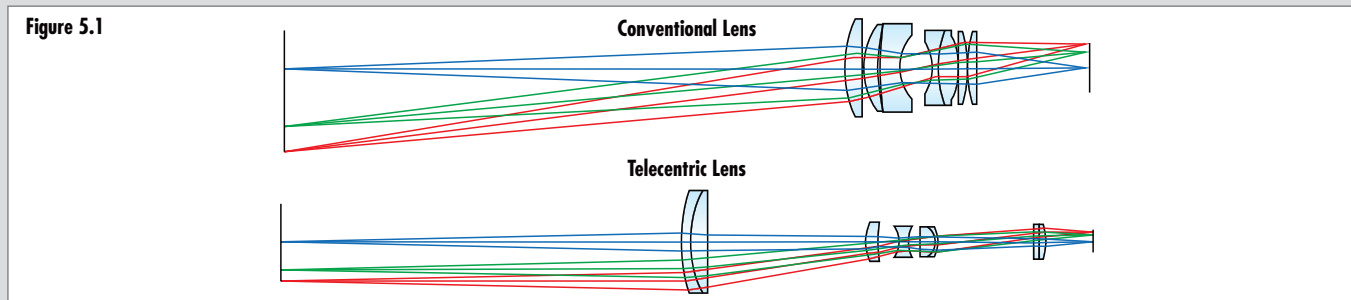


Figure 5.1: Field of view comparison of a conventional and Telecentric Lens. Note the conventional lens's angular field of view and the Telecentric Lens's zero angle field of view.

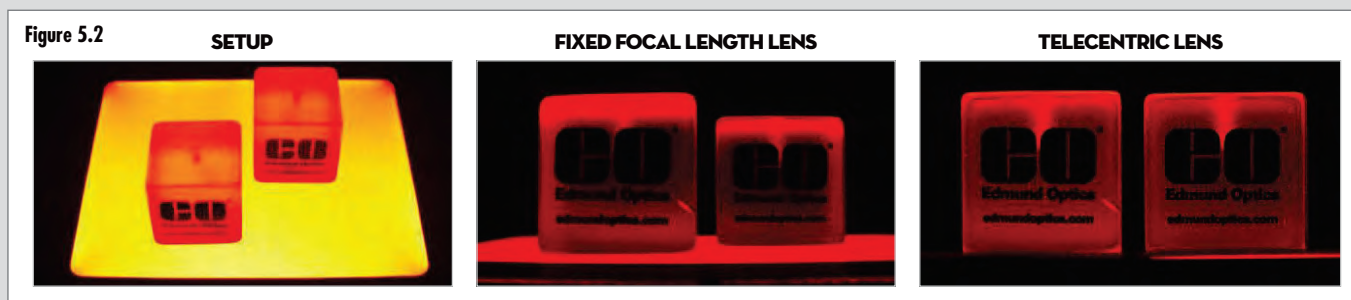


Figure 5.2: The angular field of view of the Fixed Focal Length Lens translates to parallax error in the image and causes the two cubes to appear to be different sizes.

Telecentric Lenses and Depth of Field

It is a common misconception that Telecentric Lenses inherently have a larger depth of field than conventional lenses. While depth of field is still ultimately governed by the wavelength and $f/\#$ of the lens, it is true that Telecentric Lenses can have a larger usable depth of field than conventional lenses due to the symmetrical blurring on either side of best focus. As the part under inspection shifts toward or away from the lens, it will follow the angular field of view (or the chief ray) that is associated with it. In a non-telecentric lens, when an object is moved in and out of focus, the part blurs asymmetrically due to parallax and the magnification change that is associated with its angular field of view. Telecentric Lenses, however, blur symmetrically since there is no angular component to the field of view. In practice, this means that features such as edges retain their center of mass location; an accurate measurement can still be made when the object is beyond best focus as long as the contrast remains high enough for the algorithm being used by the machine vision system to function properly.

While it may seem counterintuitive, blur can be used advantageously in certain applications with Telecentric Lenses. For example, if a machine vision system needs to find the center location of a pin, as shown in Figure 5.3a, the transition from white to black is quite sharp when the lens is in focus. In Figure 5.3b, the same pin is shown slightly defocused.

Looking at a plot of the image grey levels from a line profile taken across the edge of the part, as in Figure 5.4, the slope of the line is much shallower for the slightly defocused image, as the pin edge is spread over more pixels. Due to the symmetric blurring of the Telecentric Lens, this blur is still usable as the centroid has not moved and the amount of sub-pixel interpolation needed is decreased. This reduces sensitivity to grey level fluctuations caused by sensor noise and allows the pin center location to be found more reliably and with higher repeatability.

Figure 5.3a

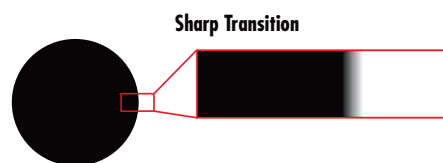


Figure 5.3b

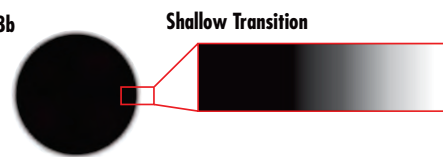


Figure 5.3a and b: The same pin imaged both in and out of focus. Note that the transition from white to black covers many more pixels when the lens is slightly out of focus (b), which can be advantageous.

Figure 5.4

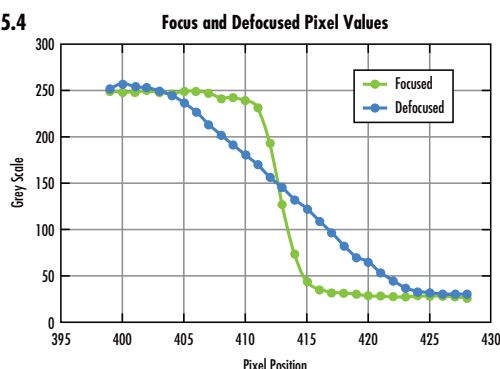


Figure 5.4: Plot showing the difference in slope between a focused and defocused edge. The defocused edge takes up many more pixels; finding the edge becomes easier without relying on sub-pixel interpolation.

Telecentricity and Distortion

Another advantage of using Telecentric Lenses in metrology applications is that Telecentric Lenses typically have lower distortion values than Fixed Focal Length Lenses. Distortion causes the actual position of an object to appear as though it is in a different location, which can further decrease measurement accuracy (see Section 4.4 for more information on distortion, pages 26-28). For example, Figure 5.5a shows jumper pins on a circuit board that has been imaged by a Fixed Focal Length Lens with high distortion. The distortion, coupled with the parallax error inherent to non-telecentric lenses, makes the pins toward the edge of the image appear as though they are bent toward the center. When looking at the same pins with a Telecentric Lens, as in Figure 5.5b, it is apparent that the pins are indeed straight.

While it is true that distortion can be calibrated out of images to partially improve the accuracy, the parallax is still present and will cause error. The other advantage to not needing to calibrate out the distortion from the Telecentric Lens is that the measurement process can run faster as there is less computing that the software needs to do, reducing CPU load and directly leading to higher system throughput and more parts measured per minute.

Because Telecentric Lenses tend to have such low distortion, they are more prone to having non-monotonic wave distortion than fixed focal length lenses, as shown in Figure 5.6. While the magnitude of the distortion is generally low enough to not have a significant impact on the measurement of the part under inspection, it is still important to check the distortion specifications of the Telecentric Lens and to properly calibrate the imaging system utilizing the Telecentric Lens. This property is also why distortion plots should be used rather than a single numerical value, as the lens can have zero distortion at the field point where it is specified, but be non-zero elsewhere.

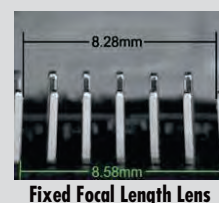
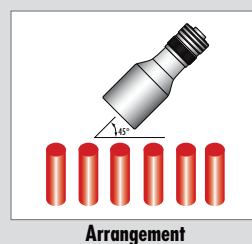


Figure 5.5a

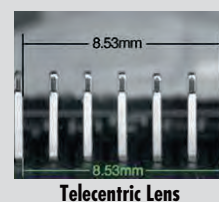


Figure 5.5b

Figure 5.5: Comparison of jumpers on a circuit board. Figure 5.5a shows an image that has been taken with a Fixed Focal Length Lens. Figure 5.5b shows an image that has been taken with a Telecentric Lens. Note that the pins do not appear bent in the telecentric image.

In applications where the object plane is tilted, Telecentric Lenses provide a good alternative to Fixed Focal Length Lenses due to their low distortion and invariant magnification. The camera can also be tilted to keep the tilted object in sharp focus; this is called the Scheimpflug condition. The **Scheimpflug** condition is a way to extend the depth that is being observed by the machine vision system by tilting the object plane and the image plane, as shown in *Figure 5.7*. If a conventional lens is used this way, it will result in keystone distortion, described in detail in *Section 4.5, pages 26-28*. Telecentric Lenses, however, will not demonstrate keystone distortion, as the magnification does not change with depth. Care must be taken in calibration, though, as the part will be observed as a geometric projection: a circle will be an ellipse, a square will be a rectangle, and so on.

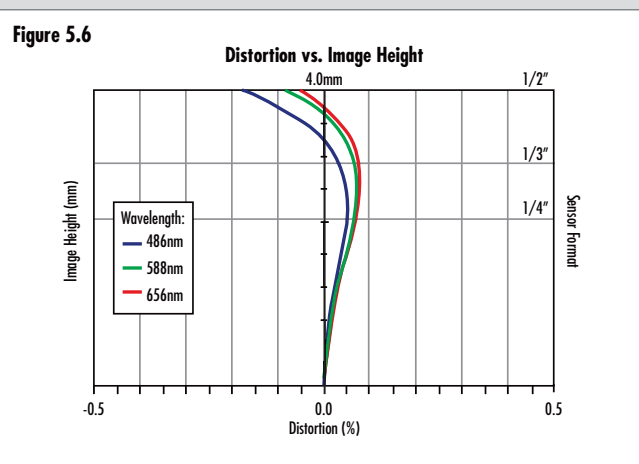


Figure 5.6: Non-monotonic, or wave distortion typical of telecentric lenses.

Figure 5.7

Telecentric Lens in the Scheimpflug Layout

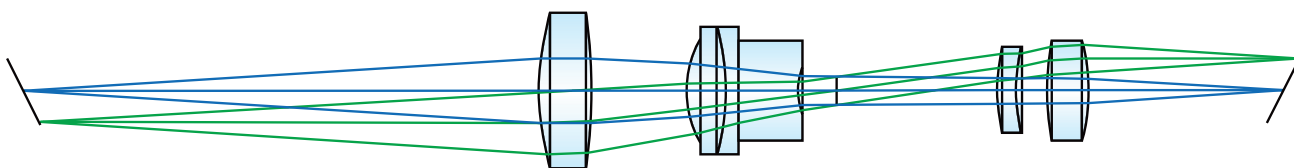


Figure 5.7: 1X Telecentric Lens in the Scheimpflug layout with tilted object and image planes.

Section 5.2: Distortion and the Telecentricity Specification

As discussed in prior sections, the elimination of both parallax and distortion play large roles in determining the quality of a particular Telecentric Lens. While distortion's specifications are discussed in much more detail in *Section 4.5, pages 26-28*, the distortion of Telecentric Lenses can be specified in two different ways: TV distortion or geometric distortion. Both are generally classified as a percentage value, but TV distortion values will almost always be lower than geometric distortion values, which can be misleading. When a telecentric lens is specified with geometric distortion values, the value that is given is at the maximum field height of the maximum sensor size that the lens is capable of. In the case where the lens has monotonic distortion, the value that is specified will be the highest. However, in the case of wave distortion, it is important to look at the plot (as in *Figure 5.6*) to determine how the distortion is actually characterized.

The other relevant specification is telecentricity, which is generally specified in degrees, and can be thought of as the residual angular field of view of the lens. Unfortunately, just as no lens has zero distortion, no lens is perfectly telecentric. *Figure 5.8* shows a plot of the telecentricity for a 1X Telecentric Lens.

The plot in *Figure 5.8* shows three different lines, each representing the telecentricity at different wavelengths (red, green, and blue). The most important nuance to note about the plot is that the telecentricity varies with wavelength, meaning that the accuracy of a measured part can change depending on the wavelength (color) of light that is used to inspect the part. While this variance is small in an absolute sense, it is important to consider when designing systems that require the highest possible accuracy. For these systems, it is best to use monochromatic illumination, preferably the wavelength where the telecentricity was optimized in the design process. Learn more about using proper illumination on *pages 152-155*.

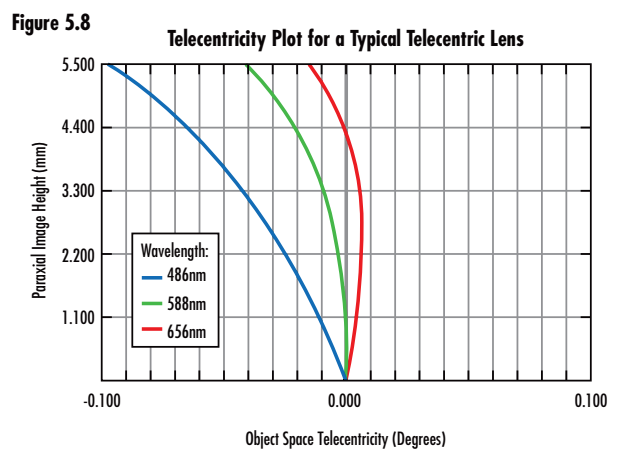


Figure 5.8: Telecentricity plot for a typical Telecentric Lens

Section 5.3: Telecentric Lens Size Control

The field of view of any Telecentric Lens is limited by the front optic diameter; the larger the required field of view, the larger the front optic diameter. Telecentric Lenses can grow quite large and heavy with small magnifications, as such magnifications require large front optics; this can be prohibitive in some setups where weight or size is a concern. The $f/\#$ of a lens also plays into the size of the lens, particularly at large magnifications where the front optics also grow with the speed of the lens. *Figure 5.9* shows two different 4X telecentric lenses of different $f/\#$ s. The lens at the top of *Figure 5.9* shows a system that runs at $f/6$, and the lens at the bottom runs at a much slower $f/16$.

If a particularly large field of view is required, Fixed Focal Length Lenses can be augmented with additional optics in order to produce a pseudo-telecentric lens for large fields of view. *Figure 5.10* shows a 25mm Fixed Focal Length Lens that has been augmented with a Fresnel Lens to make a telecentric lens that has an 8" field of view. This type of augmentation always has lower image quality than a specifically designed Telecentric Lens, but can be useful where cost-sensitive, large field of view applications require telecentricity. This approach allows for minimal flexibility with regards to working distance, as well as substantial chromatic aberrations due to the use of a Fresnel Lens.

Figure 5.9

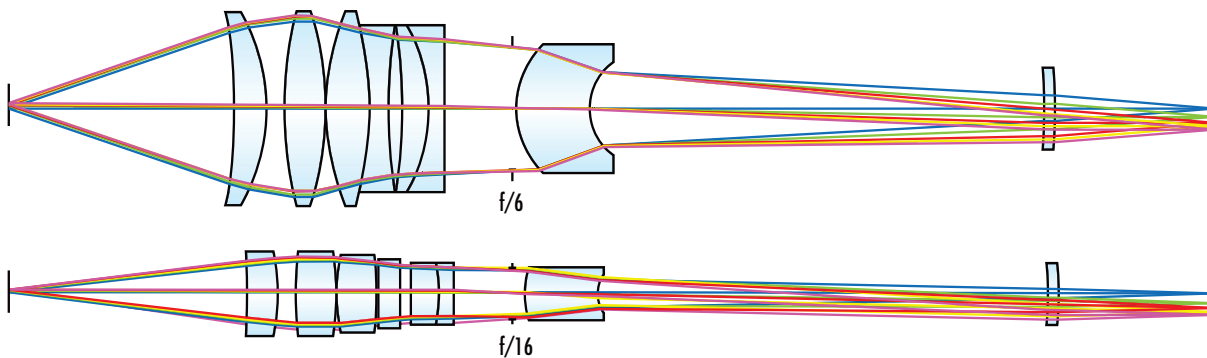


Figure 5.9: Two 4X telecentric lenses, operating at $f/6$ (top) and $f/16$ (bottom), showing how $f/\#$ can partially dictate element size for telecentric lenses.

Figure 5.10

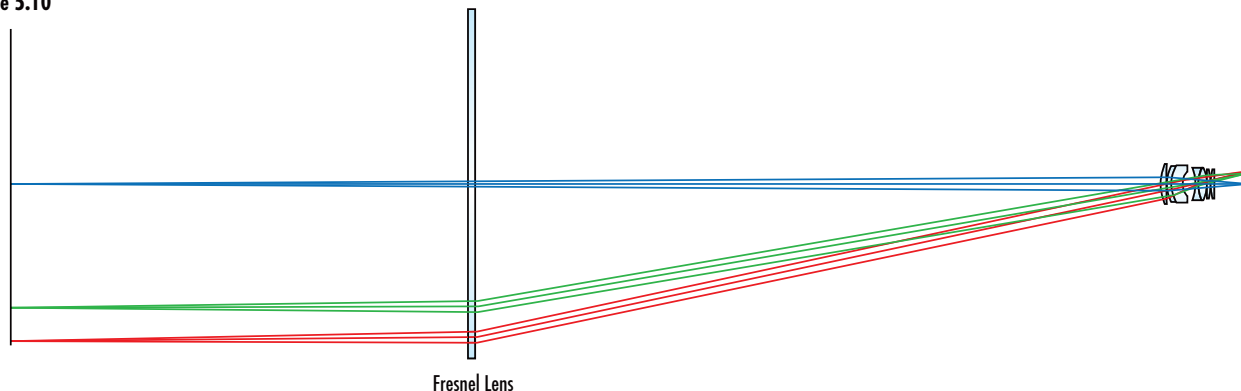


Figure 5.10: A fixed focal length lens augmented with a Fresnel lens, making it pseudo-telecentric.

Section 5.4: Telecentric Design Topics – ADVANCED

In previous sections, the lenses discussed have been divided into two different categories: Telecentric Lenses and non-telecentric lenses. However, there are two types of telecentricity: object space and image space telecentricity (which refer to the entrance pupil and exit pupil locations, respectively). The pupils of an optical system are images of the aperture stop; typically, machine vision lenses have embedded aperture stops, with individual lens components surrounding it on either side. The entrance pupil is the image of the aperture stop into image space, and the exit pupil is the image of the aperture stop into object space. See *Figure 5.11* for illustrations of entrance and exit pupils for a non-telecentric lens.

Figure 5.11

Entrance and Exit Pupils for a Non-Telecentric Lens

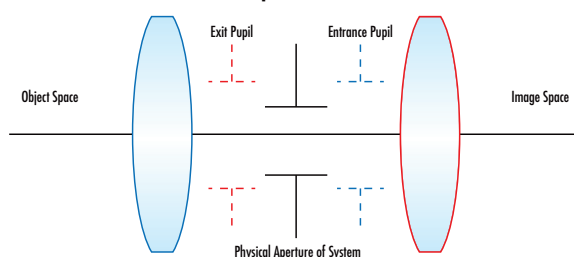


Figure 5.11: A machine vision lens with entrance and exit pupils located within the lens, which is typical of most Fixed Focal Length Lenses.

Object Space Telecentricity

When a machine vision lens is described as simply being telecentric, it is most likely object space telecentric. These have all of the properties and advantages described in the previous sections. A lens is said to be object space telecentric when the entrance pupil is located at infinity in image space (everything behind the objective), as shown in *Figure 5.12*.

In an optical design, object space telecentricity is accomplished by placing the aperture stop of the system at the focal point of the front group. The entrance pupil at infinity explains why the field of view is constant and non-angular. Since the chief ray, which defines the field of view of a system, crosses the optical axis at the aperture stop and also crosses at the entrance pupil, the ray will be parallel to the optical axis when the pupil is at infinity, and the angular field of view is zero (*Figure 5.13*). By contrast, any entrance pupil located a finite distance away from the lens will result in a non-parallel chief ray, as shown traced in *Figure 5.14* for a non-telecentric lens.

Lenses that are only object space telecentric have the ability to be focusable since the back half of the lens can be designed with moving elements, which is advantageous for systems that need the variability of working distance. They can also be designed to be variable magnification lenses, as the rear elements can be used to control magnification, or the sensor plane can be moved for small magnification shifts. The magnification in the field of view, however, will still remain constant once the magnification is set, and will retain the high measurements accuracy that is expected of a Telecentric Lens.

Object space-only Telecentric Lenses are more easily capable of hitting larger image sensor formats, even in more compact form factors, as the rays in image space are allowed to diverge; the back of the lens therefore does not need to exceed the sensor dimensions.

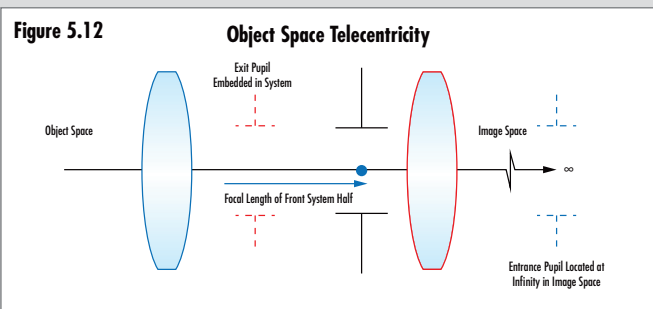


Figure 5.12: A lens which is object space telecentric, with the entrance pupil projected to image-side infinity.

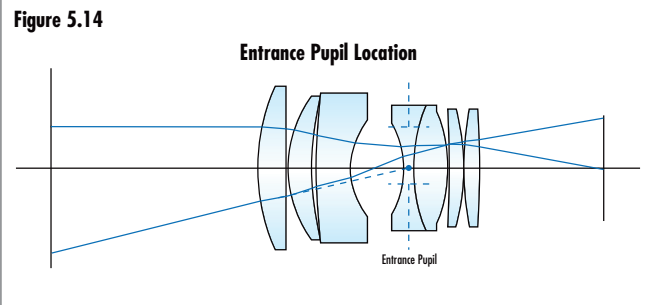


Figure 5.14: The entrance pupil's location is where the object space chief ray crosses the optical axis, as shown with a non-telecentric lens.

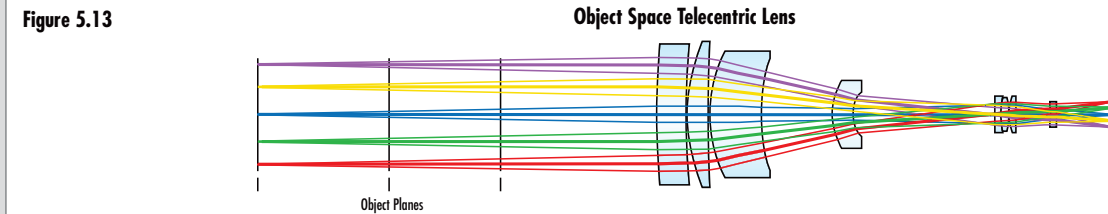


Figure 5.13: An object space telecentric lens where the chief rays are all parallel to the optical axis in object space. Note that the field of view does not change regardless of where the object plane is positioned, as the chief rays defining the field of view are all parallel to the optical axis.

Image Space Telecentricity

As object space telecentricity is defined by the position in object space of the entrance pupil, image space telecentricity can be defined by the exit pupil being located at infinity in image space. This is shown in *Figure 5.15*.

Much in the same way that the magnification of an object will not change if a lens is object space telecentric, when a lens is image space telecentric the magnification will not change with respect to the placement of the sensor plane, as shown in *Figure 5.16*. This means that sensor placement tolerance for cameras is not as important with image space telecentric lenses, as small shifts toward or away from optimal position will not cause differences in magnification between two systems with identical lenses.

Additionally, image space Telecentric Lenses do not suffer from radiometric cos⁴θ roll-off (described in detail in *Section 4.2, pages 20-23*) since the rays land perpendicular to the sensor across its entire area. This is advantageous because it allows the image to have a more even relative illumination profile assuming selective vignetting has not been built into the lens design.

Image space telecentricity is not exclusive to Telecentric Lenses as it can be specified into conventional lenses such as Fixed Focal Length Lenses. Most Fixed Focal Length Lenses on the market are not designed to be image space telecentric, however, as they usually require additional elements (and thus cost) to achieve telecentricity, and they can grow quite large in diameter depending on the sensor size that is being used. If a non-telecentric lens is image space telecentric, it will typically be denoted.

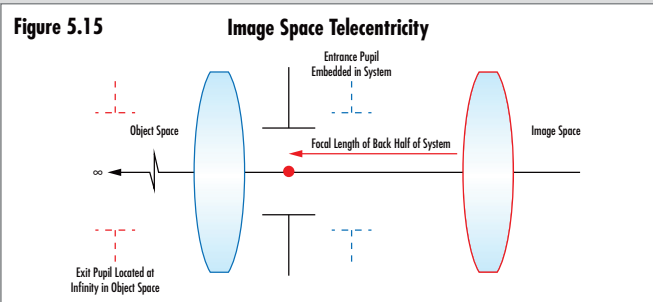


Figure 5.15: A lens which is image space telecentric, with the exit pupil projected to image space infinity.

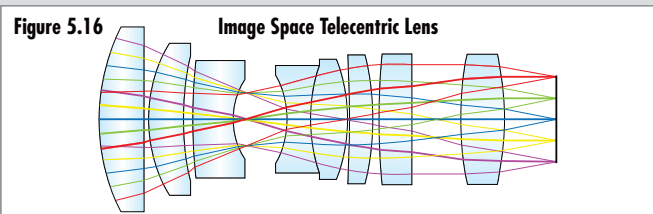


Figure 5.16: An image space telecentric lens, where the chief rays are all parallel to the optical axis in image space. Note that the image height does not change regardless of where the sensor plane is positioned, as the chief rays defining image height are all parallel to the optical axis.

Double Telecentricity

While object space telecentricity provides a substantial boost to gauging accuracy over conventional lenses, even greater accuracy can be achieved if a lens is both object and image space telecentric (doubly telecentric). The same principles of image and object space telecentricity hold true; in a doubly telecentric lens, both the entrance and exit pupils are projected to their respective infinities, as shown in Figure 5.17.

Doubly Telecentric Lenses are the most accurate type of Telecentric Lens, as the field of view is completely unaffected to change caused by shifts of the object position or the sensor position, nor do they suffer from any $\cos^4\theta$ roll-off.

Figure 5.18 shows a plot comparing three different lenses - a fixed focal length lens, an object space only telecentric lens, and a doubly telecentric lens - with the x-axis representing the change in working distance (in mm) from nominal and the y-axis representing the dimensional error as a percentage from the actual value.

As is shown in the plot, the doubly Telecentric Lens is the most accurate of the group, with less than 0.2% error throughout a 4mm shift in working distance. Doubly Telecentric Lenses should be used in applications requiring the highest accuracy and precision.

Figure 5.17

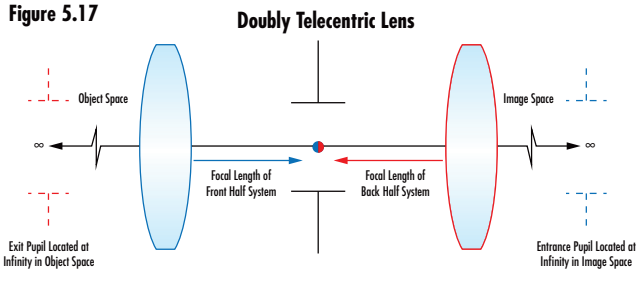


Figure 5.17: A doubly Telecentric Lens, with the entrance and exit pupils projected to image and object space infinity, respectively.

Figure 5.18

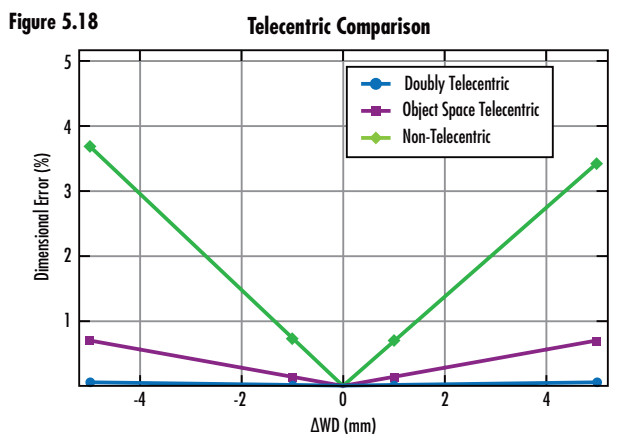


Figure 5.18: Plot comparing three different types of lenses (non-telecentric, object space telecentric, and doubly telecentric) and the dimensional error that is associated with each as the working distance is changed.

Section 6: Advanced Design Concepts

Section 6.1: Aberrational Balancing of MTF in Lens Design – ADVANCED

To design a lens with nearly perfect performance generally requires it to be optimized at a single magnification, single working distance, and for a single sensor. However, while such lens designs provide the maximum reduction of aberrational effects and achieve the highest performance, separate custom lenses would need to be built to meet the needs of each individual application.

Designing individual custom lenses for each application is neither cost effective nor practical. Instead, most lenses are designed for a large range of coverage so that they are both cost effective and capable of meeting the needs of many applications. This adaptability does have faults; the most important of which is that it is not possible to simultaneously achieve the maximum performance at all fields of view, working distances, and sensors. These lenses can be considered “jack of all trades, master of none” and are the most common lenses on the market today. However, as resolutions continue to increase, other options may need to be explored to maximize system performance.



To read more on Aberrational Balancing, visit us at WWW.EDMUNDOPTICS.COM/IMAGING-RESOURCE-GUIDE

Section 6.2: How Aberrations Affect Machine Vision Lenses – ADVANCED

While aberration theory is a vast subject, basic knowledge of a few fundamental concepts can ease understanding: spherical aberration, astigmatic aberrations, field curvature, and chromatic aberration.

Spherical Aberration

Spherical aberration refers to rays focusing at different distances depending on where across the aperture they meet the lens, and is a function of aperture size. The steeper the angle of incidence light has on the surface of a spherical lens, the greater the error in how the lens will refract the light (Figure 6.9). Lenses with large apertures (small $f/\#$ s) are more likely to have spherical aberration negatively impact the image quality. If a lens has a lot spherical aberration, image quality can be improved by increasing the $f/\#$ by closing the iris, but there is a limit to how much this will improve image quality. Closing the iris too much will cause diffraction to limit the performance (see diffraction limit in Section 3.1). Optical designs that include high index glass or additional elements can be used to correct for spherical aberration in a fast (small $f/\#$) lens; these designs will reduce the amount of refraction at each surface and, with it, the amount of spherical aberration. However, this can cause increases in the size, weight, and cost of the lens assembly.

Astigmatic Aberration

Astigmatism is a function of field angles. To summarize, astigmatic aberration occurs when a lens has to perform over a wide field, but the performance in the direction of the field is reduced compared to the performance orthogonal to the field. If one looks at a series of bars that are half horizontal and half vertical, the bars in one direction will be in focus, but the bars in the other direction will be out of focus (as shown in Figures 6.10 and 6.11). This is caused by the fact that rays away from the center of the object do not pass through rotationally symmetric surfaces like the on axis rays do (Figure 6.12). To correct this, two things need to be done: have symmetric designs about the aperture and have designs with low angles of incidence for the field rays. Keeping a design symmetric leads to forms that are similar to a double gauss lens. Keep in mind that symmetric designs prevent the use of telephoto or reverse telephoto designs, which can cause long focal length designs to be large and short focal length designs to have small back focal lengths. Reducing the angles of incidence, much like one does for spherical aberration, requires higher index glasses and additional elements, leading to an increase in size, weight, and cost of the lens. The simplified definition used here intentionally combines the effects for astigmatism and coma for ease of understanding.

Field Curvature

Field curvature (Figure 6.13) is the aberration that describes the magnitude to which the image plane wants to be naturally curved. This aberration is caused by the sum of the focal lengths of the lens elements in the system multiplied by their index of refraction not equaling zero. If the sum is positive, which is typical for an imaging lens, the image plane will have a concave curvature to it; this is why movie theaters tend to have slightly curved screens. Since curving the image plane is seldom an option for a machine vision lens, the designers must insert negative powered corrective elements to reduce the sum of the focal lengths. This makes lenses longer and typically forces a negative lens to be close to the image plane, reducing the back focal length of the lens.

Chromatic Aberration

Chromatic aberration implies different wavelengths of light focus at different points. Because the dispersion of a glass determines the refractive power of the glass at different wavelengths, chromatic aberration can be removed by designing an imaging lens that contains both positive and negative lenses that are made using glasses with different dispersions. This is illustrated in Figure 6.14, which compares a singlet to an achromatic doublet lens. A downside to such a design is that it increases the number of elements needed for a lens.

(Continued on page 38)

Figure 6.9

Spherical Aberration

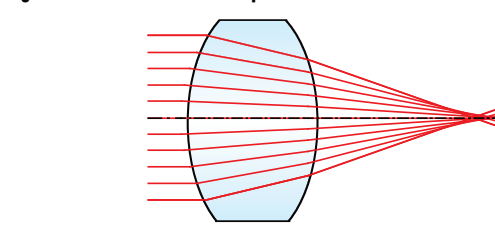


Figure 6.9: Example of spherical aberration. The light incident near the edges of the lens come to focus too early.

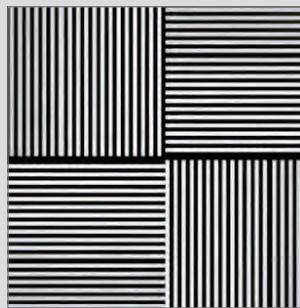


Figure 6.10: Field Point without Astigmatism.

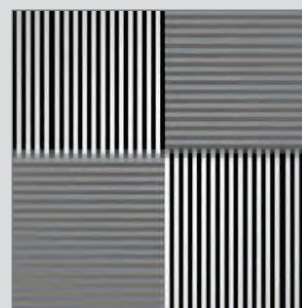


Figure 6.11: Field Point with Astigmatism.

Figure 6.12

Astigmatism

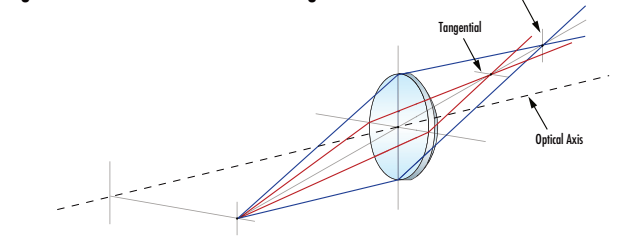


Figure 6.12: Off axis asymmetry.

Figure 6.13

Field Curvature

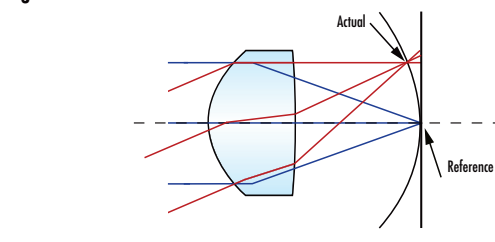


Figure 6.13: Field curvature example showing non-planar surface of best focus.

Figure 6.14

Chromatic Focal Shift

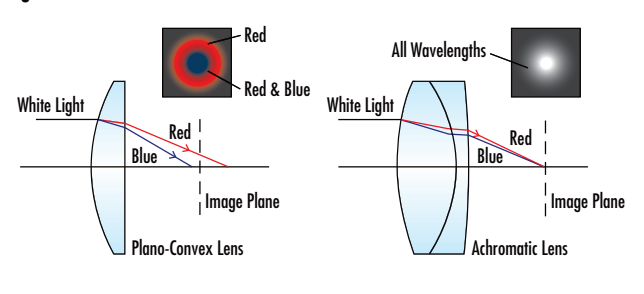


Figure 6.14: Comparison of singlet and doublet lens spots.

(Continued from page 37)

To reduce the aberration, lower index lenses (which have higher abbe numbers) typically need to be used. As mentioned before, higher index lenses are required to correct for spherical and astigmatic aberrations; if a lens needs to correct for spherical, astigmatic, and chromatic aber-

rations, additional lens elements will be required. Additionally, the most desirable glasses for color correction often have properties that make them more expensive and difficult to manufacture. When possible, minimizing chromatic aberrations by using monochromatic light can have considerable savings in cost and complexity.

Chromatic Focal Shift

A type of chromatic aberration, chromatic focal shift describes how different wavelengths focus along different longitudinal positions. The goal of most imaging lens designs is to get all the desired wavelengths to focus on the same plane (the location where the sensor is located in the system). It is physically impossible to get a singular focus plane over a wide spectral range. However, it is possible to come very close. The closer to the same plane all the wavelengths are focused, the less issues that will be observed in the image.

Figure 6.15 shows a chromatic focal shift curve. Since this is an example of an **achromatic** lens design, two wavelengths can be focused into the same plane at the same time. The vertical axis shows changing wavelength from short to long, which is blue to red in the visible spectrum. The vertical black line represents a plane, which could be the sensor location. The blue curved line represents the relative location of best focus as a function of wavelength. The curve verifies that this is an achromatic design, since even if moved slightly to the left or right, the black line intersects the blue curve at only two points/wavelengths..

The blue, green, and red dots represent wavelengths associated with common 470nm, 520nm, and 630nm (blue, green, and red) LEDs. Notice that the green dot focuses to the left of the sensor plane, while the red and blue dots focus more to the right; this is the most balanced position of focus of the lens system if all the wavelengths or white light (which encompasses all wavelengths) are used. This design displays non-ideal image quality, as none of the wavelengths are truly in focus. If only one wavelength is used, the performance will improve since the balance for the others are eliminated. While this example demonstrates that red and blue can be balanced, this is not always true. Most lens designs are achromatic, but for very small pixels, this can become problematic.

Shown at the same scale as Figure 6.15, Figure 6.16 displays an **apochromatic** lens. An apochromatic lens has three wavelengths that can be focused in the same plane at the same time. While this is a far more complicated design, it does allow for superior balancing across the wavelength spectrum. As shown, all three LED colors can be brought into focus on the same sensor plane simultaneously, which allows for superior image quality. Generally, apochromatic lens designs have high performance, but low versatility; they work very well over a smaller range of magnifications and working distances. Additionally, these are often high cost designs due to the additional required elements being made of expensive materials. Many high end, high magnification objectives are apochromatic.

Nominal vs. As-Built

"How will this lens perform?" It may sound like a simple question, but the answer can be complicated. For a machine vision lens, certain factors first need to be considered, such as the lighting used, the working distance to the object, the $f/\#$ of the lens, and the sensor size. Then the question needs to be clarified: how will the lens perform as-built as compared to nominal.

What do nominal and as-built mean? The nominal specifications assume that the lens is built exactly as it is designed. By modeling the lens in a ray tracing software, such as Zemax, Code V, or one of the numerous other options, one can predict the lens performance in any scenario and easily extract data. This is not always the best answer, though, as it assumes all factors are exactly as specified in the model, which is not likely the case.

As-built, on the other hand, is a statistical prediction of how a lens will perform using realistic manufacturing tolerances. As-built performance is difficult to predict; many factors must be modeled that may alter the performance of the lens, such as the absolute position and shape of the

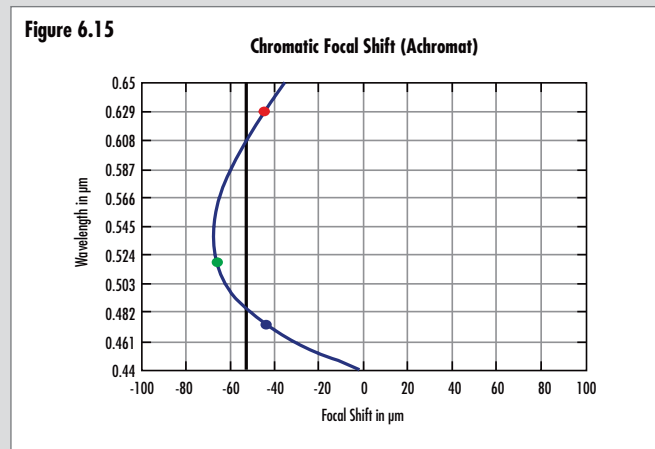


Figure 6.15: Chromatic focal shift curve for an achromatic lens.

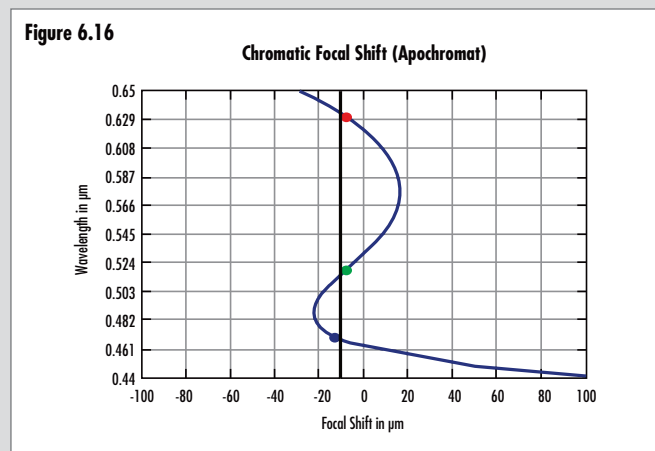


Figure 6.16: Chromatic focal shift curve for an apochromatic lens.

elements and the index and dispersion of the glass used. A typical tolerance file, the code used to tell the model all of the possible factors, has on the order of 100 - 200 components for a Zemax simulation and 200 - 400 components for a Code V simulation; this can vary significantly depending on the number of elements and the ways the elements are mounted.

A simplified description for modeling as-built performance is that every parameter is randomly varied, based on the tolerance ranges, and then statistically evaluated to determine how many random assemblies perform adequately. A few particular parameters are evaluated, such as MTF at specific frequencies and field points; from this, a probability of the lens reaching the performance requirements can be determined.

By looking at the prescription information of a lens, its nominal performance can be easily predicted for any configuration and with any criteria, such as MTF, distortion, or spot size. While this does not provide as accurate of a prediction as toleranced, as-built performance, it can provide a close approximation for the specific circumstance and a useful comparative tool.

Section 7: Understanding Hardware

Section 7.1: Lens Spacers, Shims and Focal Length Extenders

Applications can require a lens to stretch beyond its limits or be precisely dialed into its ideal design parameters. Lens spacers, shims and focal length extenders are simple tools a user can easily utilize to achieve these requirements. Spacers and focal length extenders modify the field of views or working distances in fixed focal length lenses, whereas shims can be used to precisely control the working distance of telecentric lenses.

Lens Spacers

Most fixed focal length lenses have integrated mechanics to allow focusing at different working distances. The fixed focal length nature of the design means that the elements move throughout a defined range, which dictates the working distances where it is possible to focus. This predefined range is chosen based on the design of the lens, as lenses will perform the best in the range they were designed for. However, it is often advantageous to stretch a lens beyond its limits in order to fit a particular application when smaller fields of view or shorter working distances are required. By augmenting the system with a spacer in between the camera and lens, the range of working distances over which the lens optimally performs changes. This augmentation comes with a variety of deviations from the way that the lens normally works that need to be considered carefully before implementation into any system.

Generally, the main purpose of adding a spacer is to increase the vision system's magnification or shorten the working distance; these two changes occur in tandem and are explained by the Gaussian imaging equations. *Equation 7.1* shows the relationship between image distance (*I*), object distance (*O*) and the focal length of the lens (*f*). Note that the object distance is a negative number. By increasing the image distance, the object distance (working distance of the lens) must decrease. When the working distance and image distance change, so must the magnification (PMAG), based on *Equation 7.2* (more information on magnification can be found in *Section 2.2*). *Figure 7.1* shows this effect visually. Imaging lenses are more complex systems and the calculations for spacer usage are more complicated. More details on how to do this can be found on our website.

$$\frac{1}{I} = \frac{1}{O} + \frac{1}{f} \quad 7.1$$

$$\text{PMAG} = \frac{I}{O} \quad 7.2$$

The decrease in working distance and the increase in magnification (reduction of the field of view) are the two most distinct advantages of utilizing a spacer in an optical system. Choosing the correct spacer will vary by application, but consider an example with a 35mm focal length lens compared to the same 35mm lens with an 11mm spacer. The results of the spacer can be found in *Table 7.1*.

In our example the spacer's most significant impacts on the system are that the working distance is reduced by more than half, and the magnification increases by more than a factor of two. In a space constrained system, using this type of spacer can be advantageous as well, as the total track length (length from the image plane to the object plane) is reduced.

It is also important to take into account the performance impact that spacers can have on the optical system. The working distance range over which the lens physically operates before adding spacers is generally where the best performance will be based on the optical design, and performance will typically suffer as these distances are altered with spacers. Using the same lens from the example above, *Figures 7.2* and *7.3* show the MTF curves for the lens at the minimum working distance (*Figure 7.2*) and with the 11mm spacer (*Figure 7.3*) at *f*/4 on a $\frac{2}{3}$ " sensor. As a rule of thumb, a spacer should not be used if it is more than half of the focal length.

If used correctly, spacers can be an excellent way to augment a lens and adapt it to a specific application, as long as its limitations and reductions in performance are kept in mind. Restricting the wavelength range for the lighting to be monochromatic will help to mitigate these issues. As a best practice using a lens at within its design range is the best option for optimal performance. Longer focal length lenses tend to respond better to spacers, as they are often simpler designs when compared to shorter focal length lenses, and it is important to carefully analyze the system where spacers are considered before implementation.

Figure 7.1

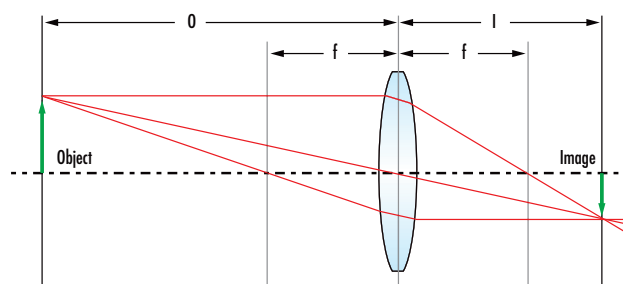


Figure 7.1: An Illustration of the relationship between image and object distance (*I* and *O* respectively) and lens focal length (*f*).

	No Spacer	11mm spacer
Focal Length	35mm	35mm
Lens Length	41mm	52mm
Image Distance	42.9mm	53.9mm
Object Distance	190.9mm	100mm
Working Distance	165mm	74.1mm
Total Track	223.5mm	143.6mm
Magnification	0.22X	0.54X
Field of View (1/2")	28.5mm	11.88mm

Table 7.1: Comparison of specifications of the same 35mm focal length lens (focused at minimum working distance) with and without a spacer. The most important system changes are in bold.

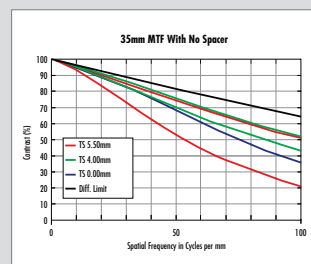


Figure 7.2: 35mm focal length lens at the minimum designed working distance.

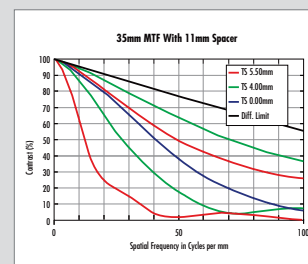


Figure 7.3: 35mm focal length lens with 11mm spacer.

Shims

Shims follow the same basic concepts as spacers, but are used for fixed magnification lenses such as telecentric lenses. Shims are very thin (0.025 - 1.0mm) stainless steel spacers used to control working distance with fine precision in order to guarantee the best image quality possible for a given setup.

Flange distance is defined as the ideal distance from the shoulder of the camera to the sensor plane and can vary slightly from the nominal design distance due to tolerancing. This departure from nominal is due to variations in housing design and sensor placement inside of a camera. An exact or custom distance may be required to control one of the following: working distance, image quality, or system to system repeatability. Shims act as thin spacers that can be placed between the lens and camera to customize this distance.

As image distance varies, image quality can also vary. If the image distance is shifted too far from the ideal design, a noticeable blur or degradation in MTF can occur. For example, this may occur when switching a lens between different cameras - even if the same model of camera and lens are being used, there may still be small variations from one camera to the next that may cause working distance or image quality changes as each new system is assembled. In this case, minor adjustments can be made using shims to bring the MTF and focus back to optimum levels. During the setup of each new system or line, slight adjustments to the image distance may be required, which is why many telecentric lenses come with shims included. With critical optical parameters dialed in for each system, software thresholds and calibration procedures will be repeatable from one system to the next.

Telecentric lenses are often chosen for applications requiring demanding manufacturing measurements, or the ability to get a certain view of an object under test. Often times these applications include other challenges such as limited working distance range due to swinging robotic arms, contaminations nearby, or limited space due to an existing mechanical layout of a machine into which the new measurement system must be fit. Similar to using lens spacers, adding or removing shims at the rear of a telecentric lens takes advantage of the relationship between image distance, object distance, and focal length (*Figure 7.1*) and adjusts the working distance slightly into a usable range. In monochromatic applications, shims can also be used to compensate or refocus for chromatic focal shift (see *Section 6*). Shims give users precision control of image distance to achieve the best possible solution for their application.

Focal Length Extenders/Multipliers

Another way to increase the magnification of a machine vision system is by using a focal length extender. A focal length extender is similar to a lens spacer in that they are both placed in between the back of the lens and the camera. A focal length extender, however, will not change the working distance range where the lens will work; focal length extenders contain a negative set of elements that change the focal length of the machine vision lens by a multiplicative factor. For example, a 25mm focal length lens with a focal length extender of 2X will have an effective focal length of 50mm, and will therefore have half of the field of view it originally had at the same working distance ranges.

Another useful advantage of focal length extenders is that they can be stacked upon one another, and have a multiplicative effect on the focal length of a lens. For example, a 25mm focal length lens used with two focal length extenders of 1.5X and 2X will have a new focal length of 75mm, as 75 is the product of 25, 1.5, and 2.

Much in the same way that the use of spacers does not come without a compromise, potential degradation of image quality should be considered when using focal length extenders. Because the individual lens elements in an objective have all been specifically designed and engineered to balance each other out in terms of optical performance, adding an additional negative element into the optical train will reduce that performance by introducing additional optical aberrations that the lens was not designed to balance out. Focal length extenders also reduce the amount of light throughput in a lens by changing the $f/\#$. For instance, a focal length extender of 2X will decrease light throughput by a factor of four. The potential negative effects on image quality should be considered before implementing a focal length extender.

Section 7.2: Ruggedization of Imaging Lenses

Imaging lenses used in many industrial machine vision applications have special requirements beyond those of standard imaging lenses. The lenses used in factory automation, robotics, and industrial inspection have to be able to work in specific and demanding environments, which could involve vibrations, shocks, temperature changes, and contaminants. Because of these environmental requirements, new classes of ruggedized lenses are being designed specifically to work in a multitude of different scenarios and therefore create different types of ruggedization. There are three distinct types of ruggedization available:

1. Industrial Ruggedization
2. Ingress Protection Ruggedization
3. Stability Ruggedization

Industrial Ruggedization

Industrial Ruggedized lenses are designed to survive vibration and shock without damage to the lens or change in focus and $f/\#$. To achieve this, flexibility is sacrificed by eliminating moving parts and making them easier to lock down.

A standard fixed focal length lens utilizes a complicated iris and focus mechanism. A typical iris is comprised of thin leaves and ball detents for adjusting $f/\#$, which can spring out of place during shock and vibration. For Industrial Ruggedization, the iris is removed and replaced with a fixed aperture stop. Additionally, the typical focusing mechanism of a threaded barrel within another threaded barrel is replaced by a single thread and rigid locking mechanism.

Figure 7.4

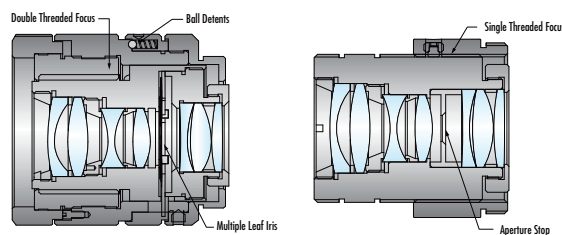


Figure 7.4: Standard Lens with complex mechanics and an adjustable iris vs. Industrial Ruggedized Lens with simplified mechanics.

Industrial Ruggedization is ideal for applications where the system will be set up once and not changed afterwards. An added cost advantage is also present in this type of lens due to the removal of the complex movements and adjustments, which results in a significant part reduction and cost savings. There are many applications for Industrial Ruggedization, such as high vibration factory environments, situations where the camera is rapidly accelerated and decelerated, inspection systems where many similar camera setups are repeated, and robotic vision.

Ingress Protection Ruggedization

Ingress Protection Ruggedization ensures that a lens assembly is sealed to prevent moisture and foreign debris from entering the lens through the use of O-rings and RTV silicone. This protection is typically added to an Industrial Ruggedized lens, since an adjustable focus and iris would be problematic for sealing. These lenses are used in environments of high humidity/moisture, sputter, dust, or small particles, and also where space is not available to fully enclose the lens and camera.

Figure 7.5

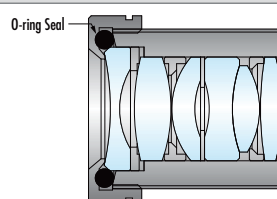


Figure 7.5: Ingress Protection Ruggedized Lens with an O-ring to seal out contaminants.

Stability Ruggedization

Similar to Industrial Ruggedized lenses, Stability Ruggedization protects the lens from damage, but also ensures optical pointing and positioning is maintained after shock and vibration. In addition to replacing the iris and a simplified focus mechanism, individual lens elements are glued in place to prevent them from moving within the housing. *Figure 7.6* shows a Stability Ruggedized lens in which the lens elements are glued in place and a clamping lock is used to simplify the focus.

Figure 7.6

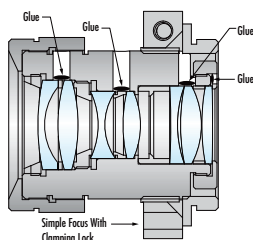


Figure 7.6: Stability Ruggedized Lens with all lens elements glued in place.

In an imaging assembly, lens elements sit within the inner bore of the barrel. The space between the outer diameter of the lens and inner diameter of the barrel is small (typically less than 50 microns). Despite the minimal amount of space, decenters of tens of microns are enough to significantly affect the pointing of the lens. When using a Stability Ruggedized lens, if an object point is in the center of the field of view and falls on the exact center pixel, it will always fall there even if the lens has been heavily vibrated (*Figure 7.7*). Stability Ruggedization is important in applications where the field of view has to be calibrated, such as measurement equipment, 3D stereo vision, lenses used for sensing for robotics, and lenses used for tracking object locations. These applications often require the optical pointing to be stabilized to values much smaller than a single pixel.

Figure 7.7a

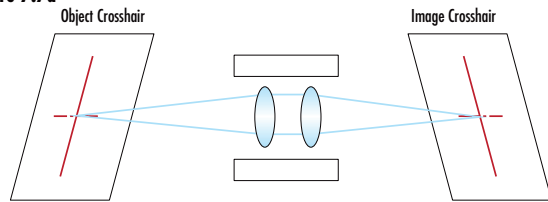


Figure 7.7a: Unperturbed system where object crosshair is mapped to the image crosshair.

Figure 7.7b

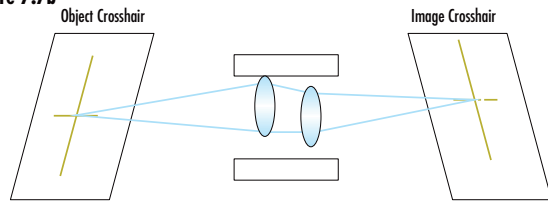


Figure 7.7b: Perturbed system where lenses are decentered within the barrel and the optical pointing stability changes. Object crosshair is mapped to a different place on the image.

Figure 7.7c

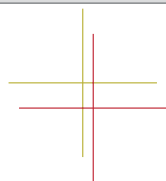


Figure 7.7c: Image crosshairs overlaid, red crosshair is image from Figure 7.7a and the decentered yellow crosshair is from Figure 7.7b. Example is highly exaggerated actual changes tend to be on the order of a pixel or less.

Section 7.3: Resolution and Contrast Comparison

High levels of optical performance are critical for successful imaging solutions. Edmund Optics® has taken care to maintain optical performance across the entire image plane. Resolution and contrast typically deteriorate at the corners of an image, thus both the center and corners of an image must be considered when comparing overall lens performance.

Shown below are comparisons of our TECHSPEC® C Series Fixed Focal Length Lens at the center and at the corner of the images to the performance of various competitor lenses. Edmund Optics® lenses show a 30% increase in contrast over the closest competitor at the center of the image. Additionally, Edmund Optics® lenses show over twice the contrast in the corner making our Compact Fixed Focal Length Lens ideal from the most simple to the most complex applications. All tests are done with a 16mm lens at $f/2$ on a 1.3MP, $\frac{1}{2}$ " sensor camera and 1.5" field of view.

Figure 7.8

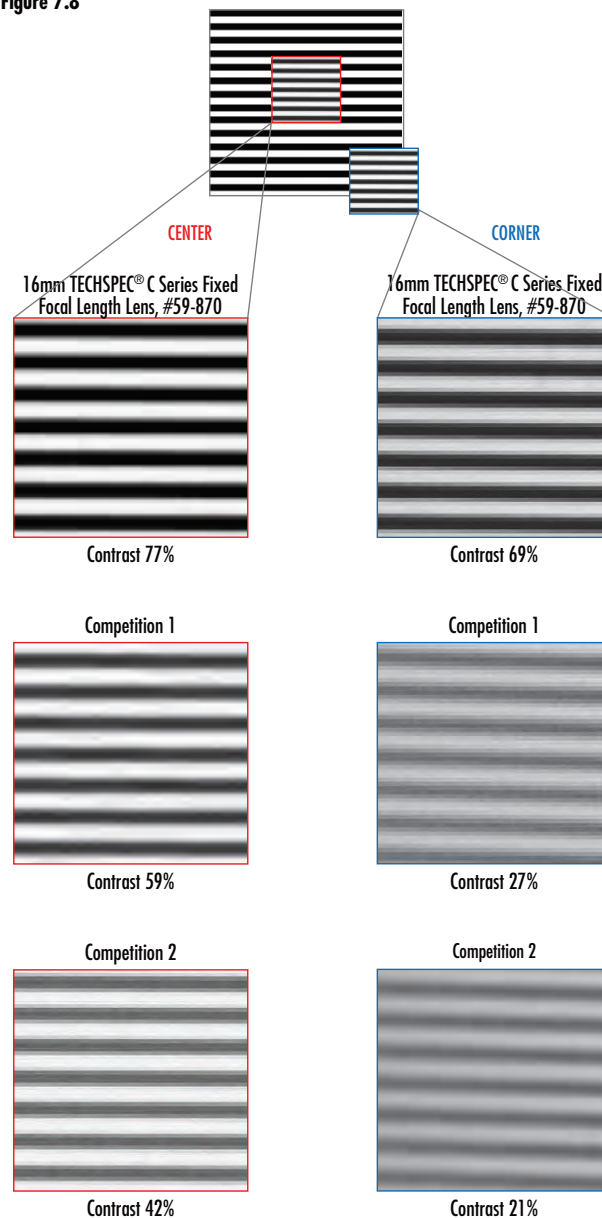


Figure 7.8: Ronchi Ruling Comparison. Ronchi Rulings are targets with high frequency black and white lines, and are used to test a lens's ability to reproduce contrast. High contrast and edge sharpness are critical for measurement and detection algorithms, especially in high resolution applications.

UC Series Fixed Focal Length Lenses



- Ultra-Compact (UC) Form Factor
- 4K Resolution Designed for Small Pixels ($< 2.2\mu\text{m}$)
- Optimized for $\frac{1}{2}$." Sensors and Supports up to $\frac{1}{4}$." 1.8"
- Ideal for Factory Automation

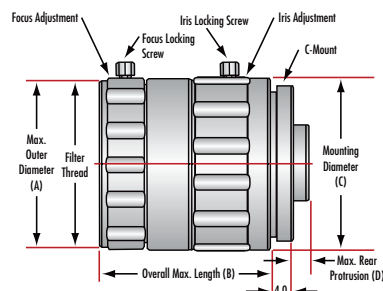


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DIMENSIONS

Focal Length (mm)	A (mm)	B (mm)	C (mm)	D (mm)	Filter Thread
4	40	40.6	30	2.8	M62.0 x 0.75 (with adapter)
6	36	40.9	30	3.2	M34.0 x 0.5
8	30	34.52	30	3.2	M39.0 x 0.5 (with adapter)
12	30	32.48	30	2.7	M25.5 x 0.5
16	30	29.13	30	3.38	M25.5 x 0.5
25	30	31.28	30	0	M25.5 x 0.5

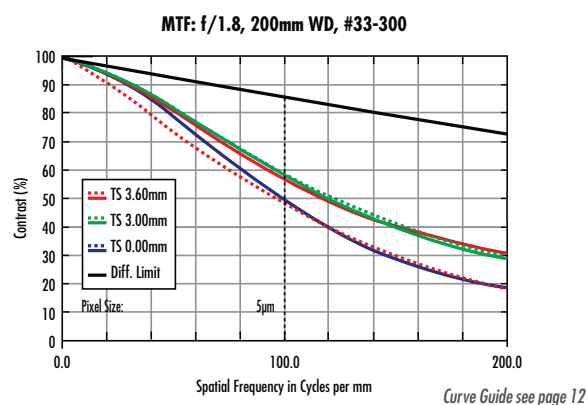
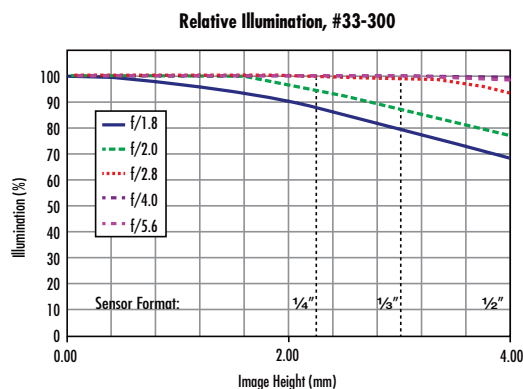


COMPATIBLE FILTERS

See pages 111-113 for pricing and additional information.

Focal Length (mm)	Color Filter - Light Red	Color Filter - Red	Color Filter - Green	Color Filter - Blue	UV Protective Filter	Linear Polarizing Filter	IR Cut-Off Filter (KG-3)	UV/IR-Cut Filter	UV/VIS Cut-Off Filter
4	#89-822	#89-832	#89-792	#89-772	#54-047	#36-444	#49-806	#49-814	#64-888
6	#89-816	#89-826	#89-786	#89-766	#64-892	#64-897	—	—	—
8	—	—	—	—	#46-579	—	#49-803	#49-811	—
12	#89-418	#89-824	#89-784	#89-764	#46-577	#46-575	#48-000	#49-808	#65-796
16	#89-418	#89-824	#89-784	#89-764	#46-577	#46-575	#48-000	#49-808	#65-796
25	#89-418	#89-824	#89-784	#89-764	#46-577	#46-575	#48-000	#49-808	#65-796

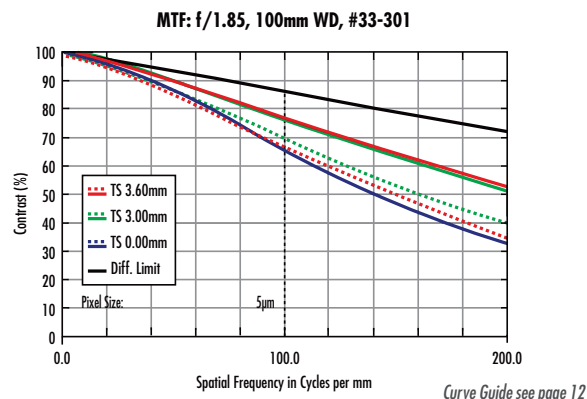
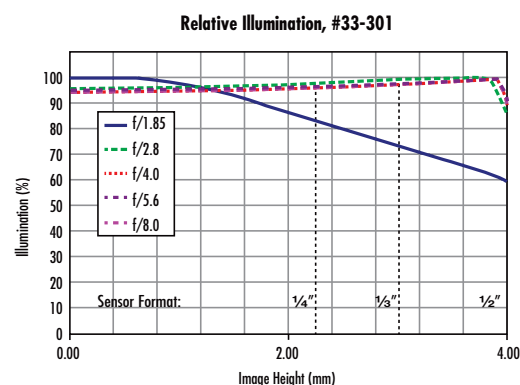
UC Series Fixed Focal Length Lenses



1/2.5" Format
4mm

Focal Length:	4mm
Maximum Camera Sensor Format:	1/2"
Optimized Sensor Format:	1/2.5"
Field of View, 1/2.5" Sensor:	19.4mm - 71.2°
Field of View, 1/2" Sensor:	22.9mm - 79.5°
Field of View, 1/4" Sensor:	—
Working Distance:	0mm - ∞
Aperture (f/#):	f/1.8 - f/11
Numerical Aperture NA, Object Side:	0.089
Number of Elements (Groups):	8 (7)
Coating:	η/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	73g
Stock No. / Price	#33-300 \$195.00
Filter Adapter / Price	#33-308 \$30.00

Call For OEM Quantity Pricing



1/2.5" Format
6mm

Focal Length:	6mm
Maximum Camera Sensor Format:	1/2"
Optimized Sensor Format:	1/2.5"
Field of View, 1/2.5" Sensor:	62.54mm - 52.78°
Field of View, 1/2" Sensor:	71.38mm - 58.97°
Field of View, 1/4" Sensor:	—
Working Distance:	50mm - ∞
Aperture (f/#):	f/1.85 - f/11
Numerical Aperture NA, Object Side:	0.00775
Number of Elements (Groups):	9 (8)
Coating:	η/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	68g
Stock No. / Price	#33-301 \$180.00
Filter Adapter / Price	N/A —

Call For OEM Quantity Pricing

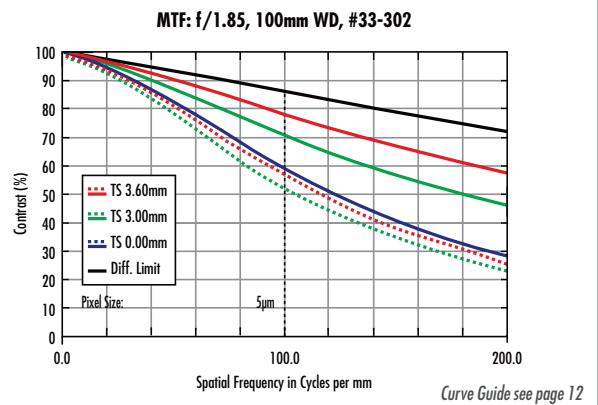
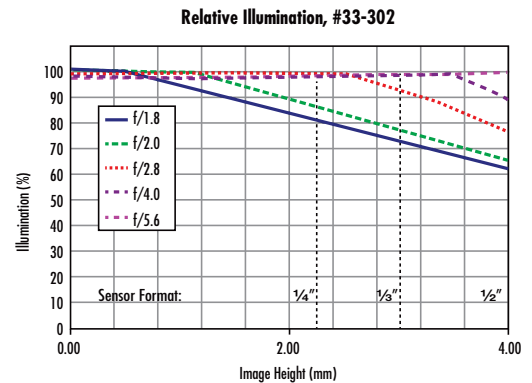
UC Series Fixed Focal Length Lenses

8mm
1/2.5" Format



Focal Length:	8mm	
Maximum Camera Sensor Format:	1/2"	
Optimized Sensor Format:	1/2.5"	
Field of View, 1/2.5" Sensor:	35.65mm - 39.24°	
Field of View, 1/2" Sensor:	40mm - 43.6°	
Field of View, 1/1.8" Sensor:	—	
Working Distance:	50mm - ∞	
Aperture (f/#):	f/1.8 - f/11	
Numerical Aperture NA, Object Side:	0.03	
Number of Elements (Groups):	8 (7)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	58g	
Stock No. / Price	#33-302	\$150.00
Filter Adapter / Price	#33-309	\$30.00

Call For OEM Quantity Pricing



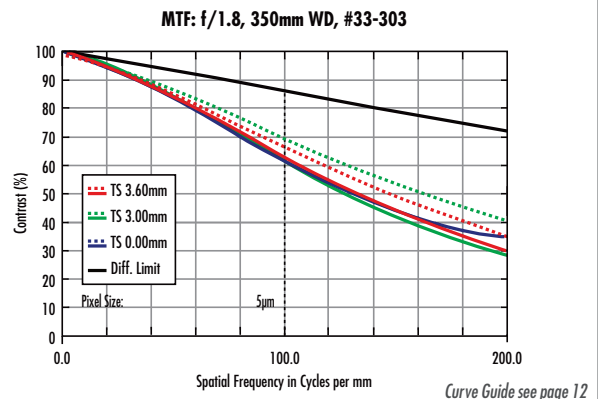
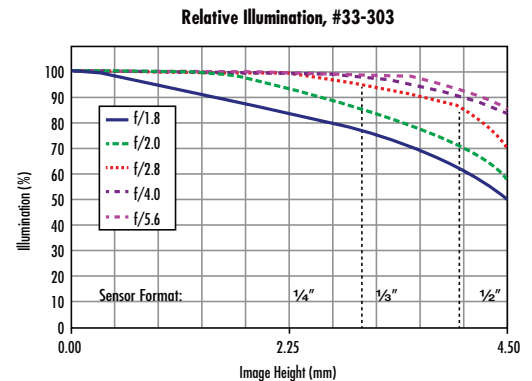
Curve Guide see page 12

12mm
1/2.5" Format



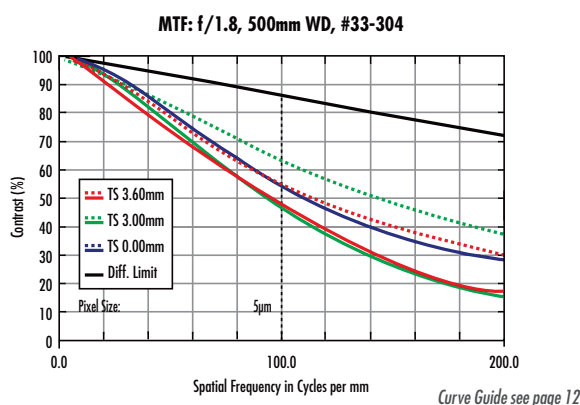
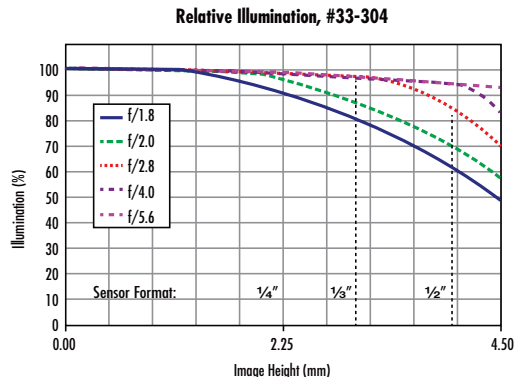
Focal Length:	12mm	
Maximum Camera Sensor Format:	1/1.8"	
Optimized Sensor Format:	1/2.5"	
Field of View, 1/2.5" Sensor:	53.2mm - 26°	
Field of View, 1/2" Sensor:	60.2mm - 29.2°	
Field of View, 1/1.8" Sensor:	68mm - 32.8°	
Working Distance:	100mm - ∞	
Aperture (f/#):	f/1.8 - f/11	
Numerical Aperture NA, Object Side:	0.029	
Number of Elements (Groups):	7 (6)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	51g	
Stock No. / Price	#33-303	\$165.00
Filter Adapter / Price	N/A	—

Call For OEM Quantity Pricing



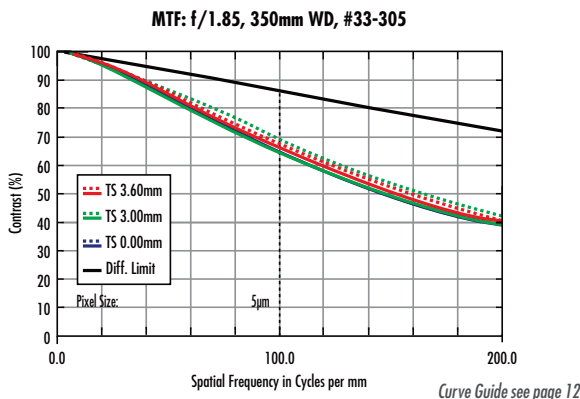
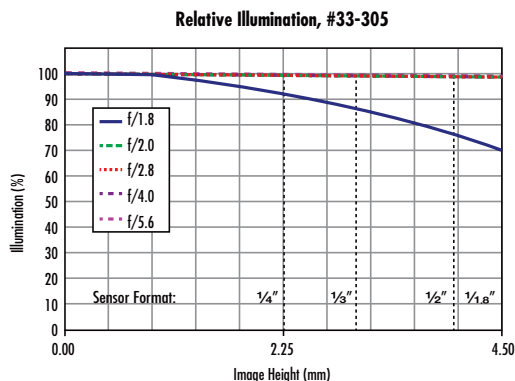
Curve Guide see page 12

UC Series Fixed Focal Length Lenses



16mm
1/2.5" Format

Focal Length:	16mm	
Maximum Camera Sensor Format:	1/1.8"	
Optimized Sensor Format:	1/2.5"	
Field of View, 1/2.5" Sensor:	71.3mm - 20.21°	
Field of View, 1/2" Sensor:	80mm - 22.62°	
Field of View, 1/1.8" Sensor:	90mm - 25.36°	
Working Distance:	200mm - ∞	
Aperture (f/#):	f/1.8 - f/11	
Numerical Aperture NA, Object Side:	0.021	
Number of Elements (Groups):	7 (5)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	42g	
Stock No. / Price	#33-304	\$165.00
Filter Adapter / Price	N/A	—
Call For OEM Quantity Pricing		



25mm
1/2.5" Format

Focal Length:	25mm	
Maximum Camera Sensor Format:	1/1.8"	
Optimized Sensor Format:	1/2.5"	
Field of View, 1/2.5" Sensor:	46.74mm - 12.54°	
Field of View, 1/2" Sensor:	52.5mm - 14.08°	
Field of View, 1/1.8" Sensor:	59.14mm - 15.87°	
Working Distance:	200mm - ∞	
Aperture (f/#):	f/1.85 - f/16	
Numerical Aperture NA, Object Side:	0.0314	
Number of Elements (Groups):	7 (5)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	47g	
Stock No. / Price	#33-305	\$180.00
Filter Adapter / Price	N/A	—
Call For OEM Quantity Pricing		

C Series Fixed Focal Length Lenses

- Compact (C) Form Factor
- Industry Leading Price to Performance Ratio
- Designed for True Factory Automation
- Supports up to ⅔" Sensors
- Low Lens-to-Lens Variation
- Feature Locking Iris and Focus Adjustment

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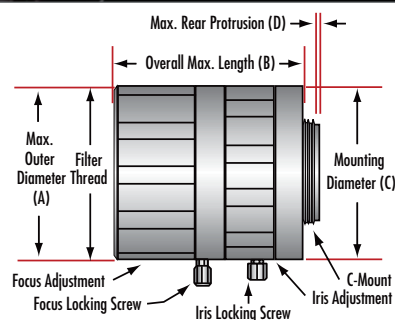


For Fixed Focal Length Extenders, see page 69



DIMENSIONS

Focal Length (mm)	A (mm)	B (mm)	C (mm)	D (mm)	Filter Thread
3.5	50.0	39.3	32.0	2.72	M105 x 1.0 (with adapter)
4.5	40.0	37.5	32.0	2.78	M58 x 0.75 (with adapter)
6	36.0	48.9	35.8	1.4	M43 x 0.75 (with adapter)
8.5	32.0	34.5	32.0	0.0	M25.5 x 0.5
12	32.0	27.9	32.0	0.5	M25.5 x 0.5
16	33.0	40.5	33.0	1.0	M25.5 x 0.5
25	31.0	30.5	31.0	1.3	M25.5 x 0.5
35	33.0	41.0	33.0	0.0	M25.5 x 0.5
50	35.8	53.7	35.8	2.85	M30.5 x 0.5
100	50.0	93.5	41.0	7.0	M46 x 0.75

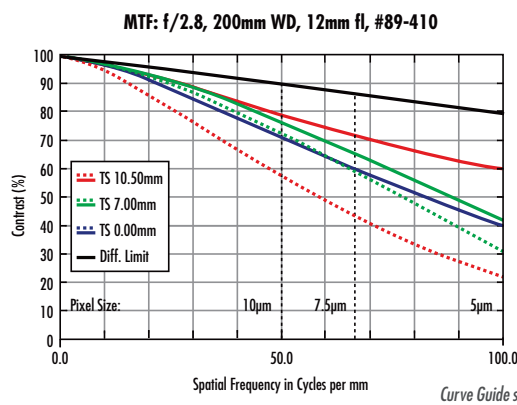
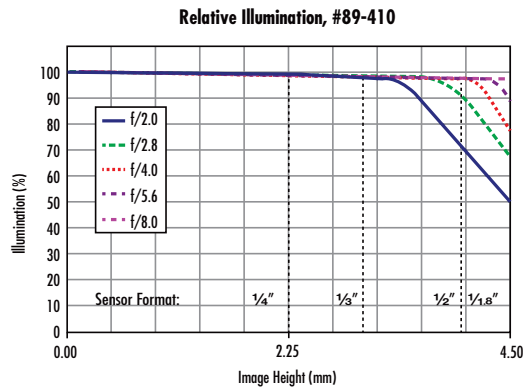


COMPATIBLE FILTERS

See pages 123-125 for pricing and additional information

Focal Length (mm)	Color Filter - Light Red	Color Filter - Red	Color Filter - Green	Color Filter - Blue	UV Protective Filter	Linear Polarizing Filter	IR Cut-Off Filter (KG-3)	UV/IR-Cut Filter	UV/VIS Cut-Off Filter
3.5	—	—	—	—	#58-648	#64-903	—	—	—
4.5	—	#54-765	#54-771	#54-777	#54-046	#36-443	#54-747	#54-751	#54-754
6	#89-819	#89-829	#89-789	#89-769	#54-040	#52-558	#49-805	#89-799	#89-839
8.5	#89-814	#89-824	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834
12	#89-814	#89-824	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834
16	#89-814	#89-824	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834
25	#89-814	#89-824	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834
35	#89-814	#89-824	#89-784	#89-764	#46-577	#46-575	#49-801	#89-794	#89-834
50	#89-815	#89-825	#89-785	#89-765	#46-576	#46-574	#89-835	#89-795	#89-835
100	#89-820	#89-830	#89-790	#89-770	#54-041	#36-439	#54-744	#89-800	#89-840

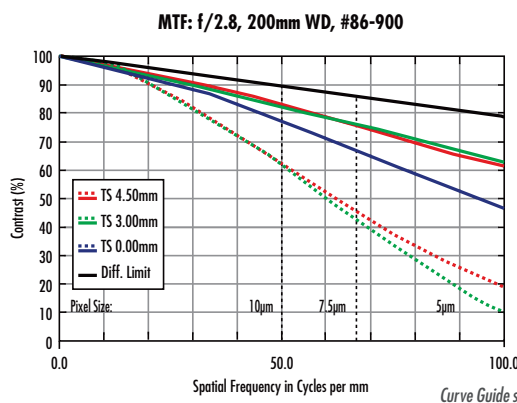
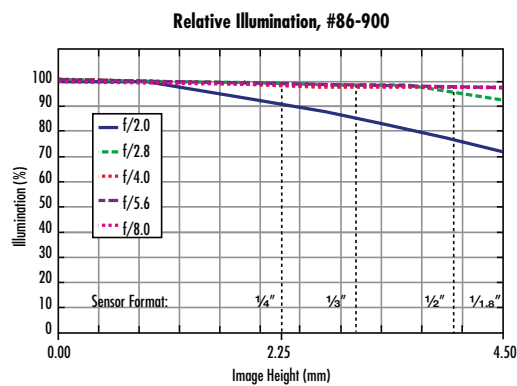
C Series Fixed Focal Length Lenses



3.5mm
1/1.8" Format

Focal Length:	3.5mm	
Maximum Camera Sensor Format:	1/1.8"	
Field of View, 1/1.8" Sensor:	41.2mm - 102.8°	
Field of View, 1/2" Sensor:	34.1mm - 94.1°	
Field of View, 1/3" Sensor:	23.0mm - 74.4°	
Working Distance:	0mm - ∞	
Aperture (f/#):	f/2.0 - f/11	
Numerical Aperture NA, Object Side:	0.003	
Number of Elements (Groups):	8 (7)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	110g	
VIS Stock No. / Price	#89-410	\$495.00
Filter Adapter / Price	#89-848	\$45.00

Call For OEM Quantity Pricing



4.5mm
1/1.8" Format

Focal Length:	4.5mm	
Maximum Camera Sensor Format:	1/1.8"	
Field of View, 1/1.8" Sensor:	72.0mm - 84.7°	
Field of View, 1/2" Sensor:	61.9mm - 76.7°	
Field of View, 1/3" Sensor:	44.0mm - 59.2°	
Working Distance:	25mm - ∞	
Aperture (f/#):	f/2.0 - f/11	
Numerical Aperture NA, Object Side:	0.005	
Number of Elements (Groups):	7 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	70g	
VIS Stock No. / Price	#86-900	\$495.00
Filter Adapter / Price	#87-425	\$29.50

Call For OEM Quantity Pricing

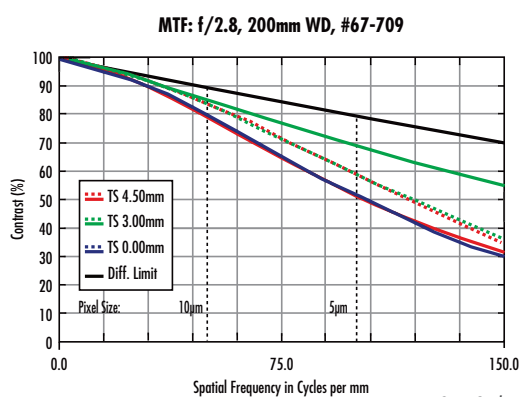
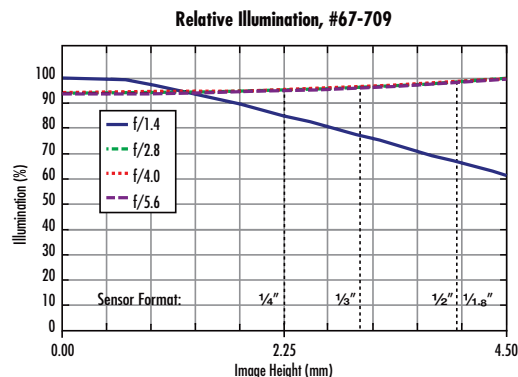
C Series Fixed Focal Length Lenses

6mm
1/1.8" Format



Focal Length:	6mm	
Maximum Camera Sensor Format:	1/1.8"	
Field of View, 1/1.8" Sensor:	110.3mm - 62.1°	
Field of View, 1/2" Sensor:	96.7mm - 55.9°	
Field of View, 1/3" Sensor:	71.0mm - 42.7°	
Working Distance:	75mm - ∞	
Aperture (f/#):	f/1.4 - f/16	
Numerical Aperture NA, Object Side:	0.005	
Number of Elements (Groups):	9 (7)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	110g	
VIS Stock No. / Price	#67-709	\$395.00
Filter Adapter / Price	#85-308	\$30.00

Call For OEM Quantity Pricing



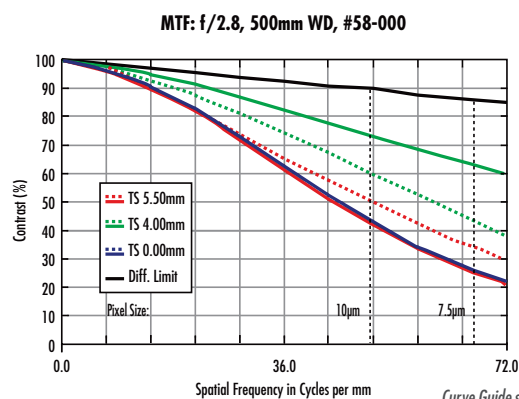
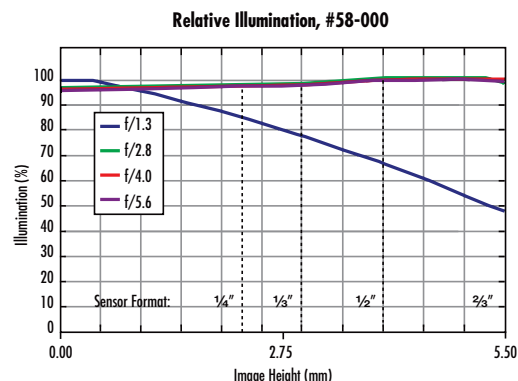
Curve Guide see page 12

8.5mm
2/3" Format



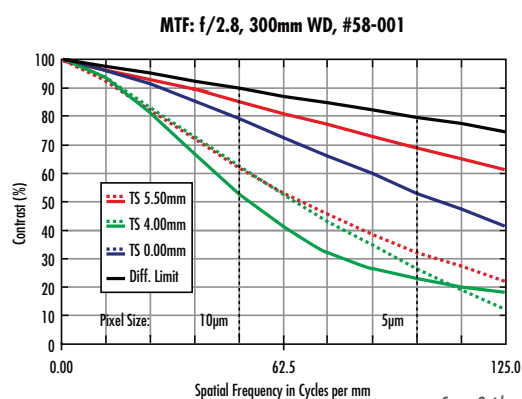
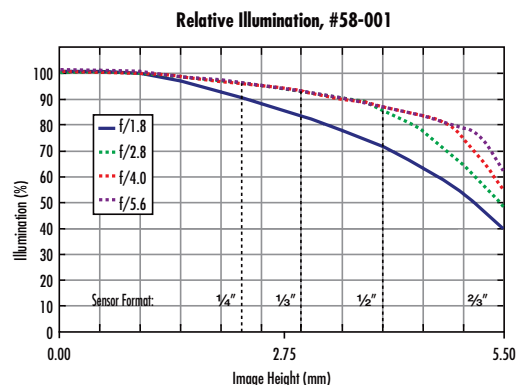
Focal Length:	8.5mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	124.1mm - 59.1°	
Field of View, 1/2" Sensor:	85.3mm - 42.6°	
Field of View, 1/3" Sensor:	62.33mm - 31.8°	
Working Distance:	100mm - ∞	
Aperture (f/#):	f/1.3 - f/16	
Numerical Aperture NA, Object Side:	0.003	
Number of Elements (Groups):	7 (5)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	54g	
VIS Stock No. / Price	#58-000	\$295.00

Call For OEM Quantity Pricing



Curve Guide see page 12

C Series Fixed Focal Length Lenses



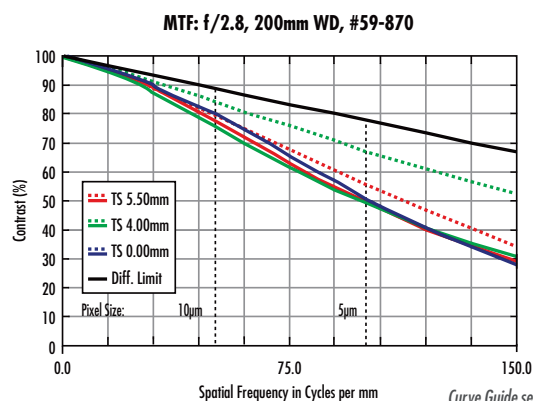
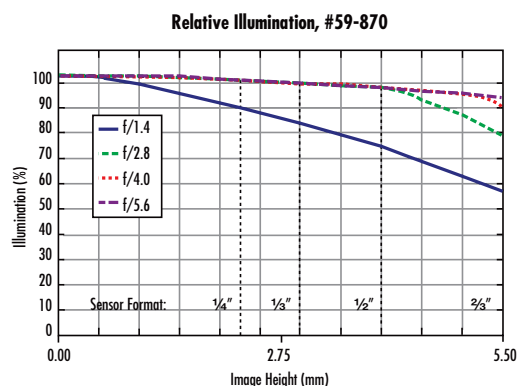
Curve Guide see page 12



2/3\" Format
12mm

Focal Length:	12mm
Maximum Camera Sensor Format:	2/3\"
Field of View, 2/3\" Sensor:	82.5mm - 39.3°
Field of View, 1/2\" Sensor:	59.5mm - 28.9°
Field of View, 1/3\" Sensor:	44.4mm - 21.8°
Working Distance:	100mm - ∞
Aperture (f/#):	f/1.8 - f/16
Numerical Aperture NA, Object Side:	0.007
Number of Elements (Groups):	7 (7)
Coating:	425 - 675nm BBAR
Lens Mount:	C-Mount
Weight:	54g
VIS Stock No. / Price	#58-001 \$295.00

Call For OEM Quantity Pricing



Curve Guide see page 12



2/3\" Format
16mm

Focal Length:	16mm
Maximum Camera Sensor Format:	2/3\"
Field of View, 2/3\" Sensor:	61.4mm - 30.9°
Field of View, 1/2\" Sensor:	44.5mm - 22.7°
Field of View, 1/3\" Sensor:	33.3mm - 17.1°
Working Distance:	100mm - ∞
Aperture (f/#):	f/1.4 - f/16
Numerical Aperture NA, Object Side:	0.013
Number of Elements (Groups):	7 (6)
Coating:	425 - 675nm BBAR
Lens Mount:	C-Mount
Weight:	74g
VIS Stock No. / Price	#59-870 \$295.00
VIS-NIR Stock No. / Price	#67-714 \$495.00

Call For OEM Quantity Pricing

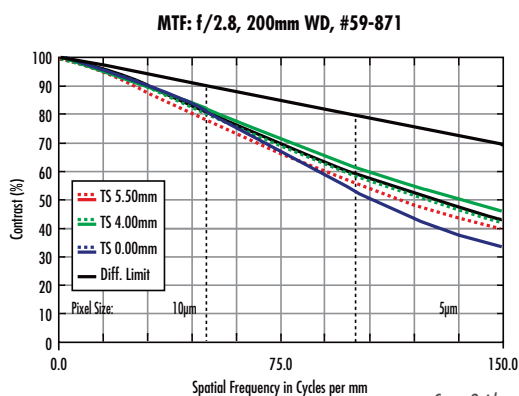
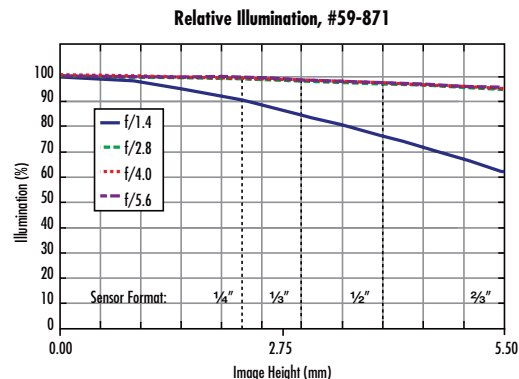
C Series Fixed Focal Length Lenses

25mm
2/3" Format



Focal Length:	25mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	35mm - 19.8°	
Field of View, 1/2" Sensor:	25.4mm - 14.5°	
Field of View, 1/3" Sensor:	19mm - 10.9°	
Working Distance:	100mm - ∞	
Aperture (f/#):	f/1.4 - f/17	
Numerical Aperture NA, Object Side:	0.023	
Number of Elements (Groups):	7 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	48g	
VIS Stock No. / Price	#59-871	\$295.00
VIS-NIR Stock No. / Price	#67-715	\$495.00

Call For OEM Quantity Pricing



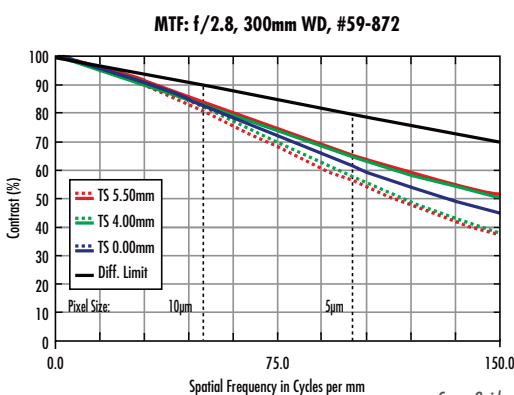
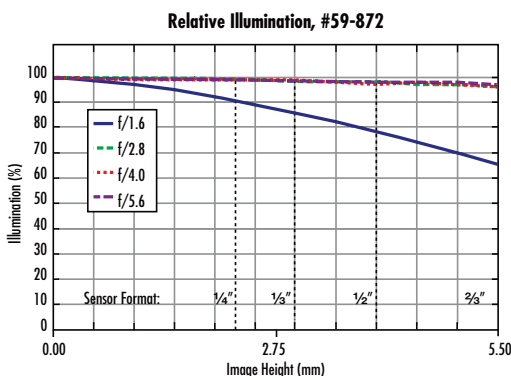
Curve Guide see page 12

35mm
2/3" Format



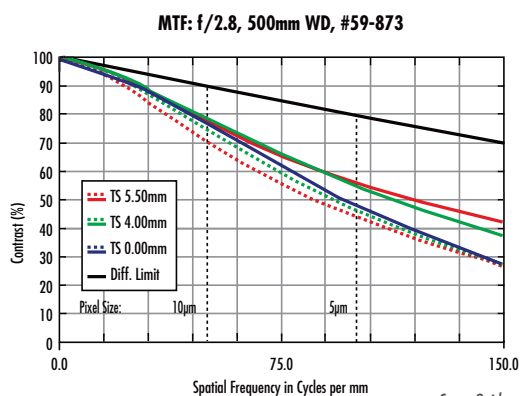
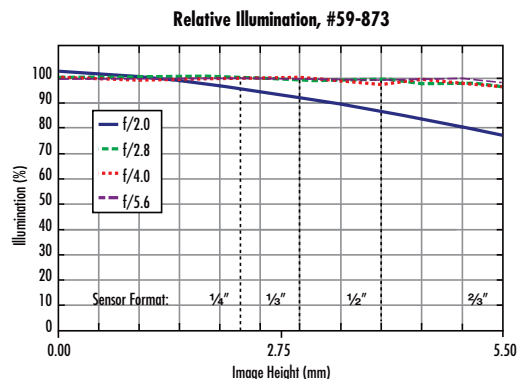
Focal Length:	35mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	39.3mm - 14.3°	
Field of View, 1/2" Sensor:	28.5mm - 10.4°	
Field of View, 1/3" Sensor:	21.4mm - 7.8°	
Working Distance:	165mm - ∞	
Aperture (f/#):	f/1.65 - f/22	
Numerical Aperture NA, Object Side:	0.021	
Number of Elements (Groups):	7 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	75g	
VIS Stock No. / Price	#59-872	\$295.00
VIS-NIR Stock No. / Price	#67-716	\$495.00

Call For OEM Quantity Pricing



Curve Guide see page 12

C Series Fixed Focal Length Lenses



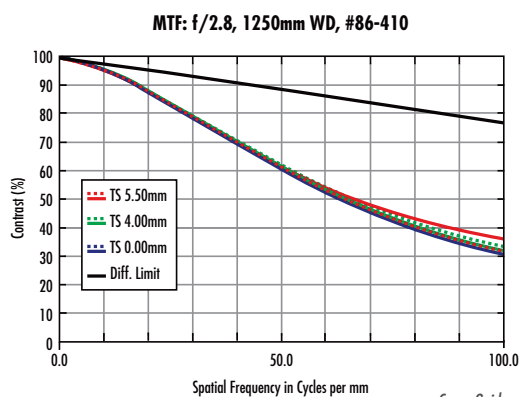
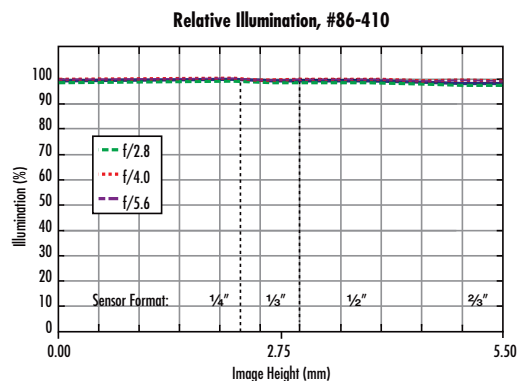
Curve Guide see page 12



2/3" Format
50mm

Focal Length:	50mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	42.5mm - 8.5°	
Field of View, 1/2" Sensor:	31.0mm - 6.2°	
Field of View, 1/3" Sensor:	23.0mm - 4.6°	
Working Distance:	250mm - ∞	
Aperture (f/#):	f/2 - f/22	
Numerical Aperture NA, Object Side:	0.018	
Number of Elements (Groups):	6 (4)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	106g	
VIS Stock No. / Price	#59-873	\$395.00
VIS-NIR Stock No. / Price	#67-717	\$550.00

Call For OEM Quantity Pricing



Curve Guide see page 12



2/3" Format
100mm

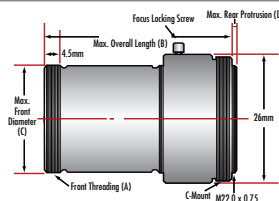
Focal Length:	100mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	52.9mm - 4.0°	
Field of View, 1/2" Sensor:	40.1mm - 2.9°	
Field of View, 1/3" Sensor:	30.1mm - 2.2°	
Working Distance:	750mm - ∞	
Aperture (f/#):	f/2.8 - f/22	
Numerical Aperture NA, Object Side:	0.014	
Number of Elements (Groups):	7 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	250g	
VIS Stock No. / Price	#86-410	\$495.00
VIS-NIR Stock No. / Price	N/A	-

Call For OEM Quantity Pricing

Ci Series Fixed Focal Length Lenses



- Compact Instrumentation (Ci) Versions of our C Series Lenses
- Industrial Ruggedized Lenses Featuring Simplified Mechanics
- Designed for Instrumentation Integration
- Wide Range of Fixed Apertures Replace the Standard Iris
- Features a Lockable, Single Thread Focus for Robust System Integration



DIMENSIONS

Focal Length (mm)	A	B (mm)	C (mm)	D (mm)
6	M34.0 x 0.5	47.8	34.0	1.17
12	M22.0 x 0.75	29.0	22.0	0.96
16	M22.0 x 0.75	40.8	22.0	1.09
25	M22.0 x 0.75	29.9	22.0	1.33
35	M25.5 x 0.5	41.0	22.5	3.82
50	M30.5 x 0.5	49.5	30.5	2.06

ACCESSORIES

Locking Retainer Nut (M22 x 0.75)	#89-944	\$25.00
C-Mount to NF-Mount Adapter	#89-945	\$25.00

Volume pricing and customization available. An EO-designed and manufactured family.



6mm
1/4.8" Format



12mm
2/3" Format



Focal Length:	6mm		
Maximum Camera Sensor Format:	1/4.8"		
Field of View, 1/4.8" Sensor:	110.3mm - 62.1°		
Field of View, 1/2" Sensor:	96.7mm - 55.9°		
Field of View, 1/3" Sensor:	71.0mm - 42.7°		
Working Distance:	75mm - ∞		
Number of Elements (Groups):	9 (7)		
Coating:	425 - 675nm BBAR		
Lens Mount:	C-Mount		
Weight:	64g		
	Stock No.	Price	
		1-10	11-24
f/1.4 / Price	#86-591	\$380.00	\$350.00
f/1.8 / Price	#86-592	\$380.00	\$350.00
f/2.8 / Price	#86-593	\$380.00	\$350.00
f/4 / Price	#86-594	\$380.00	\$350.00
f/5.6 / Price	#86-595	\$380.00	\$350.00
f/8 / Price	#86-596	\$380.00	\$350.00
M43 x 0.75 Filter Adapter / Price	#89-940	\$30.00	

Call For OEM Quantity Pricing

Focal Length:	12mm		
Maximum Camera Sensor Format:	2/3"		
Field of View, 2/3" Sensor:	82.5mm - 39.3°		
Field of View, 1/2" Sensor:	59.5mm - 28.9°		
Field of View, 1/3" Sensor:	44.4mm - 21.8°		
Working Distance:	100mm - ∞		
Number of Elements (Groups):	7 (7)		
Coating:	425 - 675nm BBAR		
Lens Mount:	C-Mount		
Weight:	54g		
	Stock No.	Price	
		1-10	11-24
f/1.8 / Price	#86-607	\$280.00	\$250.00
f/2.8 / Price	#86-608	\$280.00	\$250.00
f/4 / Price	#86-609	\$280.00	\$250.00
f/5.6 / Price	#86-610	\$280.00	\$250.00
f/8 / Price	#86-611	\$280.00	\$250.00
f/11 / Price	#86-612	\$280.00	\$250.00
f/16 / Price	#86-613	\$280.00	\$250.00
M25.5 x 0.5 Filter Adapter / Price	#89-941	\$25.00	

Call For OEM Quantity Pricing

Ci Series Fixed Focal Length Lenses



2/3" Format
16mm

Focal Length:	16mm		
Maximum Camera Sensor Format:	2/3"		
Field of View, 2/3" Sensor:	61.4mm - 30.9°		
Field of View, 1/2" Sensor:	44.5mm - 22.7°		
Field of View, 1/3" Sensor:	33.3mm - 17.1°		
Working Distance:	100mm - ∞		
Number of Elements (Groups):	7 (6)		
Coating:	425 - 675nm BBAR		
Lens Mount:	C-Mount		
Weight:	35g		
	Stock No.	Price	
		1-10	11-24
f/1.4 / Price	#85-348	\$280.00	\$250.00
f/1.8 / Price	#85-349	\$280.00	\$250.00
f/2.8 / Price	#85-350	\$280.00	\$250.00
f/4 / Price	#85-351	\$280.00	\$250.00
f/5.6 / Price	#85-352	\$280.00	\$250.00
f/8 / Price	#85-353	\$280.00	\$250.00
f/11 / Price	#85-354	\$280.00	\$250.00
f/16 / Price	#85-336	\$280.00	\$250.00
M25.5 x 0.5 Filter Adapter / Price	#89-941	\$25.00	
Call For OEM Quantity Pricing			



2/3" Format
25mm

Focal Length:	25mm		
Maximum Camera Sensor Format:	2/3"		
Field of View, 2/3" Sensor:	35mm - 19.8°		
Field of View, 1/2" Sensor:	25.4mm - 14.5°		
Field of View, 1/3" Sensor:	19mm - 10.9°		
Working Distance:	100mm - ∞		
Number of Elements (Groups):	7 (6)		
Coating:	425 - 675nm BBAR		
Lens Mount:	C-Mount		
Weight:	30g		
	Stock No.	Price	
		1-10	11-24
f/1.4 / Price	#85-355	\$280.00	\$250.00
f/1.8 / Price	#85-356	\$280.00	\$250.00
f/2.8 / Price	#85-357	\$280.00	\$250.00
f/4 / Price	#85-358	\$280.00	\$250.00
f/5.6 / Price	#85-359	\$280.00	\$250.00
f/8 / Price	#85-360	\$280.00	\$250.00
f/11 / Price	#85-361	\$280.00	\$250.00
f/16 / Price	#85-337	\$280.00	\$250.00
M25.5 x 0.5 Filter Adapter / Price	#89-941	\$25.00	
Call For OEM Quantity Pricing			



2/3" Format
35mm

Focal Length:	35mm		
Maximum Camera Sensor Format:	2/3"		
Field of View, 2/3" Sensor:	39.3mm - 14.3°		
Field of View, 1/2" Sensor:	28.5mm - 10.4°		
Field of View, 1/3" Sensor:	21.4mm - 7.8°		
Working Distance:	165mm - ∞		
Number of Elements (Groups):	7 (6)		
Coating:	425 - 675nm BBAR		
Lens Mount:	C-Mount		
Weight:	38g		
	Stock No.	Price	
		1-10	11-24
f/1.65 / Price	#85-362	\$280.00	\$250.00
f/2.8 / Price	#85-364	\$280.00	\$250.00
f/4 / Price	#85-365	\$280.00	\$250.00
f/5.6 / Price	#85-366	\$280.00	\$250.00
f/8 / Price	#85-367	\$280.00	\$250.00
f/11 / Price	#85-368	\$280.00	\$250.00
f/16 / Price	#85-338	\$280.00	\$250.00
M30.5 x 0.5 Filter Adapter / Price	#89-942	\$25.00	
C-Mount Adapter for Front Attachment	#89-946	\$25.00	
Call For OEM Quantity Pricing			



2/3" Format
50mm

Focal Length:	50mm		
Maximum Camera Sensor Format:	⅔"		
Field of View, ⅔" Sensor:	42.5mm - 8.5°		
Field of View, ½" Sensor:	31.0mm - 6.2°		
Field of View, ⅓" Sensor:	23.0mm - 4.6°		
Working Distance:	250mm - ∞		
Number of Elements (Groups):	6 (4)		
Coating:	425 - 675nm BBAR		
Lens Mount:	C-Mount		
Weight:	70g		
	Stock No.	Price	
		1-10	11-24
f/2 / Price	#86-614	\$380.00	\$350.00
f/2.8 / Price	#86-615	\$380.00	\$350.00
f/4 / Price	#86-616	\$380.00	\$350.00
f/5.6 / Price	#86-617	\$380.00	\$350.00
f/8 / Price	#86-618	\$380.00	\$350.00
f/11 / Price	#86-619	\$380.00	\$350.00
f/16 / Price	#86-620	\$380.00	\$350.00
M25.5 x 0.5 Filter Adapter / Price	#89-943	\$25.00	
Call For OEM Quantity Pricing			

Cr Series Fixed Focal Length Lenses



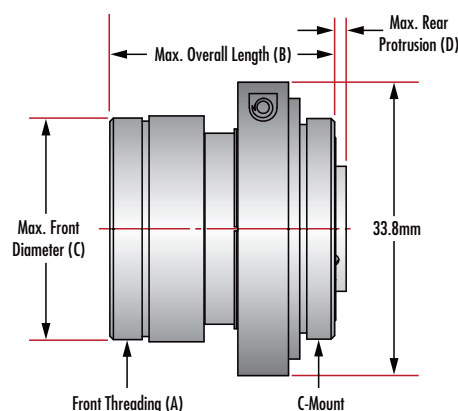
- Compact Ruggedized (Cr) Versions of our C Series Lenses
- Stability Ruggedized to Maintain Optical Pointing After Shock and Vibration
- Individual Optics are Glued in Place to Prevent Element Decenter
- Simplified Focus With Wide Range of Aperture Options
- Features Stainless Steel Locking C-Mount Clamp

Volume pricing and customization available. An EO-designed and manufactured family.



DIMENSIONS

Focal Length (mm)	A (mm)	B (mm)	C (mm)	D (mm)
6	M34.0 x 0.5	48.19	36	1.17
12	M25.5 x 0.5	31.91	26	0
16	M25.5 x 0.5	42.78	26	1.09
25	M25.5 x 0.5	32.38	26	1.33



COMPATIBLE FILTERS

See pages 111-113 for pricing and additional information.

Focal Length (mm)	Filter Adapter	Color Filter - Light Red	Color Filter - Red	Color Filter - Green	Color Filter - Blue	UV Protective Filter	Linear Polarizing Filter	IR Cut-Off Filter (KG-3)	UV/IR-Cut Filter	UV/VIS Cut-Off Filter
6	#89-940	#89-819	#89-829	#89-789	#89-769	#54-040	#52-558	#49-805	#89-799	#89-839
12	#89-942	#89-815	#89-825	#89-785	#89-765	#46-576	#46-574	#49-801	#89-795	#89-835
16	#89-942	#89-815	#89-825	#89-785	#89-765	#46-576	#46-574	#49-801	#89-795	#89-835
25	#89-942	#89-815	#89-825	#89-785	#89-765	#46-576	#46-574	#49-801	#89-795	#89-835

Cr Series Fixed Focal Length Lenses



NEW

1/1.8" Format
6mm

Focal Length:	6mm	
Maximum Camera Sensor Format:	1/1.8"	
Field of View, 1/1.8" Sensor:	110.3mm - 62.1°	
Field of View, 1/2" Sensor:	96.7mm - 55.9°	
Field of View, 1/3" Sensor:	71.0mm - 42.7°	
Working Distance:	75mm - ∞	
Number of Elements (Groups):	9 (7)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	97g	
f/1.4 / Price	#35-139	\$475.00
f/1.8 / Price	#35-140	\$475.00
f/2.8 / Price	#35-141	\$475.00
f/4 / Price	#35-142	\$475.00
f/5.6 / Price	#35-143	\$475.00
f/8 / Price	#35-144	\$475.00
M43 x 0.75 Filter Adapter / Price	#89-940	\$30.00

Call For OEM Quantity Pricing



NEW

2/3" Format
12mm

Focal Length:	12mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	159.4mm - 41.1°	
Field of View, 1/2" Sensor:	115.0mm - 30.3°	
Field of View, 1/3" Sensor:	85.9mm - 22.9°	
Working Distance:	200mm - ∞	
Number of Elements (Groups):	7 (7)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	55.4g	
f/1.8 / Price	#35-155	\$350.00
f/2.8 / Price	#35-156	\$350.00
f/4 / Price	#35-157	\$350.00
f/5.6 / Price	#35-158	\$350.00
f/8 / Price	#35-159	\$350.00
f/11 / Price	#35-160	\$350.00
f/16 / Price	#35-161	\$350.00
M30.5 x 0.5 Filter Adapter / Price	#89-942	\$25.00
C-Mount Adapter for Front Attachment	#89-946	\$25.00

Call For OEM Quantity Pricing



NEW

2/3" Format
16mm

Focal Length:	16mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	61.4mm - 30.9°	
Field of View, 1/2" Sensor:	44.5mm - 22.7°	
Field of View, 1/3" Sensor:	33.3mm - 17.1°	
Working Distance:	100mm - ∞	
Number of Elements (Groups):	7 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	61.9g	
f/1.4 / Price	#35-163	\$350.00
f/1.8 / Price	#35-164	\$350.00
f/2.8 / Price	#35-165	\$350.00
f/4 / Price	#35-166	\$350.00
f/5.6 / Price	#35-167	\$350.00
f/8 / Price	#35-168	\$350.00
f/11 / Price	#35-169	\$350.00
f/16 / Price	#35-170	\$350.00
M30.5 x 0.5 Filter Adapter / Price	#89-942	\$25.00
C-Mount Adapter for Front Attachment	#89-946	\$25.00

Call For OEM Quantity Pricing



NEW

2/3" Format
25mm

Focal Length:	25mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	35mm - 19.8°	
Field of View, 1/2" Sensor:	25.4mm - 14.5°	
Field of View, 1/3" Sensor:	19mm - 10.9°	
Working Distance:	100mm - ∞	
Number of Elements (Groups):	7 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	52.4g	
f/1.4 / Price	#35-172	\$350.00
f/1.8 / Price	#35-173	\$350.00
f/2.8 / Price	#35-174	\$350.00
f/4 / Price	#35-175	\$350.00
f/5.6 / Price	#35-176	\$350.00
f/8 / Price	#35-177	\$350.00
f/11 / Price	#35-178	\$350.00
f/16 / Price	#35-179	\$350.00
M30.5 x 0.5 Filter Adapter / Price	#89-942	\$25.00
C-Mount Adapter for Front Attachment	#89-946	\$25.00

Call For OEM Quantity Pricing

Cx Series Fixed Focal Length Lenses



- Compact Flexible (Cx) Housing Design
- Accommodates Interchangeable Accessories
- Available Accessories Include Various Liquid Lens Holders, Filter Holders, and Aperture Stops
- Modular 3-Piece Design to Fit Your Application Needs
- Features a Simplified Focus Mechanism with Easy to Use Lock Nut and Recesses Set Screw

APERTURE ACCESSORY

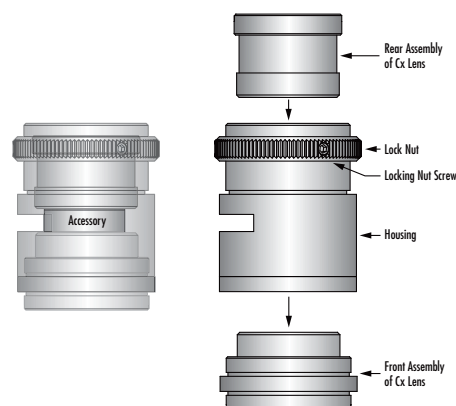
Aperture (f/#)	12mm	16mm	25mm	35mm
f/1.5	—	#33-637	—	—
f/1.65	—	—	—	#33-666
f/1.8	#33-624	#33-638	#33-653	#33-667
f/2.8	#33-625	#33-639	#33-654	#33-668
f/4.0	#33-626	#33-640	#33-655	#33-669
f/5.6	#33-627	#33-641	#33-656	#33-670
f/8.0	#33-628	#33-642	#33-657	#33-671
f/11.0	#33-629	#33-643	#33-658	#33-672
f/16.0	#33-630	#33-644	#33-659	#33-673
Price	\$9.95	\$9.95	\$9.95	\$9.95

FILTER HOLDER ACCESSORY*

Aperture (f/#)	12mm	16mm	25mm	35mm
f/1.8	#33-594	#33-601	#33-608	—
f/2.8	#33-595	#33-602	#33-609	#33-615
f/4.0	#33-596	#33-603	#33-610	#33-616
f/5.6	#33-597	#33-604	#33-611	#33-617
f/8.0	#33-598	#33-605	#33-612	#33-618
f/11.0	#33-599	#33-606	#33-613	#33-619
f/16.0	#33-600	#33-607	#33-614	#33-620
Price	\$30.00	\$30.00	\$30.00	\$30.00

*For 12.5mm Diameter, 1.5mm or 2mm Thick Filters

Cx Lens Assembly Diagram



Visit our website
for more information on
Variable Focus Liquid Lenses



LIQUID LENS HOLDER ACCESSORY*

	12mm	16mm	25mm	35mm	35mm
Compatible Liquid Lens	Artic 25H0	Artic 25H0	Artic 25H0	Artic 25H0	Artic 39H0
Compatible Liquid Lens Stock No.	#34-282	#34-282	#34-282	#34-282	#34-283
Compatible Liquid Lens Kit Stock No.	#34-284	#34-284	#34-284	#34-284	#34-285
Stock No.	#33-631	#33-645	#33-660	#33-675	#33-674
Price	\$30.00	\$30.00	\$30.00	\$30.00	\$30.00

*Liquid Lens not included

ACCESSORIES*

	Stock No.	Price
Cx Spanner Wrench	#35-029	\$9.95

*Sold Separately - not included with lens.

Cx Series Fixed Focal Length Lenses



NEW

2/3" Format
12mm

Focal Length:	12mm
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	40.7°
Field of View, 1/2" Sensor:	30°
Field of View, 1/3" Sensor:	22.7°
Working Distance:	100mm - ∞
Number of Elements (Groups):	7 (7)
Coating:	425 - 675nm BBAR
Lens Mount:	C-Mount
Weight:	33g
Stock No.	#33-562
Price	\$280.00

Call For OEM Quantity Pricing

*Accessory (One Required) for Use. See Tables on Previous Page



NEW

2/3" Format
16mm

Focal Length:	16mm
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	29.7°
Field of View, 1/2" Sensor:	21.8°
Field of View, 1/3" Sensor:	16.4°
Working Distance:	100mm - ∞
Number of Elements (Groups):	7 (6)
Coating:	425 - 675nm BBAR
Lens Mount:	C-Mount
Weight:	39g
Stock No.	#33-563
Price	\$280.00

Call For OEM Quantity Pricing

*Accessory (One Required) for Use. See Tables on Previous Page



NEW

2/3" Format
25mm

Focal Length:	25mm
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	18.7°
Field of View, 1/2" Sensor:	13.6°
Field of View, 1/3" Sensor:	10.2°
Working Distance:	150mm - ∞
Number of Elements (Groups):	7 (6)
Coating:	425 - 675nm BBAR
Lens Mount:	C-Mount
Weight:	31g
Stock No.	#33-564
Price	\$280.00

Call For OEM Quantity Pricing

*Accessory (One Required) for Use. See Tables on Previous Page



NEW

2/3" Format
35mm

Focal Length:	35mm
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	13.3°
Field of View, 1/2" Sensor:	9.7°
Field of View, 1/3" Sensor:	7.3°
Working Distance:	225mm - ∞
Number of Elements (Groups):	7 (6)
Coating:	425 - 675nm BBAR
Lens Mount:	C-Mount
Weight:	51g
Stock No.	#33-565
Price	\$280.00

Call For OEM Quantity Pricing

*Accessory (One Required) for Use. See Tables on Previous Page

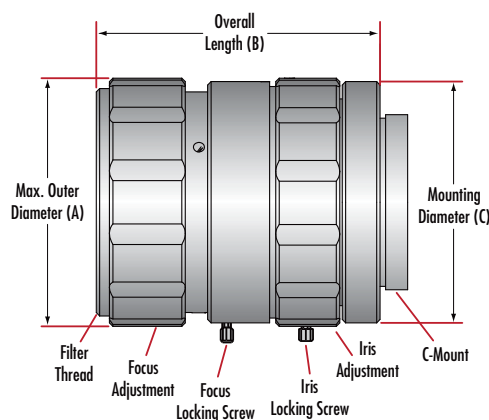
HP Series Fixed Focal Length Lenses



- High Performance (HP) Design
- Up to 9 MegaPixel Resolution Across the Field
- Multiple Options per Most Focal Lengths to Maximize Performance
- Feature Lockable Focus and Iris



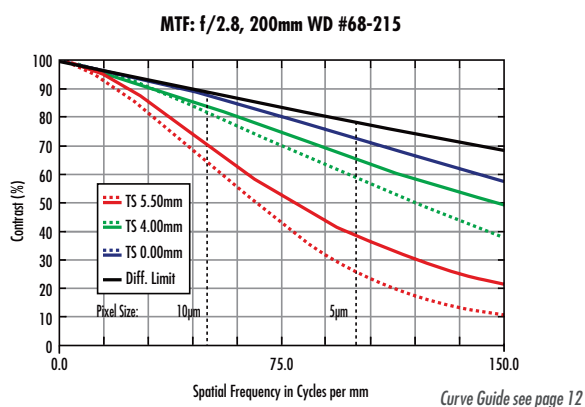
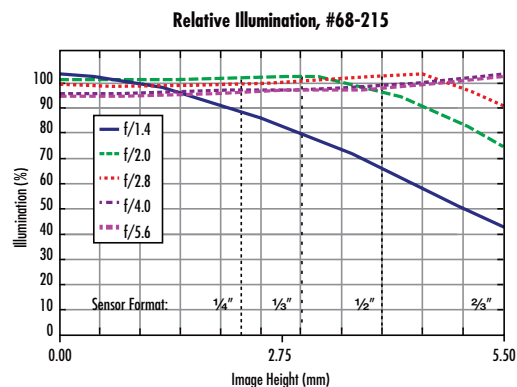
Volume pricing and customization available. An EO-designed and manufactured family.



DIMENSIONS						COMPATIBLE FILTERS				See pages 123-125 for pricing and additional information.				
Focal Length	Primary WD Range	A	B	C	Filter Thread	Color Filter Red	Color Filter Green	Color Filter Blue	UV Protective Filter	Linear Polarizing Filter	IR Cut-Off Filter	UV/IR-Cut Filter	UV/VIS-Cut Filter (R-72)	
8.5mm, 2/3" Format	200mm - ∞	42.5mm	44.5mm	33.5mm	M40.5 x 0.5	#89-818	#89-788	#89-768	#54-725	#53-999	#49-804	#89-798	#89-838	
12mm, 2/3" Format	150 - 500mm	36mm	41.1mm	35mm	M30.5 x 0.5	#89-815	#89-785	#89-765	#46-576	#46-574	#49-801	#89-795	#89-835	
12mm, 2/3" Format	400 - 2000mm	36mm	41.4mm	35mm	M30.5 x 0.5	#89-815	#89-785	#89-765	#46-576	#46-574	#49-801	#89-795	#89-835	
12mm, 2/3" Format	1000mm - ∞	36mm	41.2mm	35mm	M30.5 x 0.5	#89-815	#89-785	#89-765	#46-576	#46-574	#49-801	#89-795	#89-835	
16mm, 2/3" Format	100 - 500mm	37mm	44mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
16mm, 2/3" Format	300 - 2000mm	37mm	44mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
25mm, 2/3" Format	200 - 600mm	37.5mm	34.4mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
25mm, 2/3" Format	400 - 2000mm	37.5mm	33.7mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
25mm, 2/3" Format	1500mm - ∞	37.5mm	33.7mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
35mm, 2/3" Format	125 - 600mm	37.5mm	45mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
35mm, 2/3" Format	400 - 2000mm	37.5mm	45mm	36mm	M25.5 x 0.5	#89-814	#89-784	#89-764	#46-577	#46-575	#49-800	#89-794	#89-834	
12mm, 1" Format	100mm - ∞	48mm	64.1mm	43.5mm	M48 x 0.5	—	—	—	#54-042	#52-559	—	—	—	
16mm, 1" Format	100mm - ∞	48mm	38.8mm	57.3 - 59.5mm	M46 x 0.75	#54-762	#54-768	#46-571	#54-041	#36-439	#54-744	#54-748	#64-887	
25mm, 1" Format	150mm - ∞	37.5mm	37.5mm	45.3mm	M34 x 0.5	—	—	—	#64-892	#64-897	—	—	—	
35mm, 1" Format	200mm - ∞	48.1mm	48.1mm	60 - 66mm	M37 x 0.75	#58-642	#58-643	#58-644	#54-039	#52-556	—	—	—	
50mm, 2/3" Format	200mm - ∞	50mm	50mm	60.5 - 72.6mm	M37.5 x 0.5	—	—	—	#64-893	#64-899	—	—	—	

See pages 123-125 for pricing and additional information.

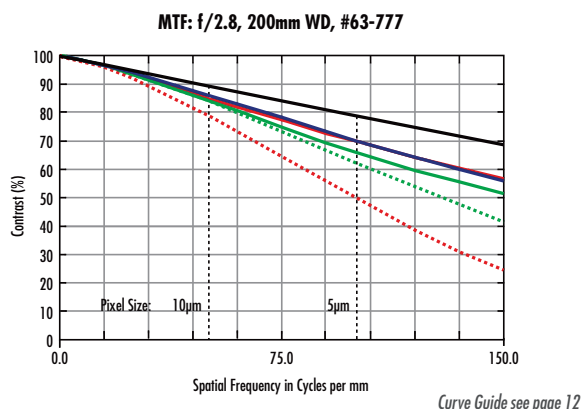
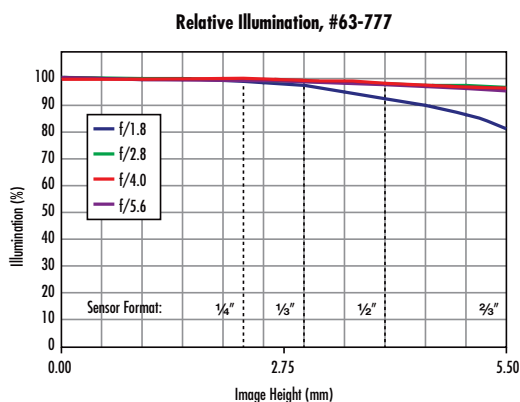
HP Series Fixed Focal Length Lenses



2/3" Format
8.5mm

Focal Length:	8.5mm, 2/3" Format	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	101.4mm - 58°	
Min. Working Distance (WD):	75mm	
Aperture (f/#):	f/1.4 - f/16	
Numerical Aperture NA, Object Side:	0.0074	
Resolution, Within Primary WD:	120 lp/mm	
Distortion:	<6.5%	
Number of Elements (Groups):	9 (8)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	120g	
Primary WD 200mm - ∞ / Price	#68-215	\$695.00

Call For OEM Quantity Pricing



2/3" Format
12mm

Focal Length:	12mm, 2/3" Format	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	139mm - 42°	
Min. Working Distance (WD):	150mm	
Aperture (f/#):	f/1.8 - f/16	
Numerical Aperture NA, Object Side:	0.015	
Resolution, Within Primary WD:	145 lp/mm	
Distortion:	<3%	
Number of Elements (Groups):	10 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	103g	
Primary WD 150 - 500mm / Price	#63-777	\$795.00
Primary WD 400 - 2000mm / Price	#63-778	\$795.00
Primary WD 1000mm - ∞ / Price	#63-779	\$795.00

Call For OEM Quantity Pricing

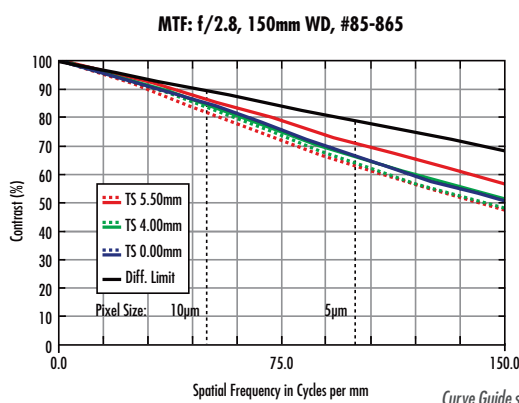
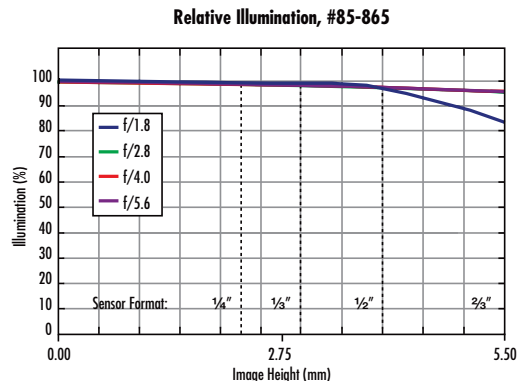
HP Series Fixed Focal Length Lenses

16mm
2/3" Format



Focal Length:	16mm, 2/3" Format	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	60mm - 31.2°	
Min. Working Distance (WD):	100mm	
Aperture (f/#):	f/1.8 - f/16	
Numerical Aperture NA, Object Side:	0.008	
Resolution, Within Primary WD:	145 lp/mm	
Distortion:	<3%	
Number of Elements (Groups):	9 (7)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	77.5g	
Primary WD 100 - 500mm / Price	#85-865	\$795.00
Primary WD 300 - 2000mm / Price	#85-866	\$795.00

Call For OEM Quantity Pricing



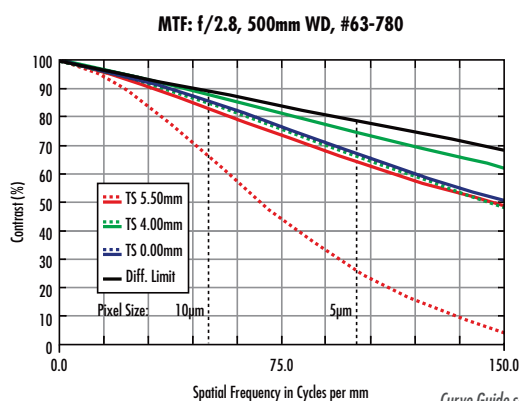
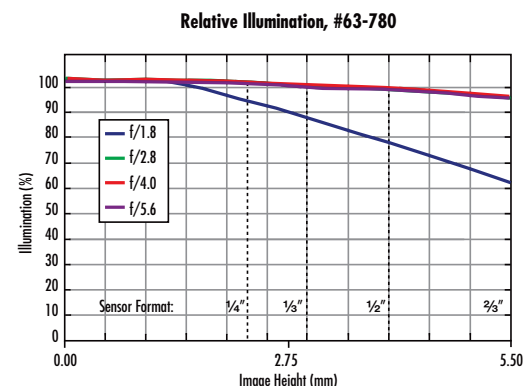
Curve Guide see page 12

25mm
2/3" Format



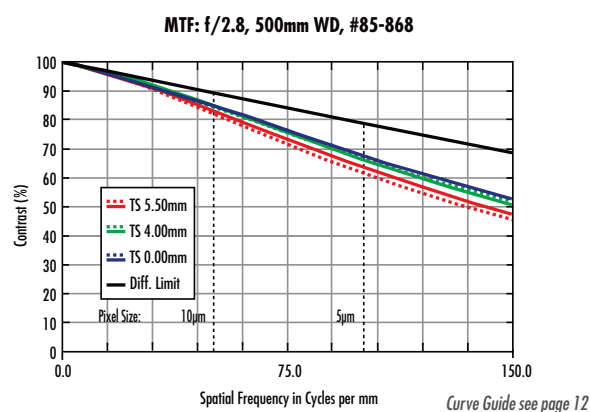
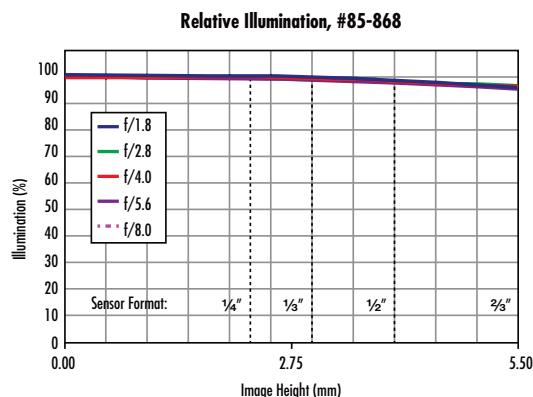
Focal Length:	25mm, 2/3" Format	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	78mm - 20.2°	
Min. Working Distance (WD):	200mm	
Aperture (f/#):	f/1.8 - f/22	
Numerical Aperture NA, Object Side:	0.03	
Resolution, Within Primary WD:	145 lp/mm	
Distortion:	<0.5%	
Number of Elements (Groups):	9 (6)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	96g	
Primary WD 200 - 600mm / Price	#63-780	\$795.00
Primary WD 400 - 2000mm / Price	#63-781	\$795.00
Primary WD 1500mm - ∞ / Price	#63-782	\$795.00

Call For OEM Quantity Pricing



Curve Guide see page 12

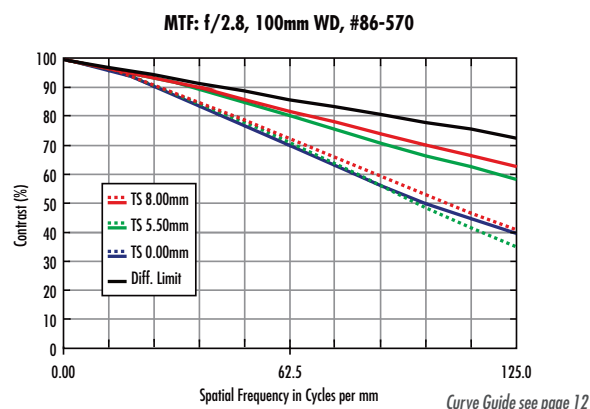
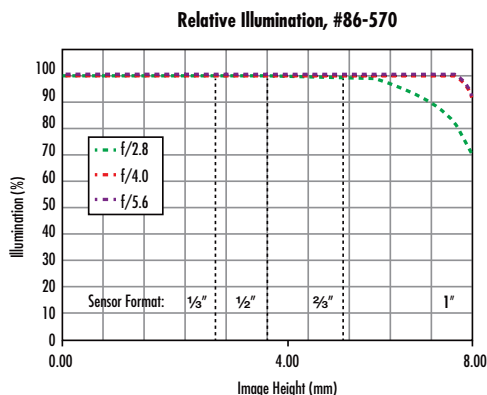
HP Series Fixed Focal Length Lenses



2/3" Format
35mm

Focal Length:	35mm, 2/3" Format	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	29mm - 12.6°	
Min. Working Distance (WD):	100mm	
Aperture (f/#):	f/1.8 - f/16	
Numerical Aperture NA, Object Side:	0.018	
Resolution, Within Primary WD:	145 lp/mm	
Distortion:	<1%	
Number of Elements (Groups):	8 (5)	
Coating:	425 - 675nm BBAR	
Lens Mount:	C-Mount	
Weight:	69.5g	
Primary WD 125 - 600mm / Price	#85-868	\$795.00
Primary WD 400 - 2000mm / Price	#85-869	\$795.00

Call For OEM Quantity Pricing



1" Format
12mm

Focal Length:	12mm, 1" Format	
Maximum Camera Sensor Format:	1"	
Field of View, 1" Sensor:	129.6mm - 52.4°	
Min. Working Distance (WD):	100mm	
Aperture (f/#):	f/2.8 - f/16	
Numerical Aperture NA, Object Side:	0.01	
Resolution, Within Primary WD:	110 lp/mm	
Distortion:	<-4.2%	
Number of Elements (Groups):	10 (9)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	260g	
Primary WD 100mm - ∞ / Price	#86-570	\$795.00

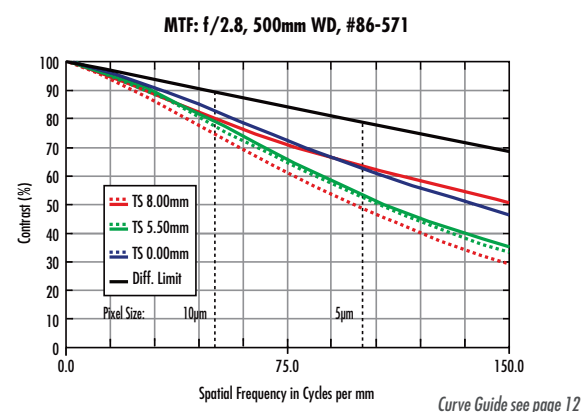
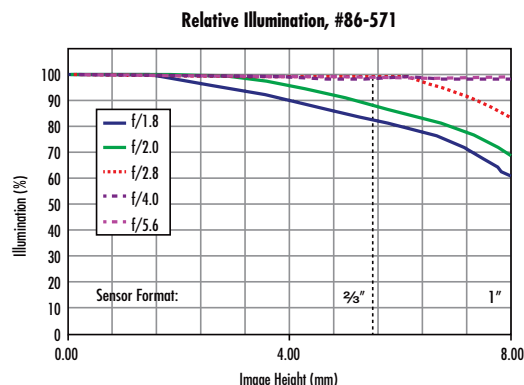
Call For OEM Quantity Pricing

HP Series Fixed Focal Length Lenses

16mm
1" Format



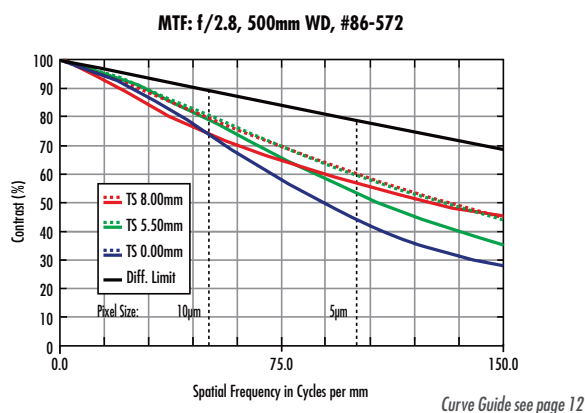
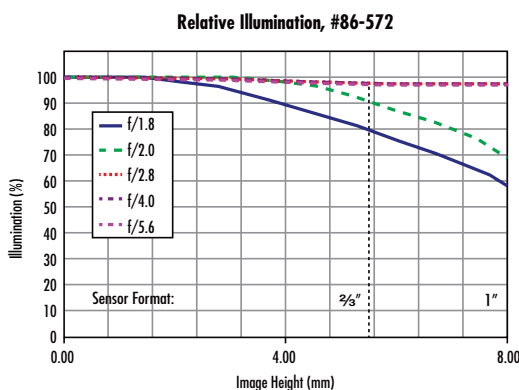
Focal Length:	16mm, 1" Format	
Maximum Camera Sensor Format:	1"	
Field of View, 1" Sensor:	127mm - 53°	
Min. Working Distance (WD):	100mm	
Aperture (f/#):	f/1.8 - f/16	
Numerical Aperture NA, Object Side:	0.02	
Resolution, Within Primary WD:	110 lp/mm	
Distortion:	<3.5%	
Number of Elements (Groups):	9 (7)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	195g	
Primary WD 100mm - ∞ / Price	#86-571	\$795.00
Call For OEM Quantity Pricing		



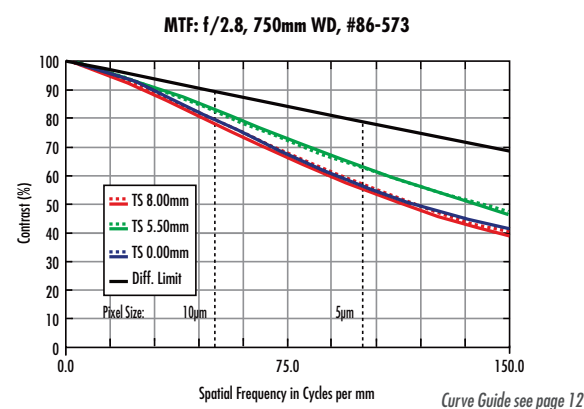
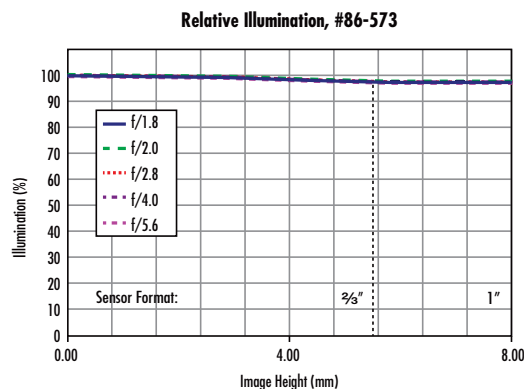
25mm
1" Format



Focal Length:	25mm, 1" Format	
Maximum Camera Sensor Format:	1"	
Field of View, 1" Sensor:	104mm - 35°	
Min. Working Distance (WD):	150mm	
Aperture (f/#):	f/1.8 - f/22	
Numerical Aperture NA, Object Side:	0.031	
Resolution, Within Primary WD:	110 lp/mm	
Distortion:	<2.0%	
Number of Elements (Groups):	7 (6)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight:	113g	
Primary WD 150mm - ∞ / Price	#86-572	\$595.00
Call For OEM Quantity Pricing		



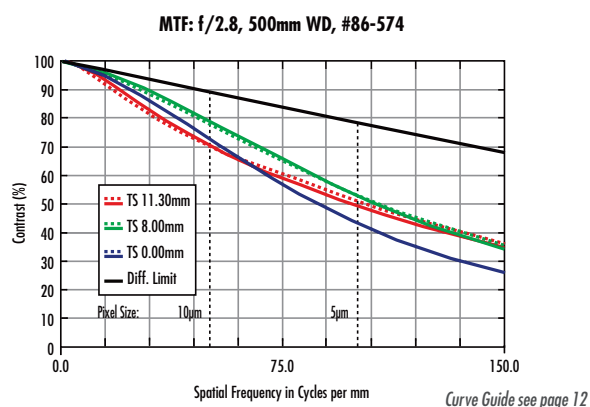
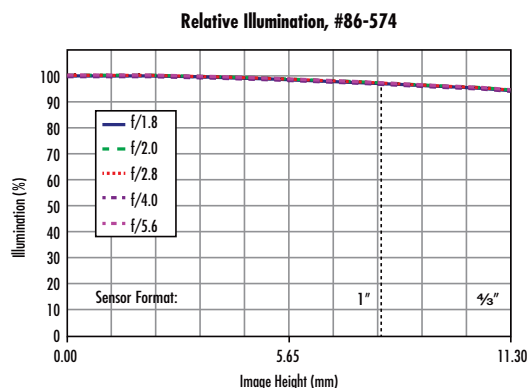
HP Series Fixed Focal Length Lenses



35mm
1" Format

Focal Length:	35mm, 1" Format
Maximum Camera Sensor Format:	1"
Field of View, 1" Sensor:	101mm - 26°
Min. Working Distance (WD):	200mm
Aperture (f/#):	f/1.8 - f/16
Numerical Aperture NA, Object Side:	0.029
Resolution, Within Primary WD:	110 lp/mm
Distortion:	<-1.5%
Number of Elements (Groups):	7 (6)
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	252g
Primary WD 200mm - ∞ / Price	#86-573 \$595.00

Call For OEM Quantity Pricing



50mm
4/3" Format

Focal Length:	50mm, 4/3" Format
Maximum Camera Sensor Format:	4/3"
Field of View, 4/3" Sensor:	75.1mm - 20.5°
Field of View, 1" Sensor:	52.9mm - 14.6°
Min. Working Distance (WD):	200mm
Aperture (f/#):	f/1.8 - f/16
Numerical Aperture NA, Object Side:	0.026
Resolution, Within Primary WD:	110 lp/mm
Distortion:	<-1.0%
Number of Elements (Groups):	7 (5)
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	295g
Primary WD 200mm - ∞ / Price	#86-574 \$695.00

Call For OEM Quantity Pricing

DG Series Fixed Focal Length Lenses

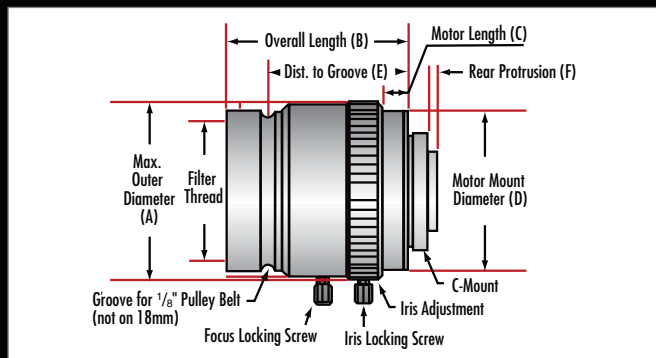


- Double Gauss (DG) Design for Low Distortion, <0.3%
- Supports Up to 1.3" Sensors
- No Vignetting
- Low-Profile Static Housing
- Up to 5 MegaPixel Resolution
- Feature Lockable Focus and Iris

Volume pricing and customization available. An EO-designed and manufactured family.



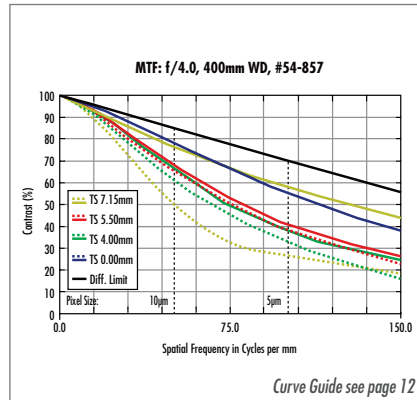
DIMENSIONS							
Focal Length (mm)	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	Filter Thread
18	48.0	32.3	4.6	40.0	—	2.5	M30.5 x 0.5
25	39.0	40.0	5.8	34.7	30.7	2.2	M30.5 x 0.5
35	45.0	50.1	11.6	40.0	42.1	0	M37.0 x 0.75
50	47.5	69.0	10.6	40.0	40.8	0	M39.0 x 0.5
75	54.0	116.2	19.2	46.0	67.7	0	M49.0 x 0.75



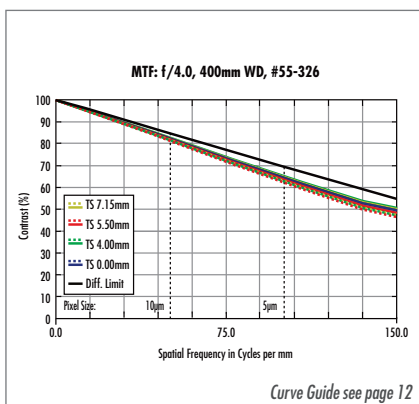
18mm
14.3mm Format



Focal Length:	18mm
Maximum Camera Sensor Format:	14.3mm
Field of View, 1" Sensor:	159.2mm - 38.4°
Field of View, 2/3" Sensor:	108.7mm - 26.8°
Field of View, 1/2" Sensor:	78.8mm - 19.6°
PMAG @ Min. WD:	0.074X
Working Distance (WD):	210mm - ∞
Aperture (f/#):	f/4 - f/12
Min. Resolution, Object Space (for 1/2" Sensor):	6 lp/mm
Distortion (@ 400mm WD):	<1%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	227g
Stock No. / Price	#54-857 \$495.00
Call For OEM Quantity Pricing	



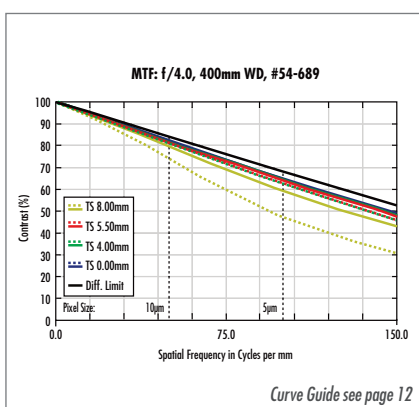
DG Series Fixed Focal Length Lenses



Focal Length:	25mm
Maximum Camera Sensor Format:	14.3mm
Field of View, 1" Sensor:	116.4mm - 28.7°
Field of View, 2/3" Sensor:	79.9mm - 19.9°
Field of View, 1/2" Sensor:	58.1mm - 14.6°
PMAG @ Min. WD:	0.106X
Working Distance (WD):	240mm - ∞
Aperture (f/#):	f/4 - Closed
Distortion (@ 400mm WD):	<0.3%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	200g
Stock No. / Price	#55-326 \$495.00
Call For OEM Quantity Pricing	



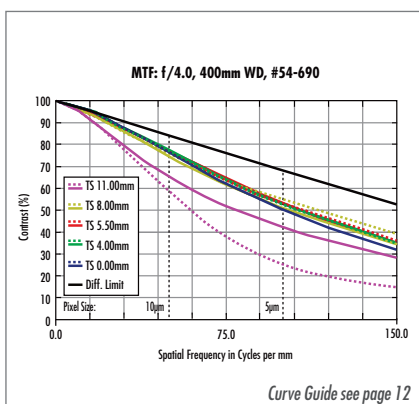
25mm
14.3mm Format



Focal Length:	35mm
Maximum Camera Sensor Format:	1"
Field of View, 1" Sensor:	82.5mm - 20.7°
Field of View, 2/3" Sensor:	56.7mm - 14.4°
Field of View, 1/2" Sensor:	41.2mm - 10.5°
PMAG @ Min. WD:	0.15X
Working Distance (WD):	240mm - ∞
Aperture (f/#):	f/4 - Closed
Distortion (@ 400mm WD):	<0.3%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	276g
Stock No. / Price	#54-689 \$495.00
Call For OEM Quantity Pricing	



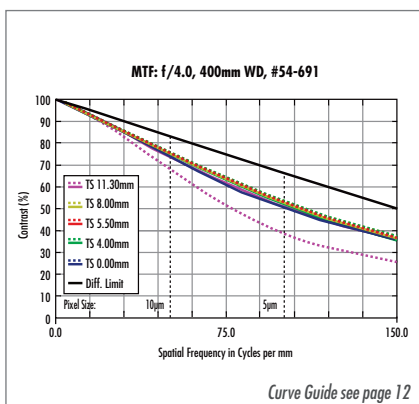
35mm
1" Format



Focal Length:	50mm
Maximum Camera Sensor Format:	4/3"
Field of View, 1" Sensor:	60.4mm - 14.5°
Field of View, 2/3" Sensor:	41.6mm - 10.0°
Field of View, 1/2" Sensor:	30.2mm - 7.3°
PMAG @ Min. WD:	0.22X
Working Distance (WD):	240mm - ∞
Aperture (f/#):	f/4 - f/18
Distortion (@ 400mm WD):	<0.3%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	248g
Stock No. / Price	#54-690 \$495.00
Call For OEM Quantity Pricing	



50mm
4/3" Format



Focal Length:	75mm
Maximum Camera Sensor Format:	4/3"
Field of View, 1" Sensor:	40.1mm - 9.8°
Field of View, 2/3" Sensor:	28.2mm - 6.7°
Field of View, 1/2" Sensor:	20.5mm - 4.9°
PMAG @ Min. WD:	0.35X
Working Distance (WD):	250mm - ∞
Aperture (f/#):	f/4 - f/30
Distortion (@ 400mm WD):	<0.3%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	C-Mount
Weight:	690g
Stock No. / Price	#54-691 \$550.00
Call For OEM Quantity Pricing	



75mm
4/3" Format

LF Series Fixed Focal Length Lenses



- Covers Large Format (LF) Sensors up to 43.3mm Diagonal
- F-Mount Compatible
- Multiple Focal Length Options Available
- Feature Lockable Focus and Iris
- Compatible with 2k – 8k Line Scan Cameras and Mid-Sized Area Scan Arrays
- Outperform Standard Photography Lenses in Machine Vision Applications

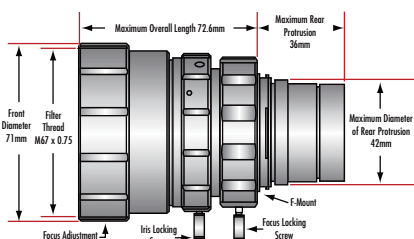
Note: 28mm focal length does not work on all F-mount cameras. F-mount Camera must have an inner diameter greater than 42mm.



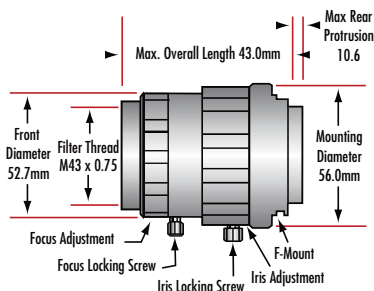
Volume pricing and customization available. An EO-designed and manufactured family.



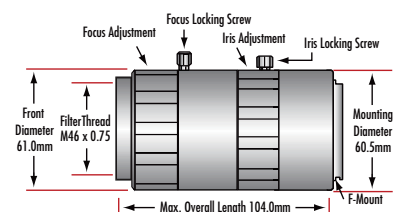
28mm Focal Length (#85-199 & #85-200)



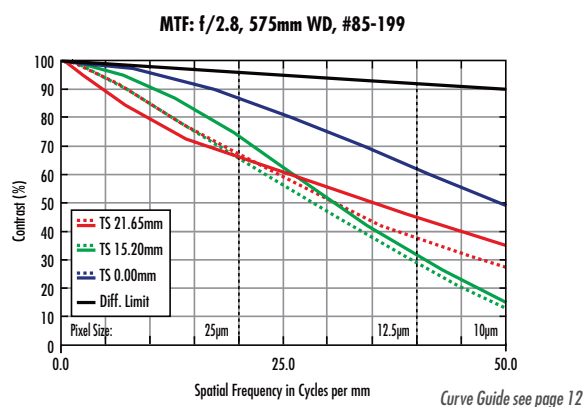
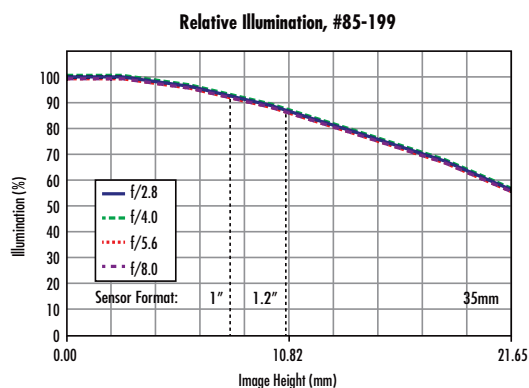
50mm Focal Length (#85-203)



100mm Focal Length (#85-204)

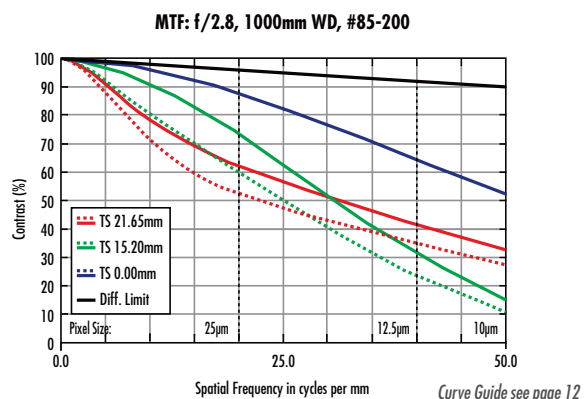
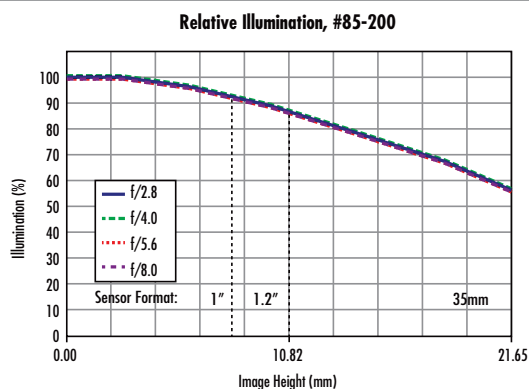


LF Series Fixed Focal Length Lenses



28mm
Short WD

Focal Length:	28mm, Short WD	
Maximum Camera Sensor Format:	35mm	
Field of View, 35mm Sensor:	540mm - 67°	
Working Distance:	400mm - ∞	
Aperture (f/#):	f/2.8 - f/22	
Numerical Aperture NA, Object Side:	0.011	
Number of Elements (Groups):	10 (8)	
Distortion (%):	<3%	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	F-Mount	
Weight:	547g	
Stock No. / Price	#85-199	\$1,695.00
Call For OEM Quantity Pricing		



28mm
Long WD

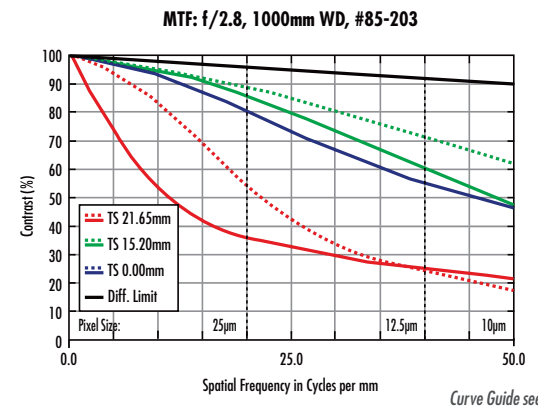
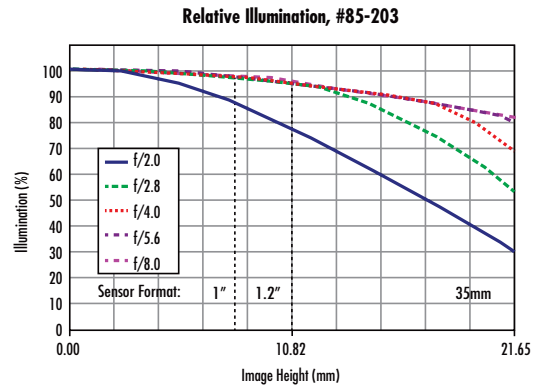
Focal Length:	28mm, Long WD	
Maximum Camera Sensor Format:	35mm	
Field of View, 35mm Sensor:	960mm - 68.4°	
Working Distance:	700mm - ∞	
Aperture (f/#):	f/2.8 - f/22	
Numerical Aperture NA, Object Side:	0.0067	
Number of Elements (Groups):	10 (8)	
Distortion (%):	<4%	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	F-Mount	
Weight:	547g	
Stock No. / Price	#85-200	\$1,695.00
Call For OEM Quantity Pricing		

LF Series Fixed Focal Length Lenses

50mm



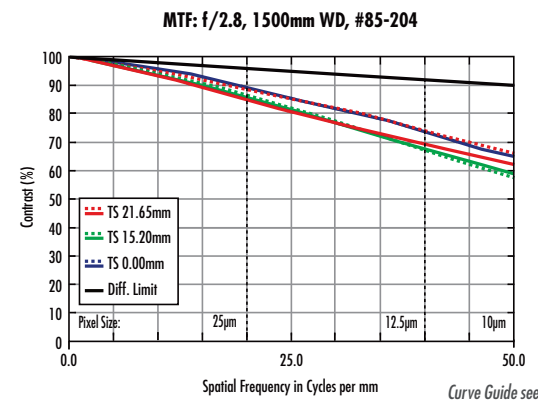
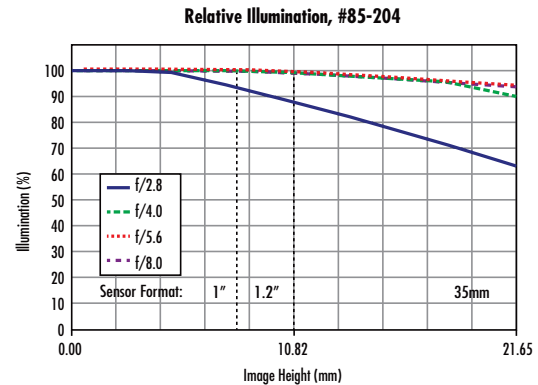
Focal Length:	50mm
Maximum Camera Sensor Format:	35mm
Field of View, 35mm Sensor:	360mm - 39.8°
Working Distance:	500mm - ∞
Aperture (f/#):	f/2.0 - f/22
Numerical Aperture NA, Object Side:	0.024
Number of Elements (Groups):	7 (5)
Distortion (%):	<1%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	F-Mount
Weight:	225g
Stock No. / Price	#85-203 \$895.00
Call For OEM Quantity Pricing	



100mm

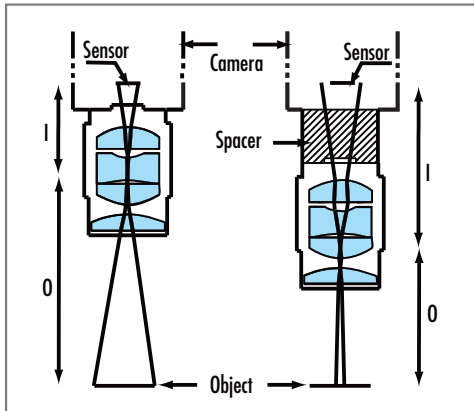


Focal Length:	100mm
Maximum Camera Sensor Format:	35mm
Field of View, 35mm Sensor:	162mm - 20.4°
Working Distance:	500mm - ∞
Aperture (f/#):	f/2.8 - f/22
Numerical Aperture NA, Object Side:	0.032
Number of Elements (Groups):	8 (5)
Distortion (%):	<1%
Coating:	1/4 MgF ₂ @ 550nm
Lens Mount:	F-Mount
Weight:	565g
Stock No. / Price	#85-204 \$1,250.00
Call For OEM Quantity Pricing	



Fixed Focal Length Lenses

TECHSPEC® FIXED FOCAL LENGTH LENS C-MOUNT SPACERS



At long working distances, most lenses are difficult to fix in bench top applications, and provide fields of view larger than required. Spacers address these issues by reducing minimum working distance and by increasing magnification, which decreases field of view. The C-Mount Extender Kit includes 0.5mm, 1mm, two 5mm, 10mm, 15mm and 40mm spacers.

C-Mount Extender Kit: Includes 0.5mm, 1mm, two 5mm, 10mm, 15mm, and 40mm spacers	#54-261	\$95.00
5mm Spacer: Converts CS-Mount camera to C-Mount	#03-618	\$20.00
M25.5 x 0.5 to C-Mount Adapter: Double Male, Rotating	#66-381	\$45.00



FIXED FOCAL LENGTH LENS EXTENDERS

As an alternative to spacers, adding a negative focal length lens to the camera end of an optical system can decrease the field of view while maintaining the original working distance specifications. For instance, increasing the focal length by 2 decreases the field of view by the same factor. Therefore, the 2X extender converts a 25mm FL lens to a 50mm FL lens. Designed for CS- or C-Mount video lenses.

FIXED FOCAL LENGTH LENS EXTENDERS

Description	CS-Mount		C-Mount	
	Stock No.	Price	Stock No.	Price
2X Focal Length Extender	#56-822	\$99.00	#54-356	\$99.00
1.5X Focal Length Extender	#56-823	\$99.00	#54-357	\$99.00



DOWNLOADABLE DATASHEETS FOR TECHSPEC® IMAGING LENSES

Download EO's TECHSPEC® Lens Data Sheets to quickly understand key factors designed to help you select and compare the right lens for your imaging system.

- **Modulation Transfer Function (MTF)**
- **Distortion**
- **Depth of Field**
- **Relative Illumination**

TECHSPEC® UC Series Lenses

- Ultra-Compact (UC) Form Factor
- 4K Resolution Designed for Small Pixels ($\leq 2.2\mu\text{m}$)
- Optimized for 1/2.5" Sensors and Supports up to 1.8"

Our ultra-compact, TECHSPEC® UC Series Fixed Focal Length Lenses are designed to optimize performance, cost, and size without sacrificing quality or feel. Designed for pixels that are $\leq 2.2\mu\text{m}$, these lenses provide high levels of resolution (>200 lp/mm) across the sensor and are compatible with all standard C-Mount cameras. TECHSPEC® UC Series Fixed Focal Length Lenses feature focus and iris adjustments, as well as recessed set screws, and are manufactured for use at typical machine vision working distances. While they are optimized for 1/2.5" sensors, macro focal lengths will work on sensors up to 1.8". The TECHSPEC® UC Series lenses are an outstanding option for use on all smaller format camera sensors, along with both short and long working distance applications, making them ideal for inspection factory automation, biomedical devices, and a broad range of other applications.

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TECHSPEC® UC Series Fixed Focal Length Lenses
#132-300 → 4mm FL → f/1.8

Performance Summary

Parameter	Value
Focal Length	4mm
Aperture Range	f/1.8 - f/16
Image Circle	18.1mm
Field of View	44.7° (diagonal)
Resolution	200 lp/mm
Depth of Field	0.05m - 0.1m
Weight	1.2g

Modulation Transfer Function (MTF)

Distortion

WWW.EDMUNDOPTICS.COM/IMAGING

SWIR Series Fixed Focal Length Lenses



Volume pricing and customization available. An EO-designed and manufactured family.



- Designed, Coated, and Tested for SWIR Wavelengths
- Compact, Lightweight, COTS Imaging Lenses
- Low f/# for High Throughput
- Anti-Reflection Coated from 0.8 - 1.8 μ m
- Cover Large, 25mm Sensors

DIMENSIONS

Focal Length (mm)	Max Dia. (mm)	Max Length (mm)	Mounting (mm)	Max Protrusion (mm)	Filter Thread
25, C-Mount	40	63.5	40	7.62	M34 x 0.5
50, C-Mount	56	112	55	0	M43 x 0.75
50, F-Mount	56	103	55	28	M43 x 0.75
50, M42 x 1.0	56	124	55	0	M43 x 0.75
100, C-Mount	84	180.1	84	0	M72 x 0.75
100, F-Mount	84	151.1	84	0	M72 x 0.75
100, M42 x 1.0	84	191.8	84	0	M72 x 0.75

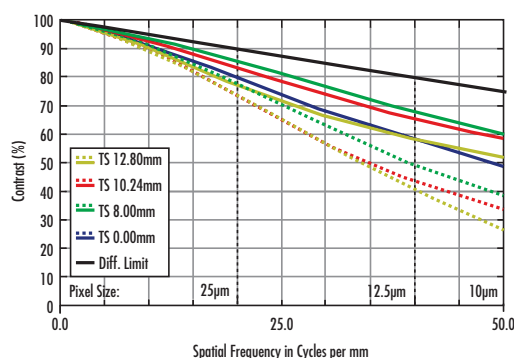
25mm
25.6mm Format



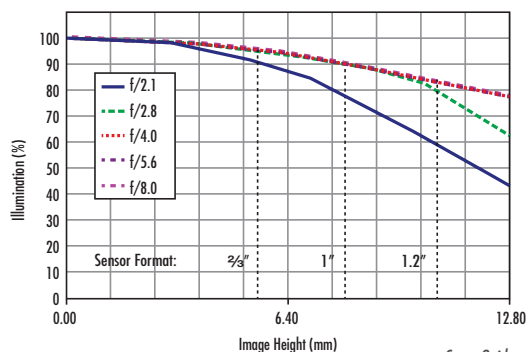
Focal Length:	25mm	
Maximum Camera Sensor Format:	25.6mm	
Field of View, 25.6mm Sensor:	206.8mm - 55.8°	
Field of View, 20.5mm Sensor:	128.2mm - 35.5°	
Working Distance:	200mm - ∞	
Aperture (f/#):	f/2.1 - f/16	
Numerical Aperture NA, Object Side:	0.02	
Number of Elements (Groups):	9 (6)	
Coating:	0.8 - 1.8 μ m BBAR	
Weight:	180g	
C-Mount (17.5mm Flange) / Price	#83-160	\$1,995.00
C-Mount to M42 x 1.0 Adapter / Price	#83-151	\$50.00

Call For OEM Quantity Pricing

MTF: f/2.8, 500mm WD, #83-160

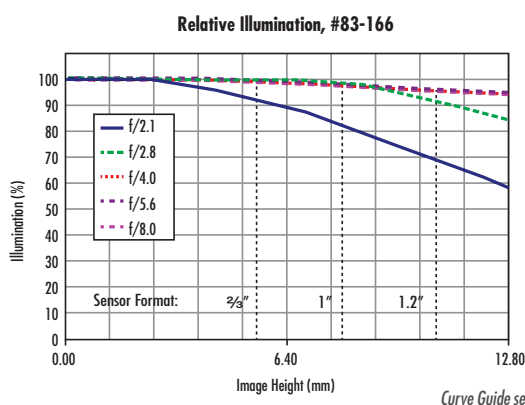
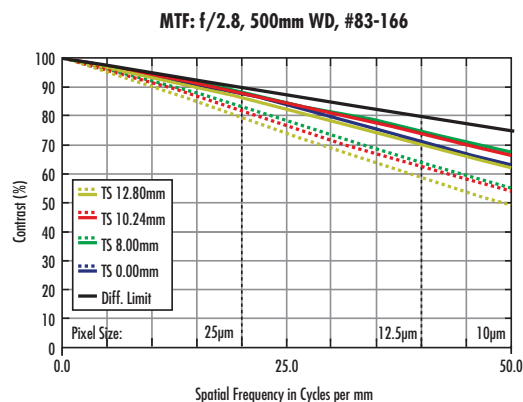


Relative Illumination, #83-160



Curve Guide see page 12

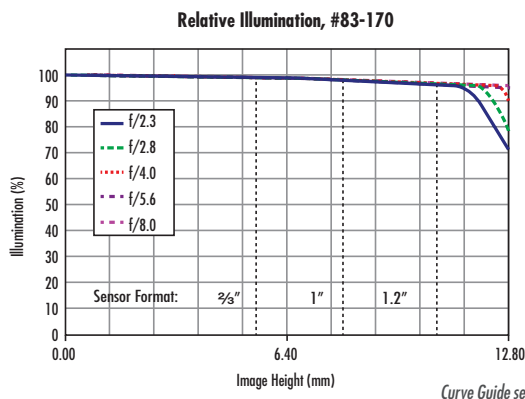
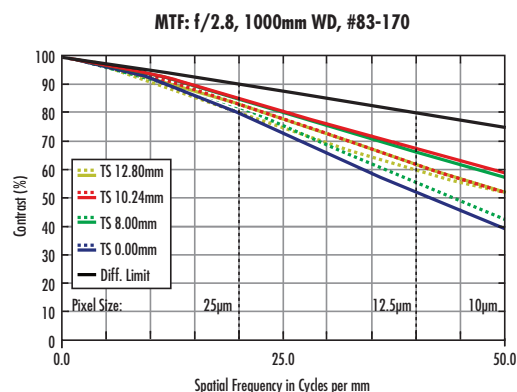
SWIR Series Fixed Focal Length Lenses



25.6mm Format
50mm

Focal Length:	50mm
Maximum Camera Sensor Format:	25.6mm
Field of View, 25.6mm Sensor:	140.7mm - 29.8°
Field of View, 20.5mm Sensor:	112.3mm - 23.4°
Working Distance:	275mm - ∞
Aperture (f/#):	f/2.15 - f/16
Numerical Aperture NA, Object Side:	0.032
Number of Elements (Groups):	10 (6)
Coating:	0.8 - 1.8μm BBAR
Weight:	< 574g (M42 x 1.0)
C-Mount (17.5mm Flange) / Price	#83-165 \$2,250.00
F-Mount (46.5mm Flange) / Price	#83-166 \$2,250.00
M42 x 1.0 (5.8mm Flange) / Price	#83-167 \$2,250.00

Call For OEM Quantity Pricing



25.6mm Format
100mm

Focal Length:	100mm
Maximum Camera Sensor Format:	25.6mm
Field of View, 25.6mm Sensor:	105.8mm - 14.6°
Field of View, 20.5mm Sensor:	660mm - 9.2°
Working Distance:	400mm - ∞
Aperture (f/#):	f/2.25 - f/22
Numerical Aperture NA, Object Side:	0.046
Number of Elements (Groups):	10 (10)
Coating:	0.8 - 1.8μm BBAR
Weight:	< 1900g (M42 x 1.0)
C-Mount (17.5mm Flange) / Price	#83-170 \$2,495.00
F-Mount (46.5mm Flange) / Price	#83-171 \$2,495.00
M42 x 1.0 (5.8mm Flange) / Price	#83-172 \$2,495.00
100mm SWIR Mounting Clamp / Price	#89-995 \$295.00

Call For OEM Quantity Pricing

LS Series Fixed Focal Length Lenses



- Covers 62mm and 90mm Line Scan (LS) Sensors
- High Resolution Over Full Image Field
- f/4.0 Designed for High Illumination Throughput
- Works with Greater than a 62mm Image Sensor

Edmund Optics® LS Series Fixed Focal Length Lenses specifically for Line Scan and Large Area Scan cameras. These high-performance imaging lenses produce excellent image resolution with impressive light throughput. In fact, at maximum aperture f/4, these high-accuracy lenses provide twice the amount of illumination throughput of comparable lenses at f/5.6 (where our iris is ½ closed).

Designed to reduce chromatic aberrations, these lenses yield stunning sharpness and contrast even at maximum apertures. Seven standard lens options are available at nominal magnification values of 0.33X - 3.0X, with excellent performance extending over a range around these magnification values. Lens cell includes locking, variable iris and front filter threading. Focusing/

Volume pricing and customization available. An EO-designed and manufactured family.



Mounting options are available for the most common camera interfaces for many of the magnification options. Typical applications include web inspection, flat panel (LCD, plasma and solar) inspection, factory automation and food/beverage inspection.

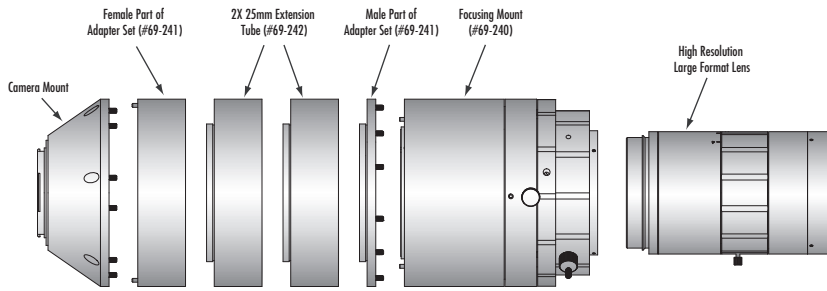
To use standard mounting with these lenses you must select a magnification, the desired camera mount and the focusing mount. Reference the table below for required adapter sets and extension tubes.

These lenses feature a robust optical design that is capable of achieving a wide magnification range around the stated nominal value. Please call us to discuss your specific magnification requirements. If one of the lenses does not perform somewhere in the range of 0.33X to 3.0X that you require, we can adjust the magnification in production, even in lower volumes.

TECHSPEC® LS SERIES FIXED FOCAL LENGTH LENSES												*Object Space	
Nominal Magnification	Maximum Sensor Size (mm)	Aperture (f/#)	Working Distance (Nominal Mag.) (mm)	Typical Mag. Range	Lens Track (mm)	Lens Length (mm)	Lens Diameter (mm)	Resolution (On 62mm Sensor)	Distortion	Front Filter Thread	Stock No.	Price 1-4	5+
0.33X	62	f/4 - f/22	386.0	0.32X - 0.39X	214	103.6	64	>100 lp/mm	<0.15%	M55 x 0.75	#68-219	\$1,195.00	Call For OEM Quantity Pricing
0.5X	>62	f/4 - f/22	271.0	0.44X - 0.52X	235	106.6	64	>100 lp/mm	<0.15%	M55 x 0.75	#68-220	\$1,195.00	
0.75X	>62	f/4 - f/22	194.5	0.69X - 0.81X	304	109.6	64	>100 lp/mm	<0.15%	M55 x 0.75	#68-221	\$1,195.00	
1.0X	90	f/4 - f/22	151.0	0.92X - 1.07X	305	115.5	64	>75 lp/mm	<0.15%	M55 x 0.75	#68-222	\$1,195.00	
1.33X	90	f/4 - f/22	158.5	1.23X - 1.47X	268	109.6	64	>100 lp/mm*	<0.15%	M46 x 0.75	#68-223	\$1,195.00	
2.0X	90	f/4 - f/22	129.0	1.86X - 2.80X	378	106.6	64	>100 lp/mm*	<0.15%	M46 x 0.75	#68-224	\$1,195.00	
3.0X	90	f/4 - f/22	110.0	2.55X - 4.50X	490	103.6	64	>100 lp/mm*	<0.15%	M46 x 0.75	#68-225	\$1,195.00	

LS Series Fixed Focal Length Lenses

Example Assembly of Lens to Camera Mount



CAMERA MOUNTING OPTIONS

*Features Tip-Tilt Control

Mount Type	Magnification	Stock No.	Price
C-Mount	0.5, 0.75	#69-225	\$150.00
C-Mount	1.0, 1.33, 2.0, 3.0	#69-226	\$150.00
F-Mount	0.75	#69-227	\$195.00
F-Mount	1.0, 1.33, 2.0, 3.0	#69-228	\$375.00
M42 x 1.0	0.33, 0.5, 0.75	#69-229	\$150.00
M42 x 1.0	1.0, 1.33, 2.0, 3.0	#69-230	\$150.00
Fixed M72 x 0.75	0.5, 0.75	#69-231	\$150.00
Fixed M72 x 0.75	1.0, 1.33, 2.0, 3.0	#69-232	\$150.00
M72 x 0.75*	0.75, 1.0, 1.33, 2.0, 3.0	#69-233	\$550.00
Bolt Pattern*	0.5, 0.75, 1.0, 1.33, 3.0	#69-234	\$550.00
Bolt Pattern*	2.0	#69-235	\$550.00
Additional Mounting Components			
Focusing Mount / Price		#69-240	\$650.00
Focus Mount Clamp, 75mm Centerline / Price		#58-502	\$195.00
Adapter Set / Price		#69-241	\$180.00
25mm Extension Tube (M72 x 0.75) / Price		#69-242	\$50.00

FIELD OF VIEW

Sensor Format	0.33X (mm)	0.5X (mm)	0.75X (mm)	1.0X (mm)	1.33X (mm)	2.0X (mm)	3.0X (mm)
11mm (2/3")	33.0	22.0	14.6	11.0	8.3	5.5	3.6
16mm (1")	48.0	32.0	21.3	16.0	12.0	8.0	5.3
22mm (1.2")	66.0	44.0	29.3	22.0	16.5	11.0	7.3
35mm (4K)	105.0	70.0	46.6	35.0	26.3	17.5	11.6
43mm (8K)	129.0	86.0	57.2	43.0	32.3	21.5	14.2
57mm (8K)	171.0	114.0	75.8	57.0	42.8	28.5	18.8
62mm (12K)	186.0	124.0	82.5	62.0	46.5	31.0	20.5

Camera Mount:	Flange Distance
C-Mount:	17.526mm
F-Mount:	46.51mm
M42 x 1.0:	6.56mm ¹
M72 x 0.75:	19.56mm ¹
Bolt Pattern:	4.0mm Designed for Dalsa Piranha

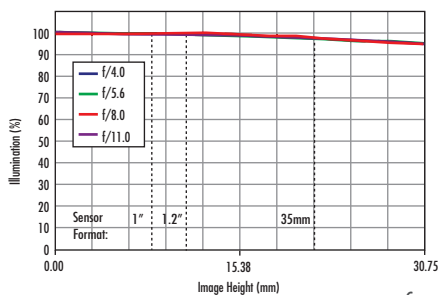
¹Camera Dependent

ADAPTER/EXTENSION TUBE GUIDE

**Fixed Version Only

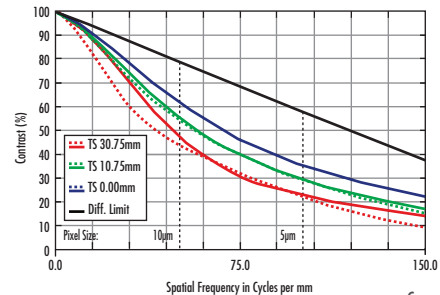
Camera Mount	C-Mount		F-Mount		M42 x 1.0		M72 x 0.75		Bolt Pattern	
Magnification	Adapter Set Needed	Additional Extension	Adapter Set Needed	Additional Extension	Adapter Set Needed	Additional Extension	Adapter Set Needed	Additional Extension	Adapter Set Needed	Additional Extension
0.33X	No Mounting	No Mounting	No Mounting	No Mounting	No	0	No Mounting	No Mounting	No Mounting	No Mounting
0.5X	No	0	No Mounting	No Mounting	No	0	No**	0**	No Mounting	No Mounting
0.75X	No	0	No	0	No	0	No	0	No	0
1.0X	Yes	0	No	0	Yes	0	Yes	0	Yes	0
1.33X	Yes	0	No	0	Yes	0	Yes	0	Yes	0
2.0X	Yes	3	Yes	2	Yes	3	Yes	3	Yes	1
3.0X	Yes	7	Yes	6	Yes	7	Yes	8	Yes	8

Relative Illumination, #68-220



Curve Guide see page 12

MTF: f/4.0, 271mm WD, #68-220



Curve Guide see page 12

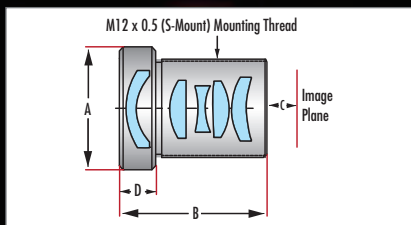
Red Series M12 μ -Video™ Imaging Lenses



- High Resolution Infinite Conjugate Designs
- S-Mount (M12 x 0.5) for Easy System Integration
- 400mm Minimum Working Distance
- Ideal for Demanding Space Constrained Applications
- All-Glass Element Design Provides High Resolution
- Harsh Environment (HEO) Versions with Weatherproof Housing Available



Volume pricing and customization available.
An EO-designed and manufactured family.

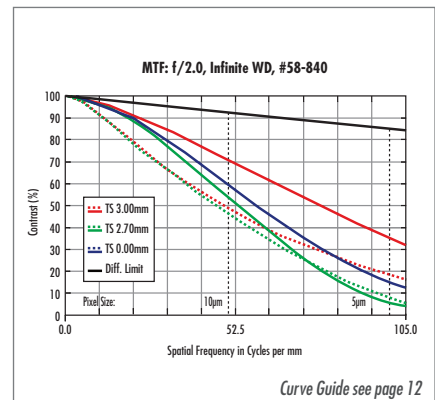


DIMENSIONS				
FL (mm)	A (mm)	B (mm)	C (mm)	D (mm)
2.2	21	16.4	1.9	5.4
3.6	14	14.5	4.5	4.2
4.4	14	24	6.4	3.8
6.4	14	30	10.2	3.8
7.2	14	22.1	8.3	4
8.0	14	15	8.7	4

2.2mm
1/3" Format



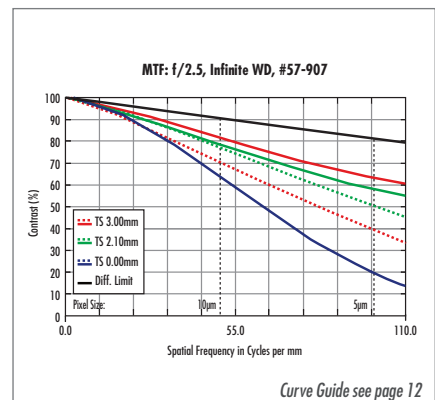
Focal Length:	2.2mm
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	110°
Working Distance:	400mm - ∞
Aperture (f/#):	f/2.0
Numerical Aperture NA, Object Side:	0.0014
Resolution, On-Axis (20% Contrast):	100 lp/mm
Distortion, Diagonal at Full Field:	-78%
Number of Elements (Groups):	7 (6)
Lens Mount:	S-Mount
Weight:	10g
Harsh Environment (HEO) (425 - 675nm Coating)	#58-840 \$145.00
Harsh Environment (HEO) (600 - 1050nm Coating)	#58-844 \$145.00
Call For OEM Quantity Pricing	



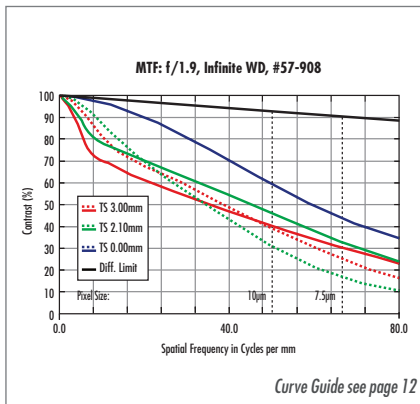
3.6mm
1/3" Format



Focal Length:	3.6mm
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	82.5°
Working Distance:	400mm - ∞
Aperture (f/#):	f/2.5
Numerical Aperture NA, Object Side:	0.0016
Resolution, On-Axis (20% Contrast):	100 lp/mm
Distortion, Diagonal at Full Field:	-46%
Number of Elements (Groups):	4 (3)
Lens Mount:	S-Mount
Weight:	4g
Standard (MgF₂ Coating):	#57-907 \$95.00
Harsh Environment (HEO) (425 - 675nm Coating)	#58-841 \$145.00
Harsh Environment (HEO) (600 - 1050nm Coating)	#58-845 \$145.00
Call For OEM Quantity Pricing	



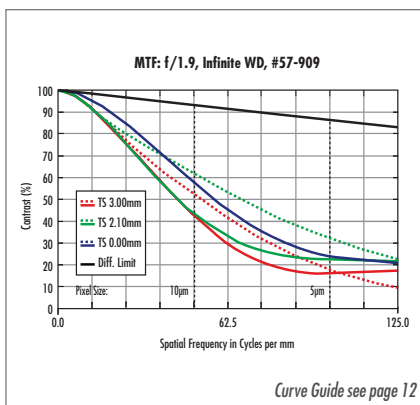
Red Series M12 μ -Video™ Imaging Lenses



Focal Length:	4.4mm
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	65.8°
Working Distance:	400mm - ∞
Aperture (f/#):	f/1.9
Numerical Aperture NA, Object Side:	0.0031
Resolution, On-Axis (20% Contrast):	100 lp/mm
Distortion, Diagonal at Full Field:	-26%
Number of Elements (Groups):	4 (3)
Lens Mount:	S-Mount
Weight:	7g
Standard (MgF₂ Coating)	#57-908 \$95.00
Call For OEM Quantity Pricing	



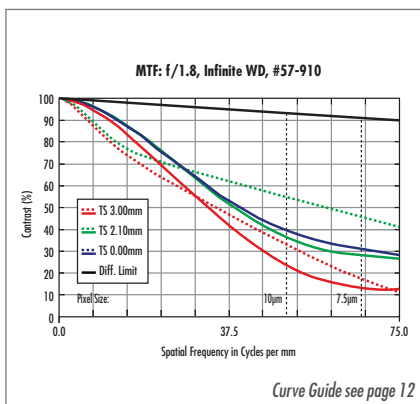
4.4mm
1/3" Format



Focal Length:	6.4mm
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	43.7°
Working Distance:	400mm - ∞
Aperture (f/#):	f/1.9
Numerical Aperture NA, Object Side:	0.0046
Resolution, On-Axis (20% Contrast):	100 lp/mm
Distortion, Diagonal at Full Field:	-11%
Number of Elements (Groups):	4 (3)
Lens Mount:	S-Mount
Weight:	7g
Standard (MgF₂ Coating)	#57-909 \$95.00
Call For OEM Quantity Pricing	



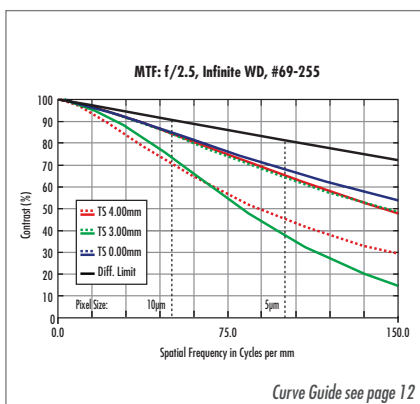
6.4mm
1/3" Format



Focal Length:	7.2mm
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	39.2°
Working Distance:	400mm - ∞
Aperture (f/#):	f/1.8
Numerical Aperture NA, Object Side:	0.0048
Resolution, On-Axis (20% Contrast):	100 lp/mm
Distortion, Diagonal at Full Field:	-8%
Number of Elements (Groups):	4 (3)
Lens Mount:	S-Mount
Weight:	5g
Standard (MgF₂ Coating)	#57-910 \$95.00
Call For OEM Quantity Pricing	



7.2mm
1/3" Format



Focal Length:	8.0mm
Maximum Camera Sensor Format:	1/2"
Field of View, Max Sensor:	46°
Working Distance:	400mm - ∞
Aperture (f/#):	f/2.5
Numerical Aperture NA, Object Side:	0.004
Resolution, On-Axis (20% Contrast):	145 lp/mm
Distortion, Diagonal at Full Field:	-10%
Number of Elements (Groups):	6 (5)
Lens Mount:	S-Mount
Weight:	5g
Standard (425 - 625nm Coating)	#69-255 \$95.00
Harsh Environment (HEO) (425 - 675nm Coating)	#63-759 \$145.00
Harsh Environment (HEO) (600 - 1050nm Coating)	#63-761 \$145.00
Call For OEM Quantity Pricing	



8.0mm
1/2" Format

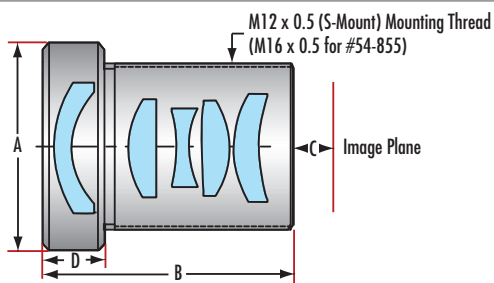
Green Series M12

μ -Video™ Imaging Lenses



- Finite Conjugate Designs
- S-Mount (M12 x 0.5) for Easy System Integration
- All Glass Multi-Element Designs
- Large Field Coverage
- Ideal for Large Area Inspection Applications
- Low Weight to Ease System Integration

Volume pricing and customization available. An EO-designed and manufactured family.



DIMENSIONS

*For optimized working distance

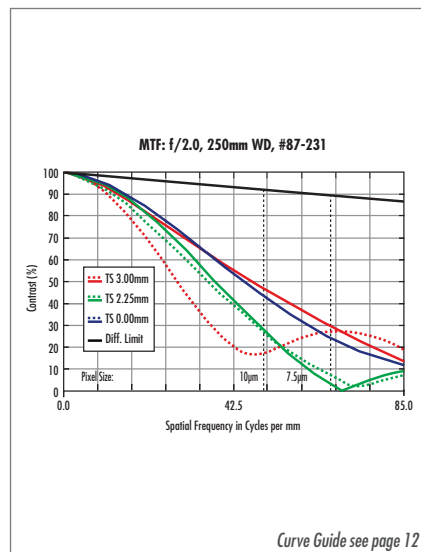
FL (mm)	A (mm)	B (mm)	C (mm)	D (mm)
6	14	11.7	4.0 - 3.9	3.5
8	14	20.4	8.9 - 8.7	6
12	16	19.5	7.1 - 6.75	6
25	18	24.4	12.6 - 11.9	9

6mm
1/3" Format

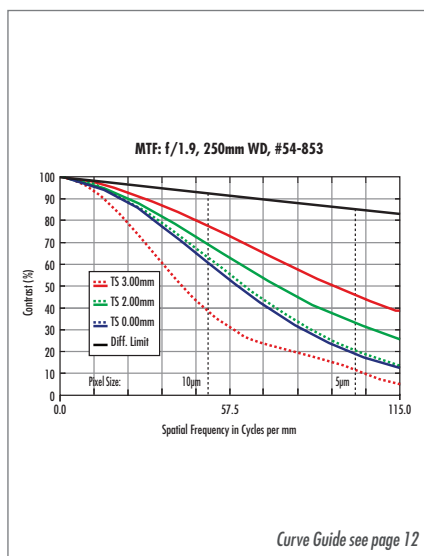


Focal Length:	6mm
Primary Magnification:	0.039X - 0.023X
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	170 - 282mm
Working Distance:	150 - 400mm
Optimized Working Distance:	150 - 250mm
Resolution (20% Contrast):	80 lp/mm
Distortion, Diagonal at Full Field:	-8.60%
Number of Elements (Groups):	5 (5)
Coating:	$\lambda/4$ MgF ₂ @ 550nm
Lens Mount:	S-Mount
Weight:	3g
f/2 / Price	#87-231 \$77.50
f/4 / Price	#69-256 \$77.50
f/5.6 / Price	#83-934 \$77.50
f/8 / Price	#83-945 \$77.50

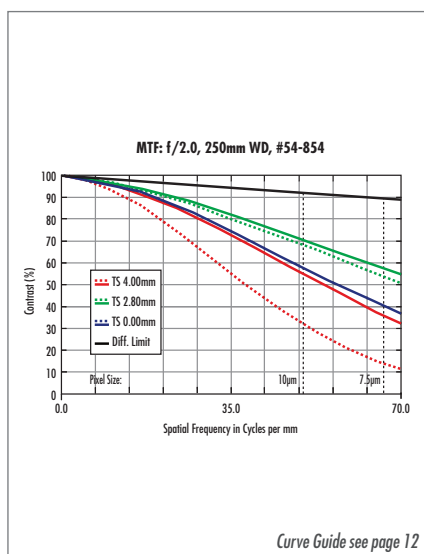
Call For OEM Quantity Pricing



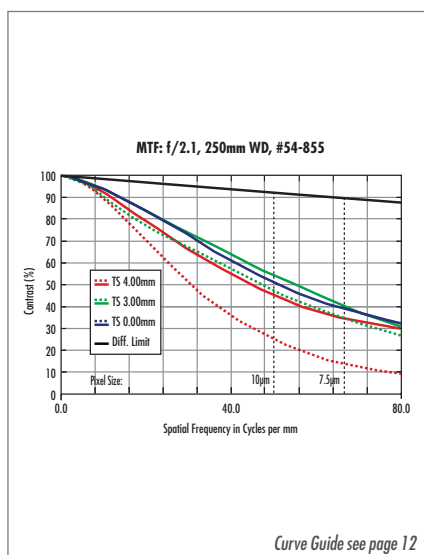
Green Series M12 μ -Video™ Imaging Lenses



Focal Length:	8mm
Primary Magnification:	0.053X - 0.032X
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	95 - 156mm
Working Distance:	150 - 400mm
Optimized Working Distance:	150 - 250mm
Numerical Aperture NA, Object Side:	0.006
Resolution (20% Contrast):	108 lp/mm
Distortion, Diagonal at Full Field:	-4.70%
Number of Elements (Groups):	5 (5)
Coating:	$\lambda/4$ MgF ₂ @ 550nm
Lens Mount:	S-Mount
Weight:	5g
f/1.9 / Price	#54-853 \$77.50
Call For OEM Quantity Pricing	



Focal Length:	12mm
Primary Magnification:	0.081X - 0.049X
Maximum Camera Sensor Format:	1/2"
Field of View, Max Sensor:	80 - 134mm
Working Distance:	150 - 400mm
Optimized Working Distance:	150 - 250mm
Numerical Aperture NA, Object Side:	0.01
Resolution (20% Contrast):	150 lp/mm
Distortion, Diagonal at Full Field:	-2.10%
Number of Elements (Groups):	5 (5)
Coating:	$\lambda/4$ MgF ₂ @ 550nm
Lens Mount:	S-Mount
Weight:	7g
f/2 / Price	#54-854 \$77.50
Call For OEM Quantity Pricing	



Focal Length:	25mm
Primary Magnification:	0.107X - 0.075X
Maximum Camera Sensor Format:	1/2"
Field of View, Max Sensor:	60 - 86mm
Working Distance:	250 - 350mm
Optimized Working Distance:	250 - 350mm
Numerical Aperture NA, Object Side:	0.026
Resolution (20% Contrast):	115 lp/mm
Distortion, Diagonal at Full Field:	-1.90%
Number of Elements (Groups):	4 (4)
Coating:	$\lambda/4$ MgF ₂ @ 550nm
Lens Mount:	M16 x 0.5
Weight:	14g
f/2.1 / Price	#54-855 \$77.50
Call For OEM Quantity Pricing	



Blue Series M12

μ -Video™ Imaging Lenses

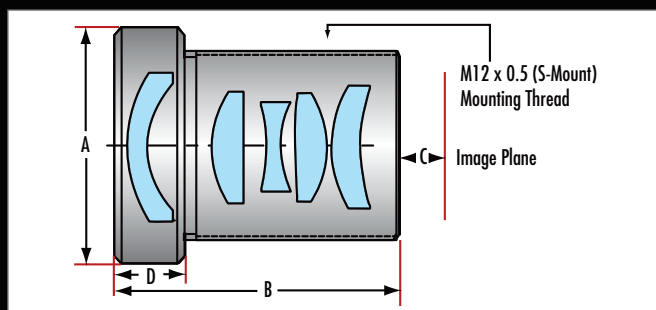


- MegaPixel High Resolution Finite Conjugate Designs
- S-Mount (M12 x 0.5) for Easy System Integration
- Multiple f/# Options for Performance from 150mm to Infinity
- Ideal for Smaller Format, Industrial Digital Cameras
- Designed for Easy Integration Into Instrumentation
- Consist of Several Precision Glass Elements

Volume pricing and customization available. An EO-designed and manufactured family.



RESOLUTION		(All Focal Lengths)
Min. Resolution @ 20% Contrast		
f/#	lp/mm	
2.5	145	
4.0	145	
5.6	120	
8.0	100	



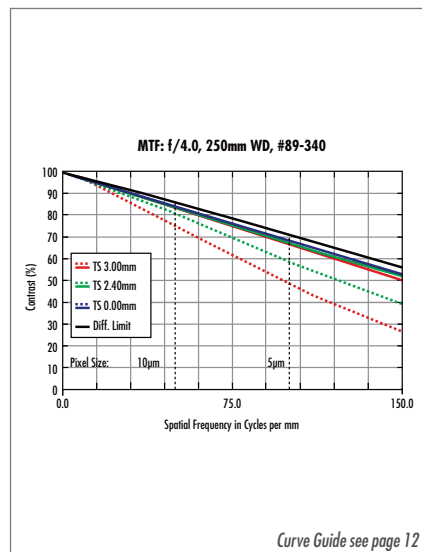
DIMENSIONS					*For optimized working distance
FL (mm)	A (mm)	B (mm)	C (mm)*	D (mm)	
3	14.0	17.1	4.8 - 4.7	5.8	
4	14.0	19.7	6.1 - 6.0	4.4	
5	14.0	14.6	4.0 - 3.9	3.7	
6	14.0	14.1	6.9 - 6.8	4.5	
8	14.0	12.3	8.8 - 8.6	3.7	
10	14.0	17.0	6.6 - 6.3	3.7	
12.5	15.0	22.9	10.1 - 9.7	4.8	
17.5	14.0	20.7	5.8 - 4.9	7.6	
25	18.0	30.0	8.5 - 6.5	11.5	

3mm
1/3" Format

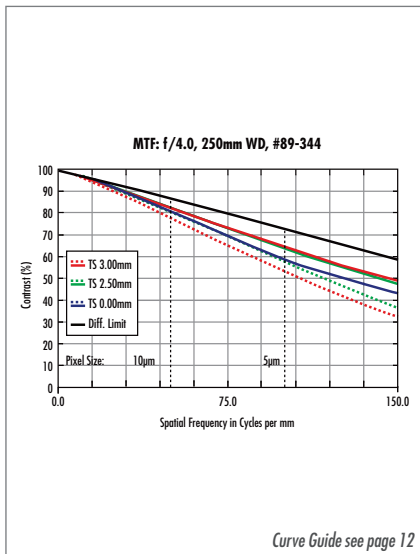


Focal Length:	3mm
Primary Magnification:	0.029X - 0.015X
Maximum Camera Sensor Format:	1/8"
Field of View, Max Sensor:	315 - 622mm
Working Distance (WD):	100 - 400mm
Optimized Working Distance (WD):	100 - 200mm
Distortion, Diagonal:	-34.7%
Distortion, Horizontal:	-21.8%
Number of Elements (Groups):	6 (5)
Lens Mount:	S-Mount
Weight:	5g
f/2.5 / Price	#89-340 \$95.00
f/4 / Price	#89-341 \$95.00
f/5.6 / Price	#89-342 \$95.00
f/8 / Price	#89-343 \$95.00

Call For OEM Quantity Pricing



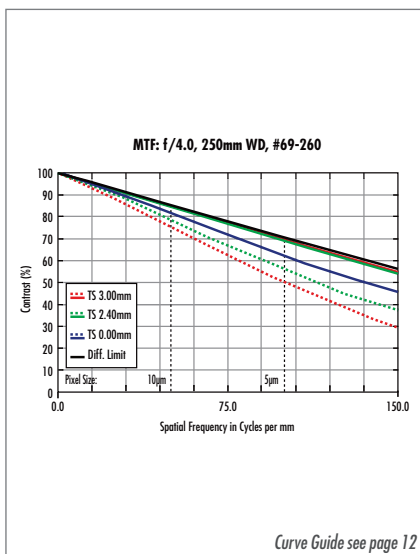
Blue Series M12 μ -Video™ Imaging Lenses



Focal Length:	4mm
Primary Magnification:	0.026X - 0.016X
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	307 - 509mm
Working Distance (WD):	150 - 400mm
Optimized Working Distance (WD):	150 - 250mm
Distortion, Diagonal:	-25.1%
Distortion, Horizontal:	-15.1%
Number of Elements (Groups):	6 (5)
Lens Mount:	S-Mount
Weight:	5g
f/2.5 / Price	#89-344 \$95.00
f/4 / Price	#89-345 \$95.00
f/5.6 / Price	#89-346 \$95.00
f/8 / Price	#89-347 \$95.00
Call For OEM Quantity Pricing	



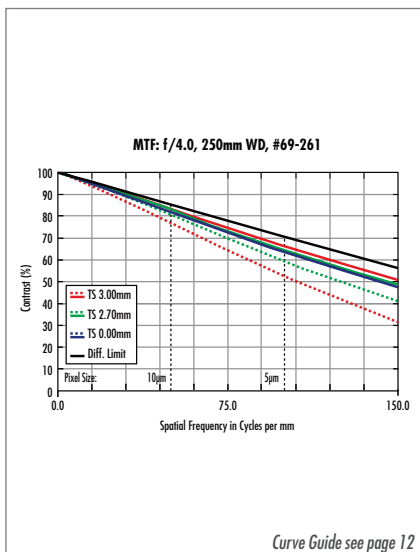
4mm
1/3" Format



Focal Length:	5mm
Primary Magnification:	0.033X - 0.020X
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	163 - 270mm
Working Distance (WD):	150 - 400mm
Optimized Working Distance (WD):	150 - 250mm
Distortion, Diagonal:	-20.0%
Distortion, Horizontal:	-11.6%
Number of Elements (Groups):	6 (5)
Lens Mount:	S-Mount
Weight:	4g
f/2.5 / Price	#58-201 \$95.00
f/4 / Price	#69-260 \$95.00
f/5.6 / Price	#83-938 \$95.00
f/8 / Price	#83-949 \$95.00
Call For OEM Quantity Pricing	



5mm
1/3" Format



Focal Length:	6mm
Primary Magnification:	0.040X - 0.024X
Maximum Camera Sensor Format:	1/3"
Field of View, Max Sensor:	132 - 220mm
Working Distance (WD):	150 - 400mm
Optimized Working Distance (WD):	150 - 250mm
Distortion, Diagonal:	-15.0%
Distortion, Horizontal:	-9.2%
Number of Elements (Groups):	5 (4)
Lens Mount:	S-Mount
Weight:	5g
f/2.5 / Price	#58-202 \$95.00
f/4 / Price	#69-261 \$95.00
f/5.6 / Price	#83-939 \$95.00
f/8 / Price	#83-950 \$95.00
Call For OEM Quantity Pricing	



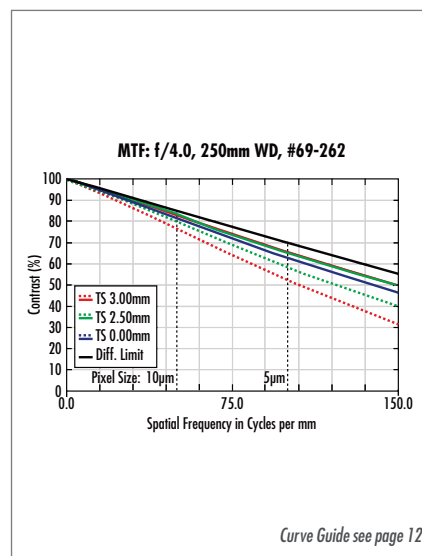
6mm
1/3" Format

Blue Series M12 μ -Video™ Imaging Lenses

8.0mm
1/3" Format



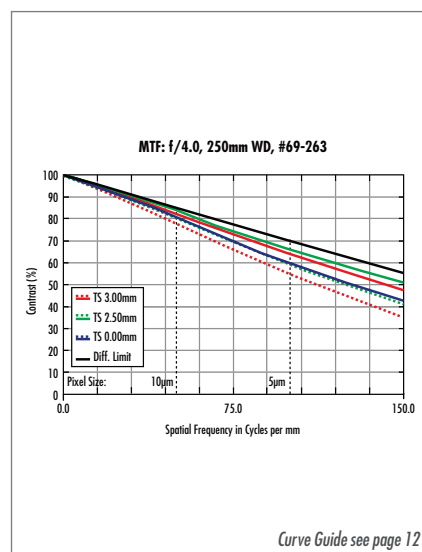
Focal Length:	8mm	
Primary Magnification:	0.053X - 0.032X	
Maximum Camera Sensor Format:	1/8"	
Field of View, Max Sensor:	92 - 154mm	
Working Distance (WD):	150 - 400mm	
Optimized Working Distance (WD):	150 - 250mm	
Distortion, Diagonal:	-6.5%	
Distortion, Horizontal:	-4.0%	
Number of Elements (Groups):	5 (5)	
Lens Mount:	S-Mount	
Weight:	3g	
f/2.5 / Price	#58-203	\$95.00
f/4 / Price	#69-262	\$95.00
f/5.6 / Price	#83-940	\$95.00
f/8 / Price	#83-951	\$95.00
Call For OEM Quantity Pricing		



10.0mm
1/3" Format



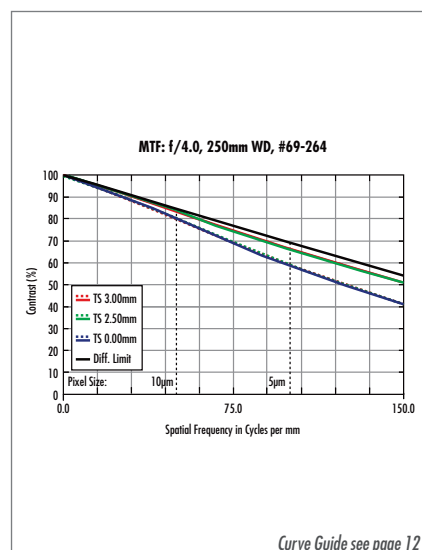
Focal Length:	10mm	
Primary Magnification:	0.068X - 0.040X	
Maximum Camera Sensor Format:	1/8"	
Field of View, Max Sensor:	72 - 120mm	
Working Distance (WD):	150 - 400mm	
Optimized Working Distance (WD):	150 - 250mm	
Distortion, Diagonal:	-1.5%	
Distortion, Horizontal:	-0.87%	
Number of Elements (Groups):	5 (4)	
Lens Mount:	S-Mount	
Weight:	5g	
f/2.5 / Price	#58-204	\$95.00
f/4 / Price	#69-263	\$95.00
f/5.6 / Price	#83-941	\$95.00
f/8 / Price	#83-952	\$95.00
Call For OEM Quantity Pricing		



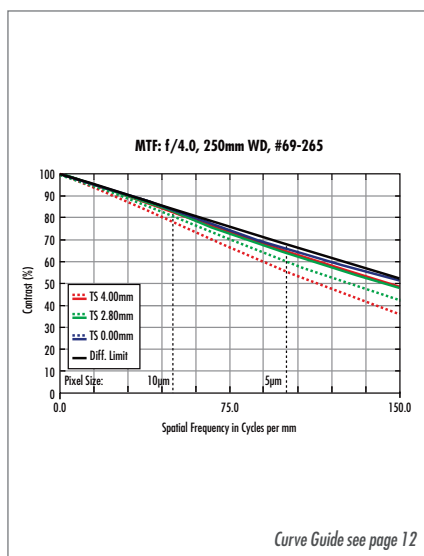
12.5mm
1/2" Format



Focal Length:	12.5mm	
Primary Magnification:	0.084X - 0.050X	
Maximum Camera Sensor Format:	1/2"	
Field of View, Max Sensor:	76 - 128mm	
Working Distance (WD):	150 - 400mm	
Optimized Working Distance (WD):	150 - 250mm	
Distortion, Diagonal:	-0.9%	
Distortion, Horizontal:	-0.61%	
Number of Elements (Groups):	5 (5)	
Lens Mount:	S-Mount	
Weight:	6g	
f/2.5 / Price	#58-205	\$95.00
f/4 / Price	#69-264	\$95.00
f/5.6 / Price	#83-942	\$95.00
f/8 / Price	#83-953	\$95.00
Call For OEM Quantity Pricing		



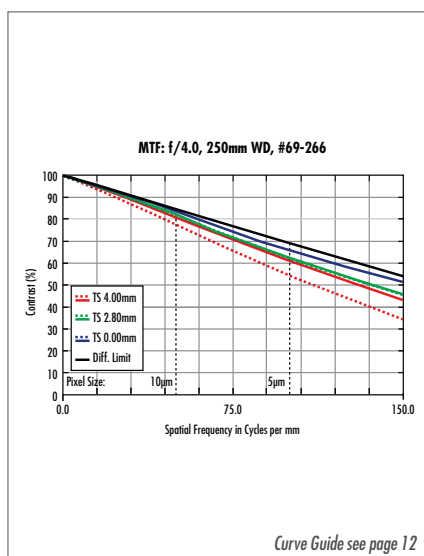
Blue Series M12 μ -Video™ Imaging Lenses



Focal Length:	17.5mm
Primary Magnification:	0.130X - 0.076X
Maximum Camera Sensor Format:	1/2"
Field of View, Max Sensor:	51 - 87mm
Working Distance (WD):	150 - 400mm
Optimized Working Distance (WD):	150 - 250mm
Distortion, Diagonal:	0.9%
Distortion, Horizontal:	0.60%
Number of Elements (Groups):	6 (5)
Lens Mount:	S-Mount
Weight:	7g
f/2.5 / Price	#58-206 \$95.00
f/4 / Price	#69-265 \$95.00
f/5.6 / Price	#83-943 \$95.00
f/8 / Price	#83-954 \$95.00
Call For OEM Quantity Pricing	



17.5mm
1/2" Format



Focal Length:	25mm
Primary Magnification:	0.190X - 0.110X
Maximum Camera Sensor Format:	1/2"
Field of View, Max Sensor:	35 - 60mm
Working Distance (WD):	150 - 400mm
Optimized Working Distance (WD):	150 - 250mm
Distortion, Diagonal:	0.3%
Distortion, Horizontal:	0.14%
Number of Elements (Groups):	6 (5)
Lens Mount:	S-Mount
Weight:	12g
f/2.5 / Price	#58-207 \$95.00
f/4 / Price	#69-266 \$95.00
f/5.6 / Price	#83-944 \$95.00
f/8 / Price	#83-955 \$95.00
Call For OEM Quantity Pricing	



25mm
1/2" Format

TECHSPEC® μ -VIDEO™ IMAGING LENSES ACCESSORIES

- μ -Video Lens (M12) to C-Mount Adapter With or Without O-Ring
- Lock Nut to Secure M12 Micro-Video Lenses to Most Holders

TECHSPEC® μ -Video™ Imaging Lens C-mount adapters are available both with or without an O-Ring. The O-Ring is recommended for use with most μ -video lenses with a full M12 x 0.5 threading, like our TECHSPEC® μ -Video™ Imaging Lenses. It helps center the lens in the adapter and prevents the lens from defocusing.

For Infinite Conjugate μ -Video™ Imaging Lenses, we recommend using the C-mount adapter without O-Ring because the thread in either component might only meet the gap of the other.

The counter nut sets the micro-video lens secure in nearly any holder. Due to its slots and holes it can be used with nearly any spanner wrench. The knurled surface also allows it to be set by hand.

The board holder, made of durable plastic, allows easy integration of micro-video lenses to customer specific video and sensor devices.



μ-VIDEO™ IMAGING LENSES ACCESSORIES		
Description	Stock No.	Price
C-Mount to Micro-Video Lens Adapter	#53-675	\$25.00
C-Mount To Micro-Video Lens Adapter w/O-Ring	#59-241	\$30.00
M12 Micro-Video Lens Holder for Camera Boards	#66-382	\$11.00
M12 Lock Nut For Micro-Video Lenses	#64-102	\$10.00

Telecentric Lenses



- Large Field of Views for Machine Vision and Metrology Applications
- Sensor Formats: 1/1.8", 2/3", 1" and 4/3"
- <0.1° Telecentricity
- Integrated Mounting Flange For Ease of Alignment
- Rear Filter Holder for Simple Filter Integration
- Adjustable Iris with Locking Set Screw

LENS SELECTION

Max. Field of View	Sensor Size			
	1/1.8"	2/3"	1"	4/3"
59.7mm	#34-000	#34-005	#34-010	#34-015
118mm	#34-001	#34-006	#34-011	#34-016
182mm	#34-002	#34-007	#34-012	#34-017
242mm	#34-003	#34-008	#34-013	#34-018

DIMENSIONS

PMAG	A (mm)	B (mm)	C (mm)	D (mm)	Bolt Circle on Mounting Flange
0.037X	266	525.9	42	298	8x Ø8mm Thru on Ø280mm
0.050X	208	383.1	42	260	8x Ø8mm Thru on Ø240mm
0.077X	150	244.8	42	200	8x Ø8mm Thru on Ø180mm
0.151X	79	138.6	42	—	—
0.045X	266	520.1	42	298	8x Ø8mm Thru on Ø280mm
0.060X	208	389.9	42	260	8x Ø8mm Thru on Ø240mm
0.093X	150	251.7	42	200	8x Ø8mm Thru on Ø180mm
0.184X	79	145.5	42	—	—
0.066X	266	536.3	42	298	8x Ø8mm Thru on Ø280mm
0.088X	208	405.8	42	260	8x Ø8mm Thru on Ø240mm
0.136X	150	267.9	42	200	8x Ø8mm Thru on Ø180mm
0.268X	79	161.7	42	—	—
0.093X	266	560.5	42	298	8x Ø8mm Thru on Ø280mm
0.124X	208	429.6	42	260	8x Ø8mm Thru on Ø240mm
0.191X	150	292.1	42	200	8x Ø8mm Thru on Ø180mm
0.377X	79	185.8	42	—	—

0.037X
1/1.8" Format

NEW



Primary Magnification PMAG:

0.037X

Maximum Camera Sensor Format:

1/1.8"

Field of View, 1/2" Sensor:

172.4mm

Field of View, 1/1.8" Sensor:

193.9mm

Working Distance:

379mm

Depth of Field (20% @ 20 lp/mm, f/8):

±284.2mm

Aperture (f/#):

f/8 - f/16

Numerical Aperture NA, Object Side:

0.0023

Resolution (@ f/8):

70 lp/mm @ 45%

Typical Telecentricity @ 588nm:

<0.1°

Typical Distortion @ 588nm:

<0.09%

Coating:

1/4 MgF₂ @ 520nm

Number of Elements (Groups):

6 (4)

Rear Filter Diameter:

12.7mm

Lens Mount:

C-Mount

Weight:

9.92kg

Stock No. / Price

#34-003

\$8,395.00

Call For OEM Quantity Pricing

TitanTL™ Telecentric Lenses

Primary Magnification PMAG:	0.050X
Maximum Camera Sensor Format:	1/1.8"
Field of View, 1/2" Sensor:	129.4mm
Field of View, 1/1.8" Sensor:	145.6mm
Working Distance:	287mm
Depth of Field (20% @ 20 lp/mm, f/8):	±159.4mm
Aperture (f/#):	f/8 - f/16
Numerical Aperture NA, Object Side:	0.0031
Resolution (@ f/8):	70 lp/mm @ 40%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.03%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	12.7mm
Lens Mount:	C-Mount
Weight:	6.72kg
Stock No. / Price	#34-002 \$4,995.00
Call For OEM Quantity Pricing	



NEW

0.050X
1/1.8" Format

Primary Magnification PMAG:	0.077X
Maximum Camera Sensor Format:	1/1.8"
Field of View, 1/2" Sensor:	83.6mm
Field of View, 1/1.8" Sensor:	94.0mm
Working Distance:	224mm
Depth of Field (20% @ 20 lp/mm, f/8):	±66.2mm
Aperture (f/#):	f/8 - f/16
Numerical Aperture NA, Object Side:	0.0048
Resolution (@ f/8):	70 lp/mm @ 44%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.19%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	12.7mm
Lens Mount:	C-Mount
Weight:	3.46kg
Stock No. / Price	#34-001 \$2,995.00
Call For OEM Quantity Pricing	



NEW

0.077X
1/1.8" Format

Primary Magnification PMAG:	0.151X
Maximum Camera Sensor Format:	1/1.8"
Field of View, 1/2" Sensor:	42.4mm
Field of View, 1/1.8" Sensor:	47.8mm
Working Distance:	111mm
Depth of Field (20% @ 20 lp/mm, f/8):	±17.1mm
Aperture (f/#):	f/8 - f/16
Numerical Aperture NA, Object Side:	0.0094
Resolution (@ f/8):	70 lp/mm @ 35%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.04%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	12.7mm
Lens Mount:	C-Mount
Weight:	0.72kg
Stock No. / Price	#34-000 \$1,495.00
Mounting Clamp / Price	#56-026 \$195.00
Color Filter - Red / Price	#46-535 \$57.50
Color Filter - Green / Price	#46-536 \$57.50
UV/Protective Filter / Price	#54-048 \$36.00
Polarizing Filter / Price	#52-560 \$43.00
UV/VIS-Cut Filter (R-72) / Price	#64-889 \$227.50
Call For OEM Quantity Pricing	



NEW

0.151X
1/1.8" Format

TitanTL™ Telecentric Lenses

0.045X
2/3" Format

NEW



Primary Magnification PMAG:	0.045X
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	193.7mm
Working Distance:	374mm
Depth of Field (20% @ 20 lp/mm, f/8):	±192.1mm
Aperture (f/#):	f/8 - f/22
Numerical Aperture NA, Object Side:	0.0028
Resolution (@ f/8):	70 lp/mm @ 35%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.05%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	9.94kg
Stock No. / Price	#34-008 \$8,395.00
Call For OEM Quantity Pricing	

0.060X
2/3" Format

NEW



Primary Magnification PMAG:	0.060X
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	145.7mm
Working Distance:	284mm
Depth of Field (20% @ 20 lp/mm, f/8):	±107.7mm
Aperture (f/#):	f/8 - f/22
Numerical Aperture NA, Object Side:	0.0038
Resolution (@ f/8):	70 lp/mm @ 40%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.08%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	6.74kg
Stock No. / Price	#34-007 \$4,995.00
Call For OEM Quantity Pricing	

0.093X
2/3" Format

NEW



Primary Magnification PMAG:	0.093X
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	94.1mm
Working Distance:	222mm
Depth of Field (20% @ 20 lp/mm, f/8):	±45.1mm
Aperture (f/#):	f/8 - f/22
Numerical Aperture NA, Object Side:	0.0058
Resolution (@ f/8):	70 lp/mm @ 40%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.10%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	3.48kg
Stock No. / Price	#34-006 \$2,995.00
Call For OEM Quantity Pricing	

TitanTL™ Telecentric Lenses

Primary Magnification PMAG:	0.184X	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	47.8mm	
Working Distance:	110mm	
Depth of Field (20% @ 20 lp/mm, f/8):	±11.5mm	
Aperture (f/#):	f/8 - f/22	
Numerical Aperture NA, Object Side:	0.0115	
Resolution (@ f/8):	70 lp/mm @ 36%	
Typical Telecentricity @ 588nm:	<0.1°	
Typical Distortion @ 588nm:	<0.05%	
Coating:	1/4 MgF ₂ @ 520nm	
Number of Elements (Groups):	6 (4)	
Rear Filter Diameter:	25.4mm	
Lens Mount:	C-Mount	
Weight:	0.74kg	
Stock No. / Price	#34-005	\$1,495.00
Mounting Clamp / Price	#56-026	\$195.00
Color Filter - Red / Price	#46-535	\$57.50
Color Filter - Green / Price	#46-536	\$57.50
UV/Protective Filter / Price	#54-048	\$36.00
Polarizing Filter / Price	#52-560	\$43.00
UV/VIS-Cut Filter (R-72) / Price	#64-889	\$227.50
Call For OEM Quantity Pricing		



NEW

2/3" Format
0.184X

Primary Magnification PMAG:	0.066X	
Maximum Camera Sensor Format:	1"	
Field of View, 1" Sensor:	193.8mm	
Working Distance:	377mm	
Depth of Field (20% @ 20 lp/mm, f/11):	±130.9mm	
Aperture (f/#):	f/11 - f/22	
Numerical Aperture NA, Object Side:	0.0030	
Resolution (@ f/11):	50 lp/mm @ 40%	
Typical Telecentricity @ 588nm:	<0.1°	
Typical Distortion @ 588nm:	<0.05%	
Coating:	1/4 MgF ₂ @ 520nm	
Number of Elements (Groups):	6 (4)	
Rear Filter Diameter:	25.4mm	
Lens Mount:	C-Mount	
Weight:	9.98kg	
Stock No. / Price	#34-013	\$8,950.00
Call For OEM Quantity Pricing		



NEW

1" Format
0.066X

Primary Magnification PMAG:	0.088X	
Maximum Camera Sensor Format:	1"	
Field of View, 1" Sensor:	145.8mm	
Working Distance:	286mm	
Depth of Field (20% @ 20 lp/mm, f/11):	±72.8mm	
Aperture (f/#):	f/11 - f/22	
Numerical Aperture NA, Object Side:	0.0040	
Resolution (@ f/11):	50 lp/mm @ 40%	
Typical Telecentricity @ 588nm:	<0.1°	
Typical Distortion @ 588nm:	<0.05%	
Coating:	1/4 MgF ₂ @ 520nm	
Number of Elements (Groups):	6 (4)	
Rear Filter Diameter:	25.4mm	
Lens Mount:	C-Mount	
Weight:	6.78kg	
Stock No. / Price	#34-012	\$5,650.00
Call For OEM Quantity Pricing		



NEW

1" Format
0.088X

TitanTL™ Telecentric Lenses

0.136X

1" Format

NEW



Primary Magnification PMAG:	0.136X
Maximum Camera Sensor Format:	1"
Field of View, 1" Sensor:	94.2mm
Working Distance:	223mm
Depth of Field (20% @ 20 lp/mm, f/11):	±30.7mm
Aperture (f/#):	f/11 - f/22
Numerical Aperture NA, Object Side:	0.0062
Resolution (@ f/11):	50 lp/mm @ 40%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.13%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	3.52kg
Stock No. / Price	#34-011 \$3,495.00
Call For OEM Quantity Pricing	

0.268X

1" Format

NEW



Primary Magnification PMAG:	0.268X
Maximum Camera Sensor Format:	1"
Field of View, 1" Sensor:	47.8mm
Working Distance:	110mm
Depth of Field (20% @ 20 lp/mm, f/11):	±7.8mm
Aperture (f/#):	f/11 - f/22
Numerical Aperture NA, Object Side:	0.0122
Resolution (@ f/11):	50 lp/mm @ 30%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.05%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	0.78kg
Stock No. / Price	#34-010 \$1,850.00
Mounting Clamp / Price	#56-026 \$195.00
Color Filter - Red / Price	#46-535 \$57.50
Color Filter - Green / Price	#46-536 \$57.50
UV/Protective Filter / Price	#54-048 \$36.00
Polarizing Filter / Price	#52-560 \$43.00
UV/VIS-Cut Filter (R-72) / Price	#64-889 \$227.50
Call For OEM Quantity Pricing	

0.093X

4/3" Format

NEW



Primary Magnification PMAG:	0.093X
Maximum Camera Sensor Format:	22.5mm
Field of View, 4/3" Sensor:	186.3mm
Working Distance:	374mm
Depth of Field (20% @ 20 lp/mm, f/11):	±64.5mm
Aperture (f/#):	f/11 - f/22
Numerical Aperture NA, Object Side:	0.0042
Resolution (@ f/11):	50 lp/mm @ 40%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.04%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	10.05kg
Stock No. / Price	#34-018 \$8,950.00
Call For OEM Quantity Pricing	

TitanTL™ Telecentric Lenses

Primary Magnification PMAG:	0.124X
Maximum Camera Sensor Format:	22.5mm
Field of View, 1/3" Sensor:	140.1mm
Working Distance:	284mm
Depth of Field (20% @ 20 lp/mm, f/11):	±37.0mm
Aperture (f/#):	f/11 - f/22
Numerical Aperture NA, Object Side:	0.0056
Resolution (@ f/11):	50 lp/mm @ 40%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.07%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	6.85kg
Stock No. / Price	#34-017 \$5,650.00
Call For OEM Quantity Pricing	



NEW

0.124X
4/3" Format

Primary Magnification PMAG:	0.191X
Maximum Camera Sensor Format:	22.5mm
Field of View, 1/3" Sensor:	90.6mm
Working Distance:	221mm
Depth of Field (20% @ 20 lp/mm, f/11):	±15.2mm
Aperture (f/#):	f/11 - f/22
Numerical Aperture NA, Object Side:	0.0087
Resolution (@ f/11):	50 lp/mm @ 35%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.11%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	3.59kg
Stock No. / Price	#34-016 \$3,495.00
Call For OEM Quantity Pricing	



NEW

0.191X
4/3" Format

Primary Magnification PMAG:	0.377X
Maximum Camera Sensor Format:	22.5mm
Field of View, 1/3" Sensor:	45.9mm
Working Distance:	110mm
Depth of Field (20% @ 20 lp/mm, f/11):	±4.0mm
Aperture (f/#):	f/11 - f/22
Numerical Aperture NA, Object Side:	0.0171
Resolution (@ f/11):	50 lp/mm @ 21%
Typical Telecentricity @ 588nm:	<0.1°
Typical Distortion @ 588nm:	<0.05%
Coating:	1/4 MgF ₂ @ 520nm
Number of Elements (Groups):	6 (4)
Rear Filter Diameter:	25.4mm
Lens Mount:	C-Mount
Weight:	0.85kg
Stock No. / Price	#34-015 \$1,850.00
Mounting Clamp / Price	#56-026 \$195.00
Color Filter - Red / Price	#46-535 \$57.50
Color Filter - Green / Price	#46-536 \$57.50
UV/Protective Filter / Price	#54-048 \$36.00
Polarizing Filter / Price	#52-560 \$43.00
UV/VIS-Cut Filter (R-72) / Price	#64-889 \$227.50
Call For OEM Quantity Pricing	



NEW

0.377X
4/3" Format

Telecentric Lenses



- Designed Specifically for Machine Vision Applications
- $<0.2^\circ$ Telecentricity
- High Resolution and Low Distortion
- Max Sensor Size: $\frac{2}{3}$ " or $\frac{1}{2}$ " Format Series
- Yield Constant Magnification over Defined Depth of Field
- Simply Refocus to Obtain Same Magnification

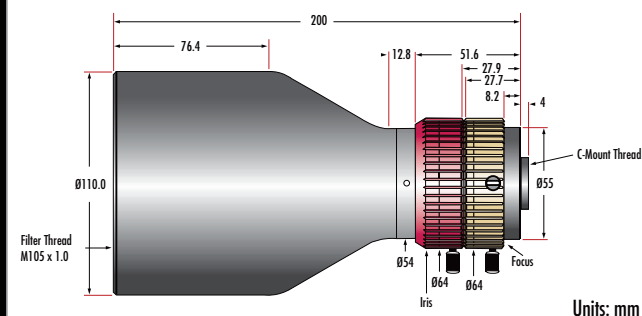


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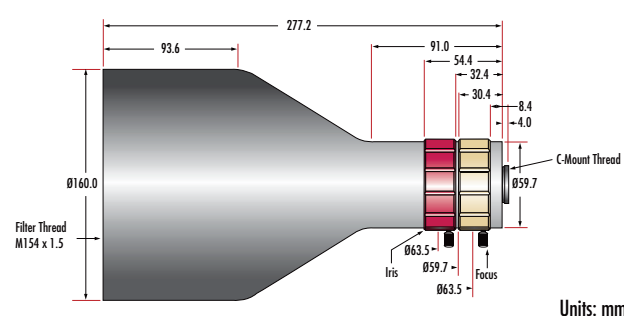


Note: Due to size and weight, mounting clamps are recommended for all telecentric lenses. The 0.125X and 0.09X lenses require a mounting clamp. The 0.06X and 0.08X lenses include a removable mounting clamp.

0.125X & 0.09X Telecentric Lenses

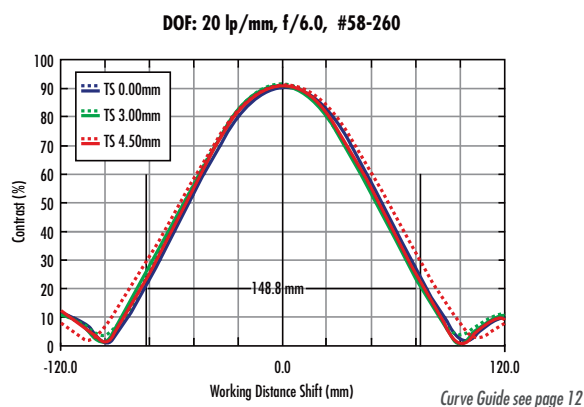
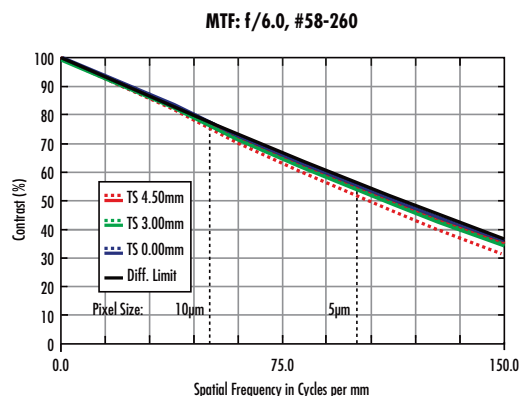


0.06X & 0.08X Telecentric Lenses



GoldTL™ Telecentric Lenses

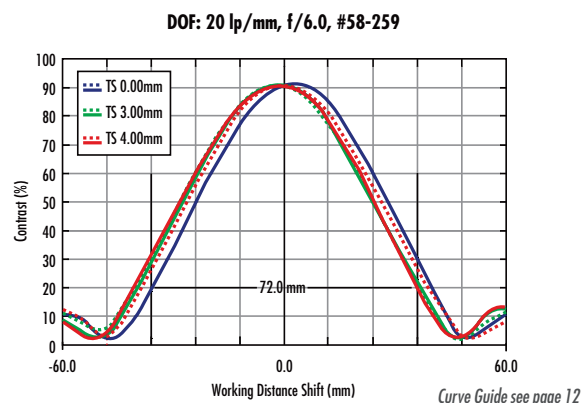
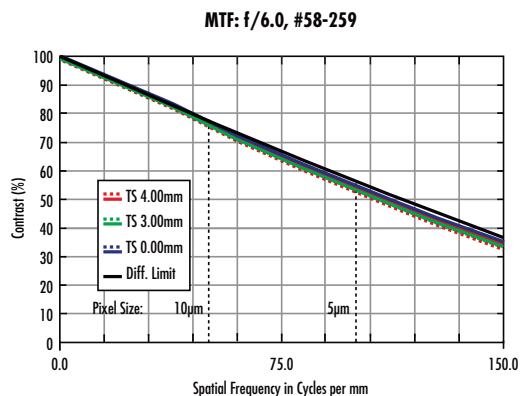
0.06X & 0.08X



Primary Magnification:	0.06X	0.08X
Maximum Camera Sensor Format:	1/4.8"	2/3"
Field of View, 2/3" Sensor:	N/A	110mm
Field of View, 1/2" Sensor:	100mm	80mm
Working Distance:	170 - 220mm	170 - 220mm
Depth of Field (20 lp/mm, f/10):	±129mm @ 20%	±81.0mm @ 20%
Aperture (f/#):	f/6 - f/25	f/6 - f/25
Numerical Aperture NA, Object Side:	0.005	0.006
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >65%	40 lp/mm @ >65%
Typical Telecentricity @ 588nm:	<0.018°	<0.018°
Typical Distortion @ 588nm:	<0.200%	<0.400%
Coating:	1/4 MgF ₂ @ 550nm	1/4 MgF ₂ @ 550nm
Number of Elements (Groups):	12 (7)	11 (7)
Lens Mount:	C-Mount	C-Mount
Weight (kg):	6.7kg	6.7kg
Stock No.	#58-260	#56-948
Price	\$4,495.00	\$4,495.00
Mounting Clamp / Price	Included	Included

Call For OEM Quantity Pricing

0.09X & 0.125X



Primary Magnification:	0.09X	0.125X
Maximum Camera Sensor Format:	1/2"	2/3"
Field of View, 2/3" Sensor:	N/A	67.4mm
Field of View, 1/2" Sensor:	70.4mm	49mm
Working Distance:	132 - 182mm	132 - 182mm
Depth of Field (20 lp/mm, f/10):	±63.6mm @ 20%	±30.4mm @ 20%
Aperture (f/#):	f/6 - f/17.4	f/6 - f/25
Numerical Aperture NA, Object Side:	0.007	0.01
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >60%	40 lp/mm @ >45%
Typical Telecentricity @ 588nm:	<0.028°	<0.028°
Typical Distortion @ 588nm:	<0.020%	<0.025%
Coating:	1/4 MgF ₂ @ 550nm	1/4 MgF ₂ @ 550nm
Number of Elements (Groups):	11 (8)	10 (8)
Lens Mount:	C-Mount	C-Mount
Weight (kg):	3.1kg	3.08kg
Stock No.	#58-259	#55-348
Price	\$2,495.00	\$2,495.00
Mounting Clamp / Price	#56-027	\$195.00

Call For OEM Quantity Pricing

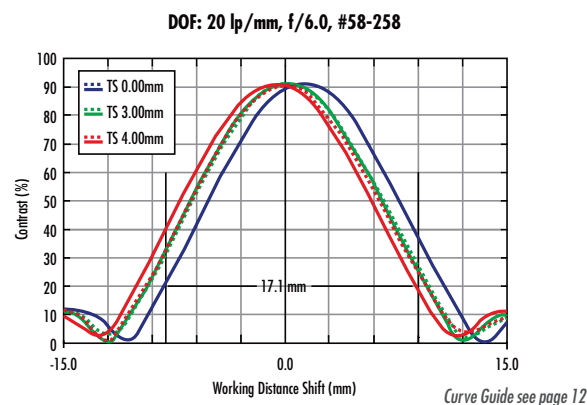
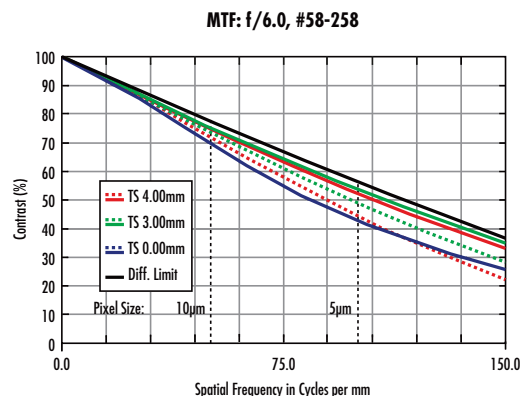
GoldTL™ Telecentric Lenses

0.18X & 0.25X



Primary Magnification:	0.18X	0.25X
Maximum Camera Sensor Format:	1/2"	2/3"
Field of View, 2/3" Sensor:	N/A	35.2mm
Field of View, 1/2" Sensor:	35.2mm	25.6mm
Working Distance:	161 - 186mm	161 - 186mm
Depth of Field (20 lp/mm, f/10):	±15.5mm @ 20%	±8.2mm @ 20%
Aperture (f/#):	f/6 - f/18	f/6 - f/25
Numerical Aperture NA, Object Side:	0.015	0.021
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >60%	40 lp/mm @ >55%
Typical Telecentricity @ 588nm:	<0.040°	<0.040°
Typical Distortion @ 588nm:	<0.045%	<0.400%
Coating:	1/4 MgF ₂ @ 550nm	1/4 MgF ₂ @ 550nm
Number of Elements (Groups):	10 (7)	10 (7)
Lens Mount:	C-Mount	C-Mount
Weight (kg):	1.6kg	1.6kg
Stock No.	#58-258	#55-349
Price	\$1,995.00	\$1,995.00
Mounting Clamp / Price	#56-026	\$195.00
Color Filter - Red / Price	#46-535	\$57.50
Color Filter - Green / Price	#46-536	\$57.50
UV/Protective Filter / Price	#54-048	\$36.00
Polarizing Filter / Price	#52-560	\$43.00
UV/VIS-Cut Filter (R-72) / Price	#64-889	\$227.50

Call For OEM Quantity Pricing

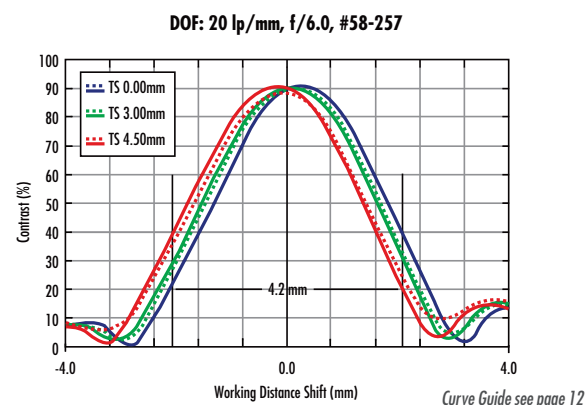
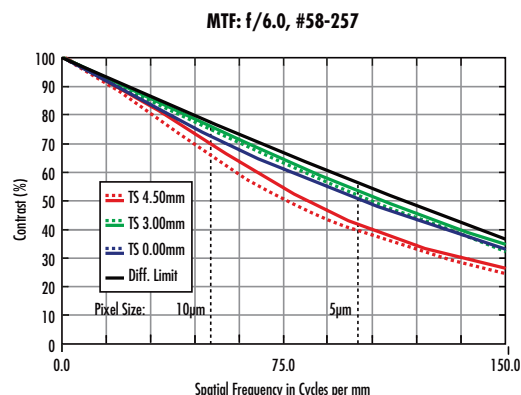


0.36X & 0.5X

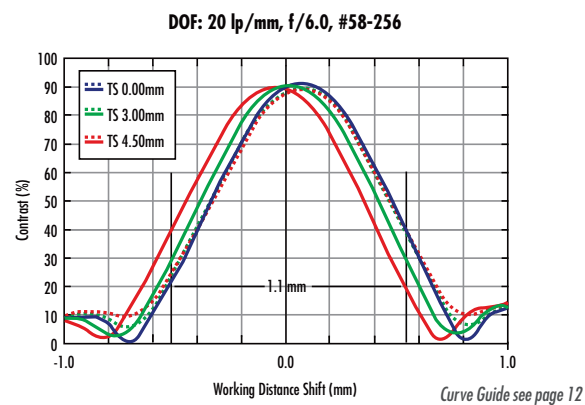
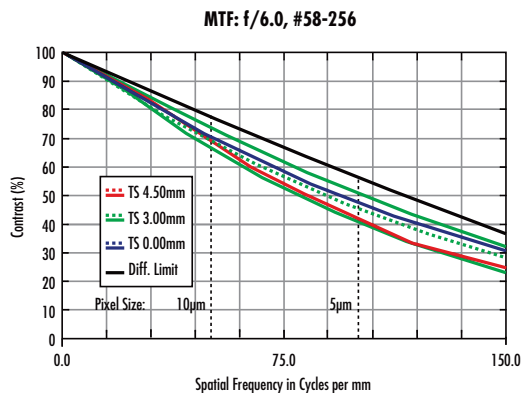


Primary Magnification:	0.36X	0.5X
Maximum Camera Sensor Format:	1/4.8"	2/3"
Field of View, 2/3" Sensor:	N/A	17.6mm
Field of View, 1/2" Sensor:	17.6mm	12.8mm
Working Distance:	117 - 142mm	117 - 142mm
Depth of Field (20 lp/mm, f/10):	±3.7mm @ 20%	±2.1mm @ 20%
Aperture (f/#):	f/6 - f/18	f/6 - f/25
Numerical Aperture NA, Object Side:	0.03	0.042
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >70%	40 lp/mm @ >55%
Typical Telecentricity @ 588nm:	<0.025°	<0.025°
Typical Distortion @ 588nm:	<0.100%	<0.015%
Coating:	1/4 MgF ₂ @ 550nm	1/4 MgF ₂ @ 550nm
Number of Elements (Groups):	10 (7)	8 (5)
Lens Mount:	C-Mount	C-Mount
Weight (kg):	0.9kg	0.91kg
Stock No.	#58-257	#54-798
Price	\$1,795.00	\$1,795.00
Mounting Clamp / Price	#56-025	\$195.00
Color Filter - Red / Price	#54-765	\$47.50
Color Filter - Green / Price	#54-771	\$47.50
Color Filter - Blue / Price	#54-777	\$47.50
UV/Protective Filter / Price	#54-046	\$33.00
Polarizing Filter / Price	#36-443	\$39.00
UV/VIS-Cut Filter (R-72) / Price	#54-754	\$87.50

Call For OEM Quantity Pricing



GoldTL™ Telecentric Lenses

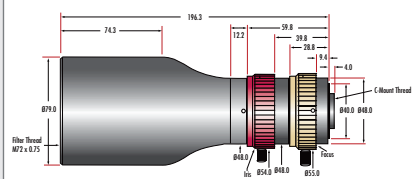


0.73X & 1X

Primary Magnification:	0.73X	1X
Maximum Camera Sensor Format:	1/1.8"	2/3"
Field of View, 2/3" Sensor:	N/A	8.8mm
Field of View, 1/2" Sensor:	8.8mm	6.4mm
Working Distance:	98 - 123mm	98 - 123mm
Depth of Field (20 lp/mm, f/10):	±0.95mm @ 20%	±0.6mm @ 20%
Aperture (f/#):	f/6 - f/19.5	f/6 - f/25
Numerical Aperture NA, Object Side:	0.061	0.087
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >65%	40 lp/mm @ >50%
Typical Telecentricity @ 588nm:	<0.003°	<0.018°
Typical Distortion @ 588nm:	<0.100%	<0.003%
Coating:	1/4 MgF ₂ @ 550nm	1/4 MgF ₂ @ 550nm
Number of Elements (Groups):	10 (7)	9 (7)
Lens Mount:	C-Mount	C-Mount
Weight (kg):	1.2kg	1.1kg
Stock No.	#58-256	#55-350
Price	\$1,695.00	\$1,695.00
Mounting Clamp / Price	#56-024	\$195.00
Color Filter - Red / Price	#46-532	\$51.50
Color Filter - Green / Price	#46-533	\$51.50
UV/Protective Filter / Price	#54-077	\$36.00
Polarizing Filter / Price	#36-444	\$39.00
UV/VIS-Cut Filter (R-72) / Price	#64-888	\$127.50

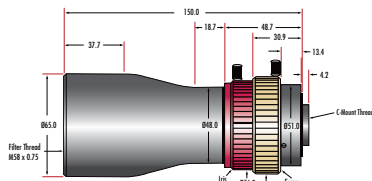
Call For OEM Quantity Pricing

0.25X & 0.18X Telecentric Lenses



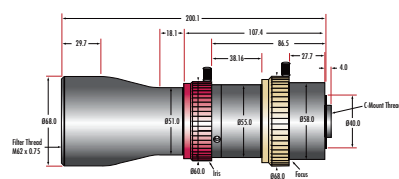
Units: mm

0.5X & 0.36X Telecentric Lenses



Units: mm

1X & 0.73X Telecentric Lenses



Units: mm

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Telecentric Lenses



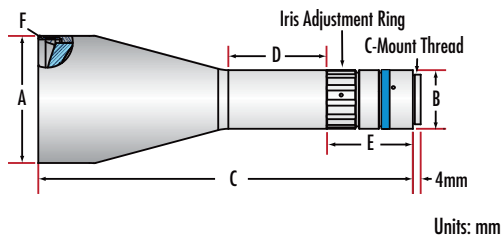
- Designed for Metrology and Gauging Applications
- Ideal for Factory Automation
- Double Telecentric to Eliminate Illumination Roll-Off
- High Light Throughput (f/6)
- Adjustable Lockable Iris

Volume pricing and customization
available. An EO-designed and
manufactured family.



DOWNLOAD
DATASHEETS

0.16X & 0.60X



DIMENSIONS

See pages 123-125 for our complete selection of filters

Primary Magnification	Max Diameter A (mm)	Mounting Diameter B (mm)	Length C (mm)	Mounting Length D (mm)	Mounting Offset E (mm)	Filter Thread
0.16X	65	30	191	50	43	M62 x 0.75
0.20X	60	30	188	42	45	M58 x 0.75
0.25X	48	30	158	49	44	M46 x 0.75
0.30X	46	30	158	60	43	M43 x 0.75
0.40X	45	30	159	67	33	M43 x 0.75
0.50X	40	30	153	42	68	M37 x 0.75
0.60X	42	30	156	57	46	M40.5 x 0.5
0.75X	36	30	151.2	34	82.2	M30.5 x 0.5
1.0X	40	30	114	32	17	M37 x 0.75
2.0X	45	30	141	45	17	M43 x 0.75
4.0X	61	30	249	99	17	M58 x 0.75

0.16X

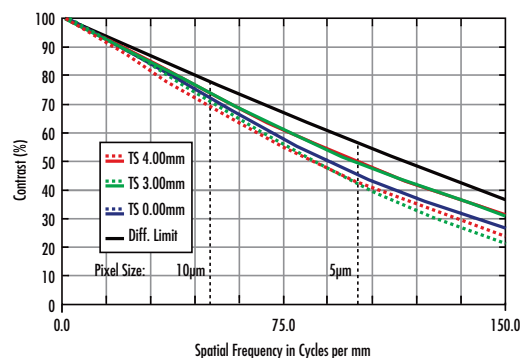
1/2" Format



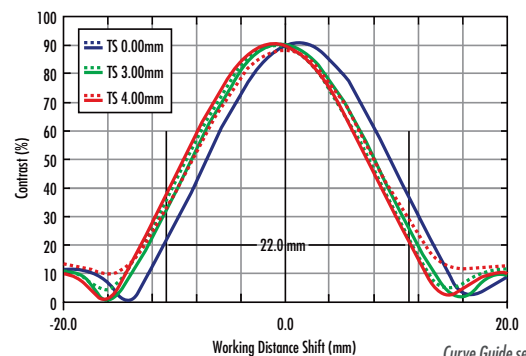
Primary Magnification:	0.16X
Maximum Camera Sensor Format:	1/2"
Field of View, 1/2" Sensor:	40mm
Field of View, 1/3" Sensor:	30mm
Working Distance (±3mm):	177mm
Depth of Field (20 lp/mm, f/10):	±19.74mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.008
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.030°
Typical Distortion @ 588nm:	<0.015%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	8 (6)
Lens Mount:	C-Mount
Weight:	500g
Stock No. / Price	#56-675 \$995.00
Color Filter - Red / Price	#89-832 \$255.00
Color Filter - Green / Price	#89-792 \$285.00
Color Filter - Blue / Price	#89-772 \$285.00
UV/Protective Filter / Price	#89-802 \$255.00
Linear Polarizing Filter / Price	#36-444 \$39.00

Call For OEM Quantity Pricing

MTF: f/6.0, #56-675

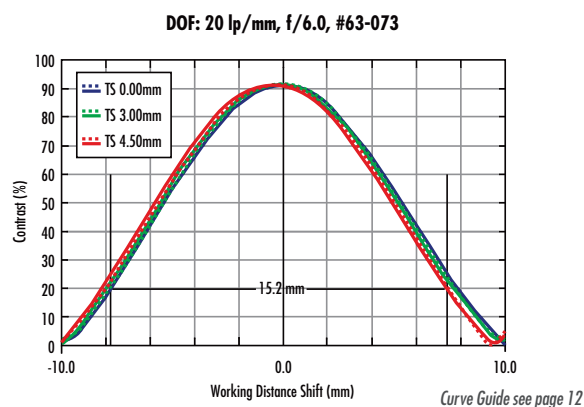
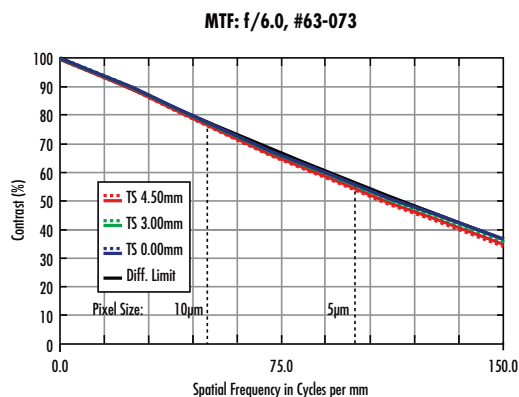


DOF: 20 lp/mm, f/6.0, #56-675



Curve Guide see page 12

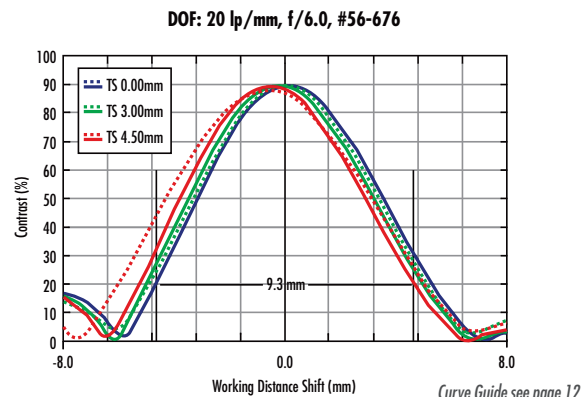
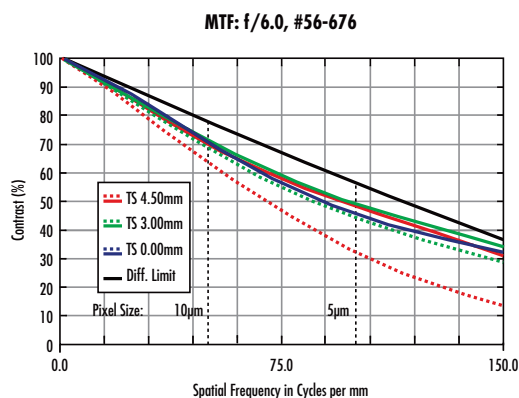
SilverTL™ Telecentric Lenses



1/1.8" Format
0.20X

Primary Magnification:	0.20X
Maximum Camera Sensor Format:	1/4.8"
Field of View, 1/2" Sensor:	32mm
Field of View, 1/8" Sensor:	24mm
Working Distance (±3mm):	164mm
Depth of Field (20 lp/mm, f/10):	±12.9mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.016
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.055°
Typical Distortion @ 588nm:	<0.150%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	6 (5)
Lens Mount:	C-Mount
Weight:	475g
Stock No. / Price	#63-073 \$995.00
Color Filter - Red / Price	#54-765 \$47.50
Color Filter - Green / Price	#54-771 \$47.50
Color Filter - Blue / Price	#54-777 \$47.50
UV/Protective Filter / Price	#54-046 \$33.00
Linear Polarizing Filter / Price	#36-443 \$39.00

Call For OEM Quantity Pricing



1/1.8" Format
0.25X

Primary Magnification:	0.25X
Maximum Camera Sensor Format:	1/4.8"
Field of View, 1/2" Sensor:	25.6mm
Field of View, 1/8" Sensor:	19.2mm
Working Distance (±3mm):	160mm
Depth of Field (20 lp/mm, f10):	±8.2mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.021
Resolution, Image Space MTF @ f10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.035°
Typical Distortion @ 588nm:	<0.040%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	8 (5)
Lens Mount:	C-Mount
Weight:	300g
Stock No. / Price	#56-676 \$975.00
Color Filter - Red / Price	#54-762 \$47.50
Color Filter - Green / Price	#54-768 \$47.50
Color Filter - Blue / Price	#46-571 \$47.50
UV/Protective Filter / Price	#54-041 \$31.00
Linear Polarizing Filter / Price	#36-439 \$36.00

Call For OEM Quantity Pricing

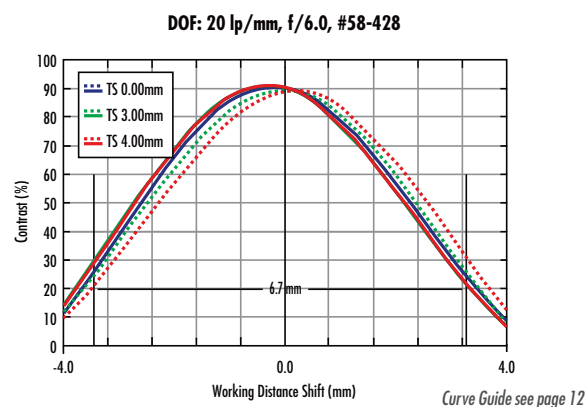
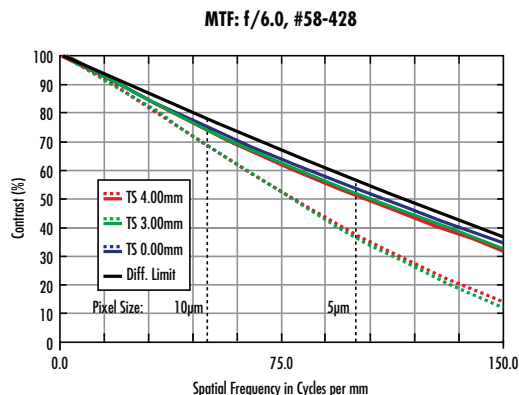
SilverTL™ Telecentric Lenses

0.30X
1/2" Format



Primary Magnification:	0.30X
Maximum Camera Sensor Format:	1/2"
Field of View, 1/2" Sensor:	21.3mm
Field of View, 1/8" Sensor:	16mm
Working Distance (±3mm):	139mm
Depth of Field (20 lp/mm, f/10):	±5.7mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.025
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.025°
Typical Distortion @ 588nm:	<0.015%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	7 (6)
Lens Mount:	C-Mount
Weight:	350g
Stock No. / Price	#58-428 \$995.00
Color Filter - Red / Price	#89-829 \$160.00
Color Filter - Green / Price	#89-789 \$175.00
Color Filter - Blue / Price	#89-769 \$175.00
UV/Protective Filter / Price	#89-799 \$160.00
Linear Polarizing Filter / Price	#52-558 \$35.00

Call For OEM Quantity Pricing

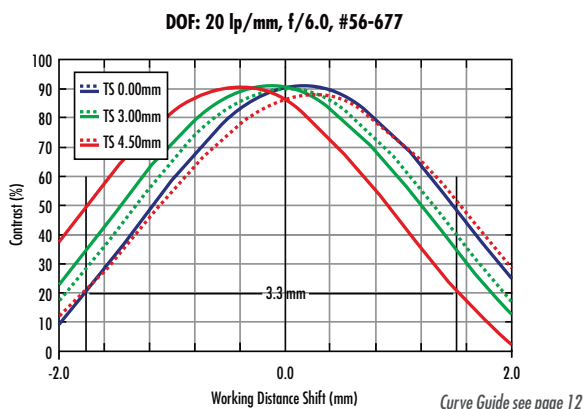
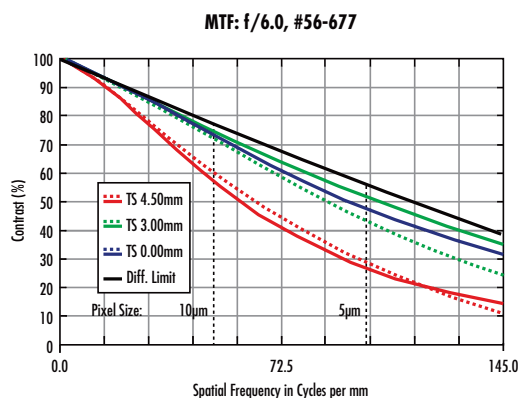


0.40X
1/1.8" Format

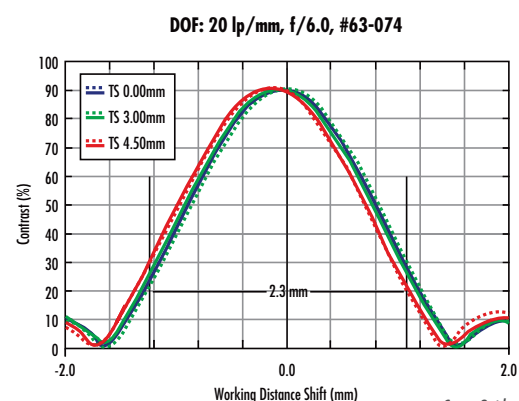
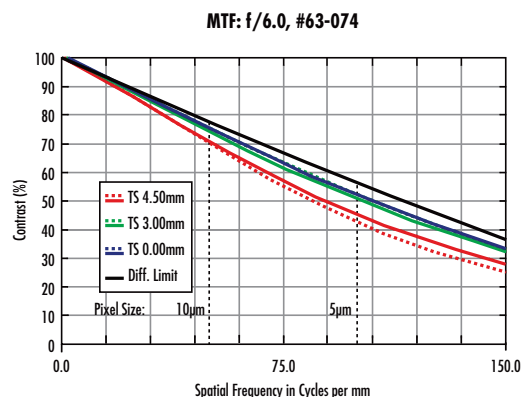


Primary Magnification:	0.40X
Maximum Camera Sensor Format:	1/1.8"
Field of View, 1/2" Sensor:	16mm
Field of View, 1/8" Sensor:	12mm
Working Distance (±3mm):	103mm
Depth of Field (20 lp/mm, f/10):	±3.0mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.033
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.015°
Typical Distortion @ 588nm:	<0.020%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	4 (7)
Lens Mount:	C-Mount
Weight:	290g
Stock No. / Price	#56-677 \$975.00
Color Filter - Red / Price	#89-829 \$160.00
Color Filter - Green / Price	#89-789 \$175.00
Color Filter - Blue / Price	#89-769 \$175.00
UV/Protective Filter / Price	#89-799 \$160.00
Linear Polarizing Filter / Price	#52-558 \$35.00

Call For OEM Quantity Pricing



SilverTL™ Telecentric Lenses



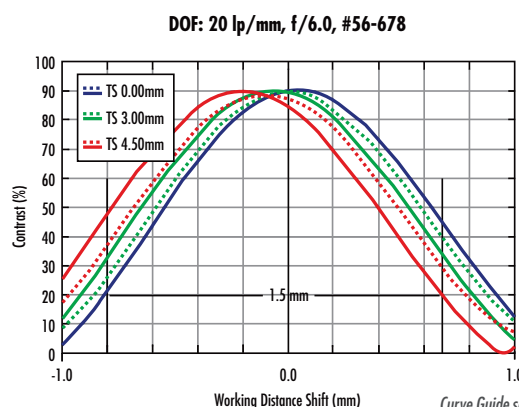
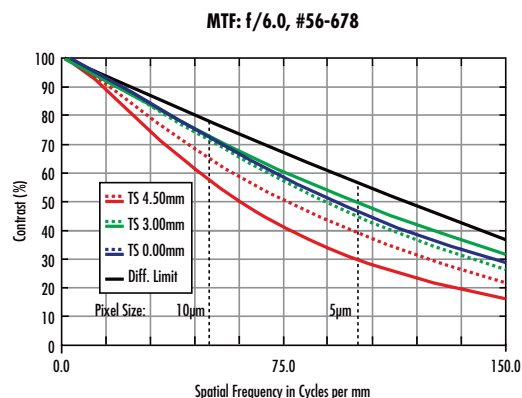
Curve Guide see page 12



0.50X
1/1.8" Format

Primary Magnification:	0.50X
Maximum Camera Sensor Format:	1/1.8"
Field of View, 1/2" Sensor:	12.8mm
Field of View, 1/3" Sensor:	9.6mm
Working Distance (±3mm):	120mm
Depth of Field (20 lp/mm, f/10):	±2.1mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.041
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.012°
Typical Distortion @ 588nm:	<0.200%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	6 (5)
Lens Mount:	C-Mount
Weight:	300g
Standard Stock No. / Price	#63-074 / \$895.00
In-Line Stock No. / Price	#88-344 / \$1,695.00
Color Filter - Red / Price	#58-642 / \$47.50
Color Filter - Green / Price	#58-643 / \$47.50
Color Filter - Blue / Price	#58-644 / \$47.50
UV/Protective Filter / Price	#54-039 / \$30.00
Linear Polarizing Filter / Price	#52-556 / \$33.00

Call For OEM Quantity Pricing



Curve Guide see page 12



0.60X
1/1.8" Format

Primary Magnification:	0.60X
Maximum Camera Sensor Format:	1/1.8"
Field of View, 1/2" Sensor:	10.7mm
Field of View, 1/3" Sensor:	8mm
Working Distance (±3mm):	103mm
Depth of Field (20 lp/mm, f/10):	±1.4mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.05
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.007°
Typical Distortion @ 588nm:	<0.035%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	7 (4)
Lens Mount:	C-Mount
Weight:	250g
Stock No. / Price	#56-678 / \$975.00
Color Filter - Red / Price	#89-828 / \$155.00
Color Filter - Green / Price	#89-788 / \$170.00
Color Filter - Blue / Price	#89-768 / \$170.00
UV/Protective Filter / Price	#89-798 / \$155.00
Linear Polarizing Filter / Price	#53-999 / \$35.00

Call For OEM Quantity Pricing

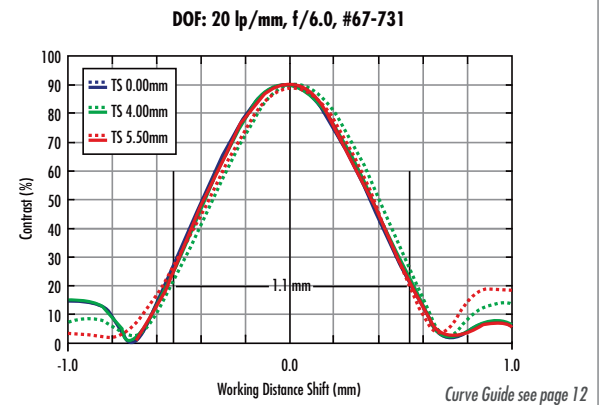
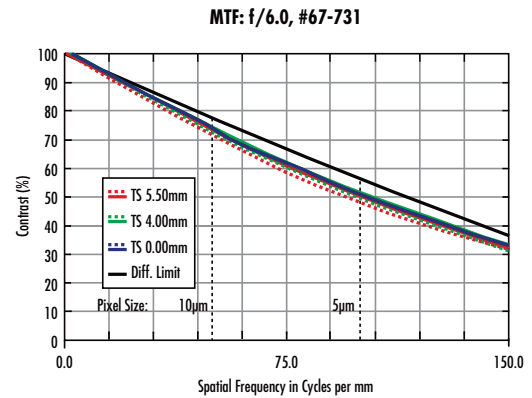
SilverTL™ Telecentric Lenses

0.75X
2/3" Format



Primary Magnification:	0.75X
Maximum Camera Sensor Format:	2/3"
Field of View, 1/2" Sensor:	8.5mm
Field of View, 1/3" Sensor:	6.4mm
Working Distance (±3mm):	100mm
Depth of Field (20 lp/mm, f/10):	±0.8mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.062
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.080°
Typical Distortion @ 588nm:	<0.080%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	6 (4)
Lens Mount:	C-Mount
Weight:	250g
Standard Stock No. / Price	#67-731 / \$895.00
In-Line Stock No. / Price	#88-346 / \$1,695.00
Color Filter - Red / Price	#89-825 / \$125.00
Color Filter - Green / Price	#89-785 / \$135.00
Color Filter - Blue / Price	#89-765 / \$135.00
UV/Protective Filter / Price	#89-795 / \$125.00
Linear Polarizing Filter / Price	#46-574 / \$31.00

Call For OEM Quantity Pricing

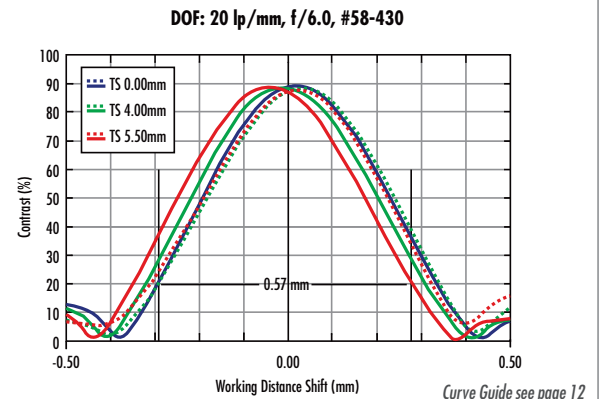
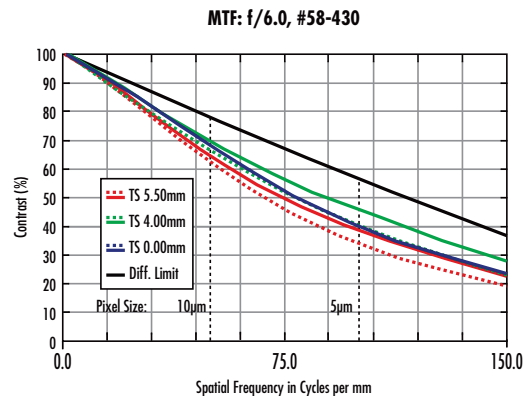


1.0X
2/3" Format

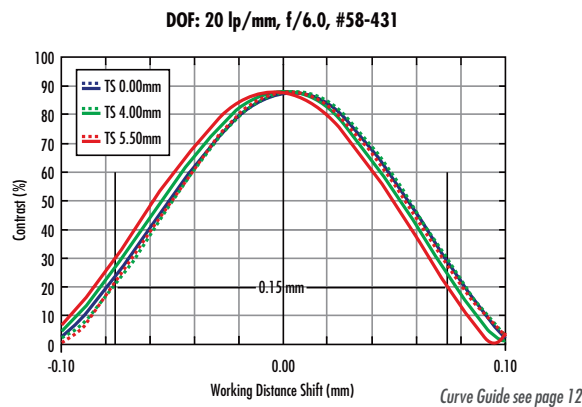
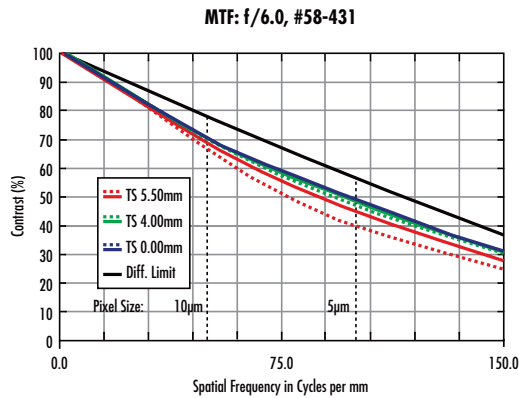


Primary Magnification:	1.0X
Maximum Camera Sensor Format:	2/3"
Field of View, 1/2" Sensor:	6.4mm
Field of View, 1/3" Sensor:	4.8mm
Working Distance (±3mm):	83mm
Depth of Field (20 lp/mm, f/10):	±0.5mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.082
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.045°
Typical Distortion @ 588nm:	<0.060%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	6 (5)
Lens Mount:	C-Mount
Weight:	190g
Stock No. / Price	#58-430 / \$975.00
Color Filter - Red / Price	#58-642 / \$47.50
Color Filter - Green / Price	#58-643 / \$47.50
Color Filter - Blue / Price	#58-644 / \$47.50
UV/Protective Filter / Price	#54-039 / \$30.00
Linear Polarizing Filter / Price	#52-556 / \$33.00

Call For OEM Quantity Pricing



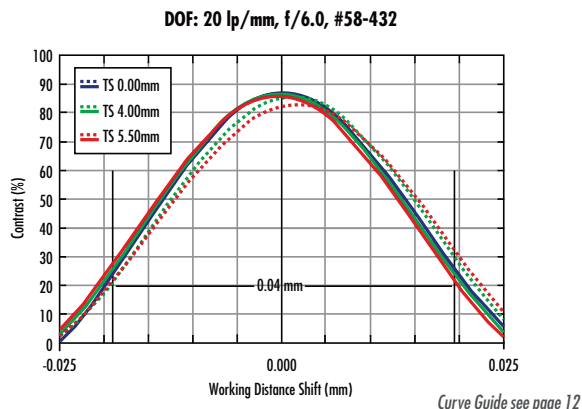
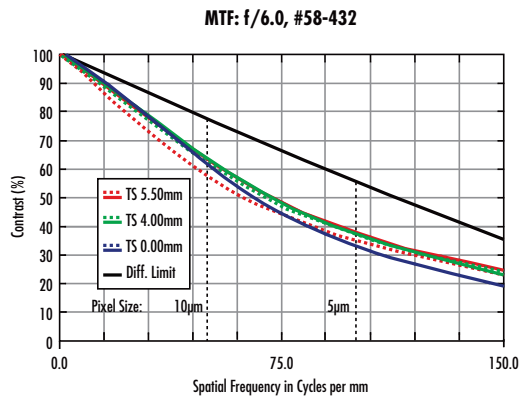
SilverTL™ Telecentric Lenses



2.0X
2/3" Format

Primary Magnification:	2.0X
Maximum Camera Sensor Format:	2/3"
Field of View, 1/2" Sensor:	3.2mm
Field of View, 1/3" Sensor:	2.4mm
Working Distance (±3mm):	75mm
Depth of Field (20 lp/mm, f/10):	±0.13mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.164
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.075°
Typical Distortion @ 588nm:	<0.040%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	7 (6)
Lens Mount:	C-Mount
Weight:	350g
Standard Stock No. / Price	#58-431 / \$995.00
In-Line Stock No. / Price	#88-348 / \$1,895.00
Color Filter - Red / Price	#89-829 / \$160.00
Color Filter - Green / Price	#89-789 / \$175.00
Color Filter - Blue / Price	#89-769 / \$175.00
UV/Protective Filter / Price	#89-799 / \$160.00
Linear Polarizing Filter / Price	#52-558 / \$35.00

Call For OEM Quantity Pricing



4.0X
2/3" Format

Primary Magnification:	4.0X
Maximum Camera Sensor Format:	2/3"
Field of View, 1/2" Sensor:	1.6mm
Field of View, 1/3" Sensor:	1.2mm
Working Distance (±3mm):	44mm
Depth of Field (20 lp/mm, f/10):	±0.03mm @ 20%
Aperture (f/#):	f/6 - Closed
Numerical Aperture NA, Object Side:	0.32
Resolution, Image Space MTF @ f/10:	40 lp/mm @ >40%
Typical Telecentricity @ 588nm:	<0.050°
Typical Distortion @ 588nm:	<0.060%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	8 (7)
Lens Mount:	C-Mount
Weight:	850g
Stock No. / Price	#58-432 / \$1,250.00
Color Filter - Red / Price	#54-765 / \$47.50
Color Filter - Green / Price	#54-771 / \$47.50
Color Filter - Blue / Price	#54-777 / \$47.50
UV/Protective Filter / Price	#54-046 / \$33.00
Linear Polarizing Filter / Price	#36-443 / \$39.00

Call For OEM Quantity Pricing

CompactTL™ Telecentric Lenses



- Ultra-Compact Design
- Ideal for Volume Inspection Applications
- In-line Illumination Versions Available for Maximum Versatility
- High Performance at Competitive Price for Inspection Applications
- Feature Fixed Iris and Focus to Maintain Stability in Factory or Assembly Applications

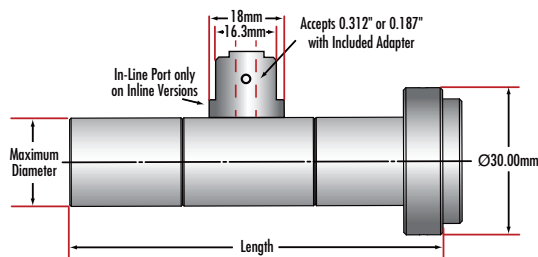


Volume pricing and **customization** available. An EO-designed and manufactured family.



DIMENSIONS

Working Distance (mm)	Primary Magnification	Maximum Diameter (mm)	Length (mm)	
			Standard Model	In-Line Model
40	1X	18	50	53.5
40	2X	18	37	40
40	3X	18	48	52.3
40	4X	18	47.1	50.3
65	0.5X	32	86.7	90
65	0.8X	22	86.5	89.9
65	1X	18	76.1	79.5
65	2X	18	76.5	79.9
65	3X	18	76.3	79.4
65	4X	18	81	84.4
65	6X	18	116.1	119.5
65	8X	18	100	103.7
110	0.5X	40	166.6	170
110	0.75X	29.5	156.2	160
110	1X	22	106.6	110
110	2X	18	126.6	130
110	3X	18	100	103.6
220	1X	36	162.5	164.7
300	1X	36	174.5	177.3
300	2X	31	198.9	202.3



TECHSPEC® COMPACT TELECENTRIC LENS ACCESSORIES

Type	Compatible Diameter Telecentric	Note	Stock No.	Price 1-5	6 to 10	11+
M25.5 x 0.5 Filter Adapter	18mm	—	#88-212	\$29.50	\$25.00	Call
M25.5 x 0.5 Filter Adapter	22mm	—	#88-213	\$29.50	\$25.00	
Right Angle Adapter	18mm	21.2mm Distance from Input to Output	#88-215	\$120.00	\$102.00	

CompactTL™ Telecentric Lenses



40mm WD
1X

Primary Magnification:	1X	
Working Distance (±1mm):	40mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	8.8mm	
Field of View, 1/2" Sensor:	6.4mm	
Field of View, 1/3" Sensor:	4.8mm	
Depth of Field (20% @ 20 lp/mm):	±0.5mm	
Aperture (f/#):	f/11	
Numerical Aperture NA, Object Side:	0.045	
Typical Telecentricity @ 588nm:	<0.035°	
Typical Distortion @ 588nm:	<0.002%	
Number of Elements (Groups):	5 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	31g	
Standard Stock No. / Price	#63-745	\$525.00
In-Line Stock No. / Price	#67-319	\$925.00

Call For OEM Quantity Pricing



40mm WD
2X

Primary Magnification:	2X	
Working Distance (±1mm):	40mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	4.4mm	
Field of View, 1/2" Sensor:	3.2mm	
Field of View, 1/3" Sensor:	2.4mm	
Depth of Field (20% @ 20 lp/mm):	±0.17mm	
Aperture (f/#):	f/14.3	
Numerical Aperture NA, Object Side:	0.069	
Typical Telecentricity @ 588nm:	<0.090°	
Typical Distortion @ 588nm:	<0.140%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	30g	
Standard Stock No. / Price	#63-746	\$550.00
In-Line Stock No. / Price	#67-320	\$950.00

Call For OEM Quantity Pricing



40mm WD
3X

Primary Magnification:	3X	
Working Distance (±1mm):	40mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	2.9mm	
Field of View, 1/2" Sensor:	2.1mm	
Field of View, 1/3" Sensor:	1.6mm	
Depth of Field (20% @ 20 lp/mm):	±0.08mm	
Aperture (f/#):	f/16	
Numerical Aperture NA, Object Side:	0.093	
Typical Telecentricity @ 588nm:	<0.075°	
Typical Distortion @ 588nm:	<0.200%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	32g	
Standard Stock No. / Price	#63-747	\$575.00
In-Line Stock No. / Price	#67-321	\$975.00

Call For OEM Quantity Pricing



40mm WD
4X

Primary Magnification:	4X	
Working Distance (±1mm):	40mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	2.2mm	
Field of View, 1/2" Sensor:	1.6mm	
Field of View, 1/3" Sensor:	1.2mm	
Depth of Field (20% @ 20 lp/mm):	±0.05mm	
Aperture (f/#):	f/20	
Numerical Aperture NA, Object Side:	0.099	
Typical Telecentricity @ 588nm:	<0.065°	
Typical Distortion @ 588nm:	<0.180%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	60g	
Standard Stock No. / Price	#63-748	\$595.00
In-Line Stock No. / Price	#67-322	\$995.00

Call For OEM Quantity Pricing

CompactTL™ Telecentric Lenses

0.5X
65mm WD



Primary Magnification:	0.5X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	17.6mm	
Field of View, 1/2" Sensor:	12.8mm	
Field of View, 1/3" Sensor:	9.6mm	
Depth of Field (20% @ 20 lp/mm):	±1.85mm	
Aperture (f/#):	f/9	
Numerical Aperture NA, Object Side:	0.028	
Typical Telecentricity @ 588nm:	<0.035°	
Typical Distortion @ 588nm:	<0.025%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	74g	
Standard Stock No. / Price	#63-741	\$625.00
In-Line Stock No. / Price	#67-310	\$995.00

Call For OEM Quantity Pricing

0.8X
65mm WD



Primary Magnification:	0.8X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	11mm	
Field of View, 1/2" Sensor:	8mm	
Field of View, 1/3" Sensor:	6mm	
Depth of Field (20% @ 20 lp/mm):	±1.2mm	
Aperture (f/#):	f/14.9	
Numerical Aperture NA, Object Side:	0.027	
Typical Telecentricity @ 588nm:	<0.065°	
Typical Distortion @ 588nm:	<0.004%	
Number of Elements (Groups):	4 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	42g	
Standard Stock No. / Price	#63-742	\$625.00
In-Line Stock No. / Price	#67-311	\$995.00

Call For OEM Quantity Pricing

1X
65mm WD



Primary Magnification:	1X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	8.8mm	
Field of View, 1/2" Sensor:	6.4mm	
Field of View, 1/3" Sensor:	4.8mm	
Depth of Field (20% @ 20 lp/mm):	±0.9mm	
Aperture (f/#):	f/18.6	
Numerical Aperture NA, Object Side:	0.027	
Typical Telecentricity @ 588nm:	<0.035°	
Typical Distortion @ 588nm:	<0.050%	
Number of Elements (Groups):	4 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	45g	
Standard Stock No. / Price	#63-733	\$525.00
In-Line Stock No. / Price	#67-312	\$925.00

Call For OEM Quantity Pricing

2X
65mm WD



Primary Magnification:	2X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	4.4mm	
Field of View, 1/2" Sensor:	3.2mm	
Field of View, 1/3" Sensor:	2.4mm	
Depth of Field (20% @ 20 lp/mm):	±0.23mm	
Aperture (f/#):	f/17.3	
Numerical Aperture NA, Object Side:	0.058	
Typical Telecentricity @ 588nm:	<0.100°	
Typical Distortion @ 588nm:	<0.065%	
Number of Elements (Groups):	5 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	45g	
Standard Stock No. / Price	#63-734	\$550.00
In-Line Stock No. / Price	#67-313	\$950.00

Call For OEM Quantity Pricing

CompactTL™ Telecentric Lenses



65mm WD
3X

Primary Magnification:	3X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	2.9mm	
Field of View, 1/2" Sensor:	2.1mm	
Field of View, 1/3" Sensor:	1.6mm	
Depth of Field (20% @ 20 lp/mm):	±0.12mm	
Aperture (f/#):	f/21.9	
Numerical Aperture NA, Object Side:	0.068	
Typical Telecentricity @ 588nm:	<0.075°	
Typical Distortion @ 588nm:	<0.080%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	45g	
Standard Stock No. / Price	#63-735	\$575.00
In-Line Stock No. / Price	#67-314	\$975.00

Call For OEM Quantity Pricing



65mm WD
4X

Primary Magnification:	4X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	2.2mm	
Field of View, 1/2" Sensor:	1.6mm	
Field of View, 1/3" Sensor:	1.2mm	
Depth of Field (20% @ 20 lp/mm):	±0.09mm	
Aperture (f/#):	f/27	
Numerical Aperture NA, Object Side:	0.074	
Typical Telecentricity @ 588nm:	<0.016°	
Typical Distortion @ 588nm:	<0.007%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	50g	
Standard Stock No. / Price	#63-736	\$595.00
In-Line Stock No. / Price	#67-315	\$995.00

Call For OEM Quantity Pricing



65mm WD
6X

Primary Magnification:	6X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	1.5mm	
Field of View, 1/2" Sensor:	1.1mm	
Field of View, 1/3" Sensor:	0.8mm	
Depth of Field (20% @ 20 lp/mm):	±0.05mm	
Aperture (f/#):	f/35	
Numerical Aperture NA, Object Side:	0.085	
Typical Telecentricity @ 588nm:	<0.075°	
Typical Distortion @ 588nm:	<0.025%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	60g	
Standard Stock No. / Price	#63-743	\$625.00
In-Line Stock No. / Price	#67-316	\$995.00

Call For OEM Quantity Pricing



65mm WD
8X

Primary Magnification:	8X	
Working Distance (±1mm):	65mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	1.1mm	
Field of View, 1/2" Sensor:	0.8mm	
Field of View, 1/3" Sensor:	0.6mm	
Depth of Field (20% @ 20 lp/mm):	±0.03mm	
Aperture (f/#):	f/45	
Numerical Aperture NA, Object Side:	0.088	
Typical Telecentricity @ 588nm:	<0.065°	
Typical Distortion @ 588nm:	<0.160%	
Number of Elements (Groups):	6 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	42g	
Standard Stock No. / Price	#63-744	\$675.00
In-Line Stock No. / Price	#67-317	\$1,050.00

Call For OEM Quantity Pricing

CompactTL™ Telecentric Lenses

0.5X
110mm WD



Primary Magnification:	0.5X	
Working Distance (±1mm):	110mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	17.6mm	
Field of View, 1/2" Sensor:	12.8mm	
Field of View, 1/3" Sensor:	9.6mm	
Depth of Field (20% @ 20 lp/mm):	±1.9mm	
Aperture (f/#):	f/9.3	
Numerical Aperture NA, Object Side:	0.027	
Typical Telecentricity @ 588nm:	<0.250°	
Typical Distortion @ 588nm:	<0.050%	
Number of Elements (Groups):	4 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	182g	
Standard Stock No. / Price	#63-729	\$625.00
In-Line Stock No. / Price	#67-303	\$995.00

Call For OEM Quantity Pricing

0.75X
110mm WD



Primary Magnification:	0.75X	
Working Distance (±1mm):	110mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	11.7mm	
Field of View, 1/2" Sensor:	8.5mm	
Field of View, 1/3" Sensor:	6.4mm	
Depth of Field (20% @ 20 lp/mm):	±1.2mm	
Aperture (f/#):	f/13.3	
Numerical Aperture NA, Object Side:	0.028	
Typical Telecentricity @ 588nm:	<0.100°	
Typical Distortion @ 588nm:	<0.020%	
Number of Elements (Groups):	4 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	104g	
Standard Stock No. / Price	#63-730	\$625.00
In-Line Stock No. / Price	#67-304	\$995.00

Call For OEM Quantity Pricing

1X
110mm WD



Primary Magnification:	1X	
Working Distance (±1mm):	110mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	8.8mm	
Field of View, 1/2" Sensor:	6.4mm	
Field of View, 1/3" Sensor:	4.8mm	
Depth of Field (20% @ 20 lp/mm):	±1.2mm	
Aperture (f/#):	f/20.9	
Numerical Aperture NA, Object Side:	0.024	
Typical Telecentricity @ 588nm:	<0.090°	
Typical Distortion @ 588nm:	<0.040%	
Number of Elements (Groups):	4 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	55g	
Standard Stock No. / Price	#63-731	\$525.00
In-Line Stock No. / Price	#67-305	\$925.00

Call For OEM Quantity Pricing

2X
110mm WD



Primary Magnification:	2X	
Working Distance (±1mm):	110mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	4.4mm	
Field of View, 1/2" Sensor:	3.2mm	
Field of View, 1/3" Sensor:	2.4mm	
Depth of Field (20% @ 20 lp/mm):	±0.49mm	
Aperture (f/#):	f/33	
Numerical Aperture NA, Object Side:	0.03	
Typical Telecentricity @ 588nm:	<0.075°	
Typical Distortion @ 588nm:	<0.045%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	60g	
Standard Stock No. / Price	#63-732	\$575.00
In-Line Stock No. / Price	#67-306	\$975.00

Call For OEM Quantity Pricing

CompactTL™ Telecentric Lenses



110mm WD
3X

Primary Magnification:	3X	
Working Distance (±1mm):	110mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	2.9mm	
Field of View, 1/2" Sensor:	2.1mm	
Field of View, 1/3" Sensor:	1.6mm	
Depth of Field (20% @ 20 lp/mm):	±0.18mm	
Aperture (f/#):	f/35	
Numerical Aperture NA, Object Side:	0.043	
Typical Telecentricity @ 588nm:	<0.065°	
Typical Distortion @ 588nm:	<0.160%	
Number of Elements (Groups):	5 (3)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	51g	
Standard Stock No. / Price	#63-738	\$625.00
In-Line Stock No. / Price	#67-307	\$995.00

Call For OEM Quantity Pricing



220mm WD
1X

Primary Magnification:	1X	
Working Distance (±1mm):	220mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	8.8mm	
Field of View, 1/2" Sensor:	6.4mm	
Field of View, 1/3" Sensor:	4.8mm	
Depth of Field (20% @ 20 lp/mm):	±0.6mm	
Aperture (f/#):	f/11	
Numerical Aperture NA, Object Side:	0.044	
Typical Telecentricity @ 588nm:	<0.03°	
Typical Distortion @ 588nm:	<0.03%	
Number of Elements (Groups):	5 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	135g	
Standard Stock No. / Price	#33-096	\$725.00
In-Line Stock No. / Price	#33-110	\$1,095.00

Call For OEM Quantity Pricing



300mm WD
1X

Primary Magnification:	1X	
Working Distance (±1mm):	300mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	8.8mm	
Field of View, 1/2" Sensor:	6.4mm	
Field of View, 1/3" Sensor:	4.8mm	
Depth of Field (20% @ 20 lp/mm):	±0.75mm	
Aperture (f/#):	f/14.3	
Numerical Aperture NA, Object Side:	0.035	
Typical Telecentricity @ 588nm:	<0.07°	
Typical Distortion @ 588nm:	<0.02%	
Number of Elements (Groups):	5 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	140g	
Standard Stock No. / Price	#33-100	\$725.00
In-Line Stock No. / Price	#33-114	\$1,095.00

Call For OEM Quantity Pricing



300mm WD
2X

Primary Magnification:	2X	
Working Distance (±1mm):	300mm	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	4.4mm	
Field of View, 1/2" Sensor:	3.2mm	
Field of View, 1/3" Sensor:	2.4mm	
Depth of Field (20% @ 20 lp/mm):	±0.3mm	
Aperture (f/#):	f/28.5	
Numerical Aperture NA, Object Side:	0.035	
Typical Telecentricity @ 588nm:	<0.06°	
Typical Distortion @ 588nm:	<0.03%	
Number of Elements (Groups):	5 (4)	
Coating:	1/4 MgF ₂ @ 550nm	
Lens Mount:	C-Mount	
Weight (Standard Model):	120g	
Standard Stock No. / Price	#33-101	\$725.00
In-Line Stock No. / Price	#33-115	\$1,095.00

Call For OEM Quantity Pricing

PlatinumTL™ Telecentric Lenses

- Supports up to 28.7mm Max. Diagonal Sensors
- Superior Light Collecting f/6 Designs
- Double Telecentric Design Eliminates Illumination Roll-Off and Increases Accuracy
- Locking Iris Prevents Unintentional Lens Adjustments
- Ideal for Precise Measurement and Gauging



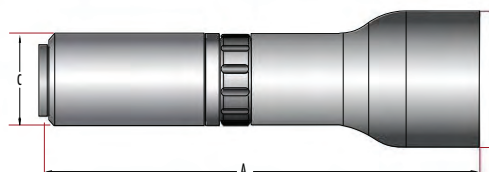
Volume pricing and customization available. An EO-designed and manufactured family.



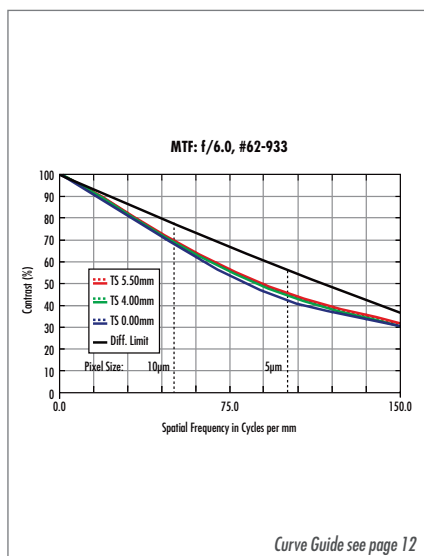
TECHSPEC® PlatinumTL™ TELECENTRIC LENS DIMENSIONS												
Magnification:	0.28X, Large Format				0.5X, Large Format				0.9X, Large Format			
Mount:	C-Mount	F-Mount	M42 x 1.0	M42 x 1.0	C-Mount	F-Mount	M42 x 1.0	M42 x 1.0	C-Mount	F-Mount	M42 x 1.0	M42 x 1.0
Stock No.	#62-921	#62-922	#62-923	#62-924	#62-911	#62-912	#62-913	#62-914	#62-901	#62-902	#62-903	#62-904
Length (A) (mm):	197.5	167.6	208.5	195.5	172.9	143	184	171.1	199.8	170.8	210.7	197.8
Front Diameter (B) (mm):	138.6	138.6	138.6	138.6	90	90	90	90	65	65	65	65
Back Diameter (C) (mm):	50	55	50	50	50	55	50	50	53	55	53	53
Filter Thread:	M132 x 0.75	M132 x 0.75	M132 x 0.75	M132 x 0.75	M86 x 1.0	M86 x 1.0	M86 x 1.0	M86 x 1.0	M62 x 0.75	M62 x 0.75	M62 x 0.75	M62 x 0.75
Mounting Clamp:	#63-440	#63-440	#63-440	#63-440	#63-441	#63-441	#63-441	#63-441	#56-025	#56-025	#56-025	#56-025
Mounting Clamp Price:	\$350.00	\$350.00	\$350.00	\$350.00	\$295.00	\$295.00	\$295.00	\$295.00	\$195.00	\$195.00	\$195.00	\$195.00

TECHSPEC® PlatinumTL™ TELECENTRIC LENS DIMENSIONS					
Magnification:	0.28X, 3/8"	0.5X, 1/2"	1.7X, 3/4"	0.367X, 1"	0.55X, 1"
Mount:	C-Mount	C-Mount	C-Mount	C-Mount	C-Mount
Stock No.	#62-933	#62-932	#63-232	#88-602	#88-603
Length (A) (mm):	203.8	174.9	189.5	163.5	182.5
Front Diameter (B) (mm):	60.5	50	60	70	62
Back Diameter (C) (mm):	33.5	33.5	46	43.5	43.5
Filter Thread:	M58 x 0.75	M46 x 0.75	M58 x 0.75	M67 x 0.75	M58 x 0.75
Mounting Clamp:	#63-442	#63-442	#63-233	#89-721	#89-721
Mounting Clamp Price:	\$295.00	\$295.00	\$195.00	\$175.00	\$175.00

TECHSPEC® PlatinumTL™ Telecentric Lenses



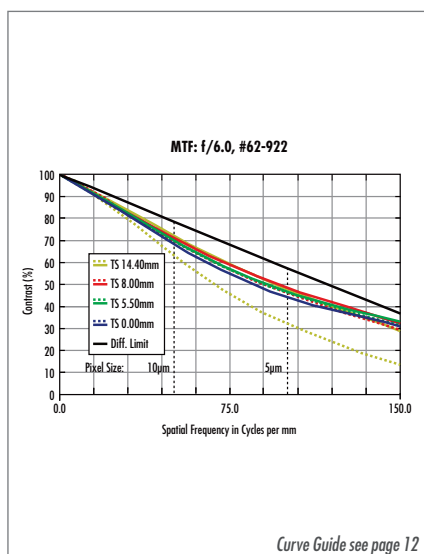
PlatinumTL™ Telecentric Lenses



Primary Magnification:	0.28X, $\frac{2}{3}$"
Maximum Camera Sensor Format:	$\frac{2}{3}$ "
Field of View, $\frac{2}{3}$" Sensor:	31.8mm
Field of View, $\frac{1}{2}$" Sensor:	23.1mm
Working Distance:	180mm
Depth of Field (20 lp/mm, f/10):	± 6.9 mm @ 20%
Aperture (f/#):	f/6 - f/22
Numerical Aperture NA, Object Side:	0.023
Resolution (@72 lp/mm, Full Field):	>40%
Typical Telecentricity @ 588nm:	<0.030°
Typical Distortion @ 588nm:	<0.006%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	<400g
C-Mount (17.5mm Flange) / Price	#62-933 \$1,995.00
Color Filter - Red / Price	#54-765 \$47.50
Color Filter - Green / Price	#54-771 \$47.50
Color Filter - Blue / Price	#54-777 \$47.50
UV Protective Filter / Price	#54-046 \$33.00
Linear Polarizing Filter / Price	#36-443 \$39.00
Call For OEM Quantity Pricing	



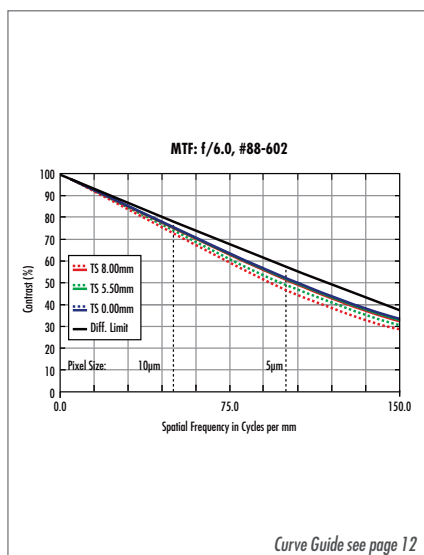
0.28X
 $\frac{2}{3}$ " Format



Primary Magnification:	0.28X, Large Format
Maximum Camera Sensor Format:	28.7mm*
Field of View, 28.7mm Sensor:	103.6mm
Field of View, $\frac{4}{3}$" Sensor:	65.3mm
Field of View, $\frac{2}{3}$" Sensor:	31.8mm
Working Distance:	182mm
Depth of Field (20 lp/mm, f/10):	± 6.9 mm @ 20%
Aperture (f/#):	f/6 - f/22
Numerical Aperture NA, Object Side:	0.023
Resolution (@72 lp/mm, Full Field):	>40%
Typical Telecentricity @ 588nm:	<0.035°
Typical Distortion @ 588nm:	<0.012%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	<2812g
C-Mount (17.5mm Flange)* / Price	#62-921 \$4,995.00
F-Mount (46.5mm Flange) / Price	#62-922 \$4,995.00
M42 x 1.0 (19.53mm Flange) / Price	#62-924 \$4,995.00
M42 x 1.0 (6.56mm Flange) / Price	#62-923 \$4,995.00
Call For OEM Quantity Pricing	



0.28X
28.7mm Format



Primary Magnification:	0.367X, 1"
Maximum Camera Sensor Format:	1"
Field of View, 1" Sensor (mm):	34.9mm
Field of View, $\frac{2}{3}$" Sensor:	24mm
Working Distance:	169mm
Depth of Field (20 lp/mm, f/10):	± 2.3 mm @ 20%
Aperture (f/#):	f/6 - f/16
Numerical Aperture NA, Object Side:	0.017
Resolution (@72 lp/mm, Full Field):	>40%
Typical Telecentricity @ 588nm:	<0.035°
Typical Distortion @ 588nm:	<0.003%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	660g
C-Mount (17.5mm Flange) / Price	#88-602 \$1,995.00
UV Protective Filter / Price	#46-578 \$41.00
Linear Polarizing Filter / Price	#64-900 \$43.00
Call For OEM Quantity Pricing	



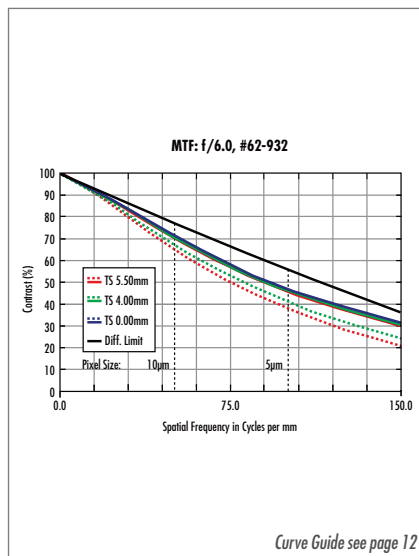
0.367X
1" Format

PlatinumTL™ Telecentric Lenses

0.5X
2/3" Format



Primary Magnification:	0.5X, 2/3"
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	17.7mm
Field of View, 1/2" Sensor:	12.9mm
Working Distance:	173mm
Depth of Field (20 lp/mm, f/10):	±2.1mm @ 20%
Aperture (f/#):	f/6 - f/22
Numerical Aperture NA, Object Side:	0.041
Resolution (@72 lp/mm, Full Field):	>40%
Typical Telecentricity @ 588nm:	<0.050°
Typical Distortion @ 588nm:	<0.006%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	430g
C-Mount (17.5mm Flange) / Price	#62-932 \$1,495.00
Color Filter - Red / Price	#54-762 \$47.50
Color Filter - Green / Price	#54-768 \$47.50
Color Filter - Blue / Price	#46-571 \$47.50
UV Protective Filter / Price	#54-041 \$31.00
Linear Polarizing Filter / Price	#36-439 \$36.00
Call For OEM Quantity Pricing	

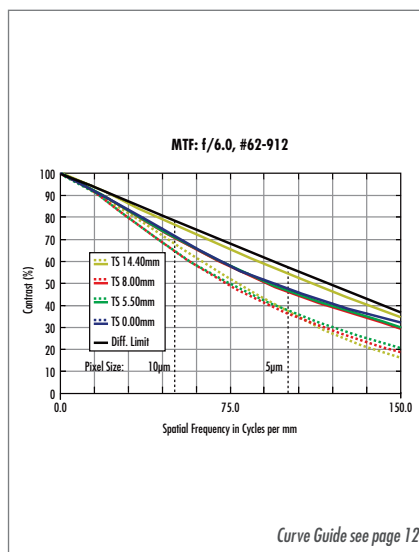


0.5X
28.7mm Format



Primary Magnification:	0.5X, Large Format
Maximum Camera Sensor Format:	28.7mm*
Field of View, 28.7mm Sensor:	57.75mm
Field of View, 2/3" Sensor:	36.42mm
Field of View, 1/2" Sensor:	17.7mm
Working Distance:	175mm
Depth of Field (20 lp/mm, f/10):	±2.05mm @ 20%
Aperture (f/#):	f/6 - f/22
Numerical Aperture NA, Object Side:	0.041
Resolution (@72 lp/mm, Full Field):	>45%
Typical Telecentricity @ 588nm:	<0.055°
Typical Distortion @ 588nm:	<0.020%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	<1070g
C-Mount (17.5mm Flange)* / Price	#62-911 \$2,295.00
F-Mount (46.5mm Flange) / Price	#62-912 \$2,795.00
M42 x 1.0 (19.53mm Flange) / Price	#62-914 \$2,795.00
M42 x 1.0 (6.56mm Flange) / Price	#62-913 \$2,795.00
UV Protective Filter / Price	#64-895 \$95.00
Linear Polarizing Filter / Price	#64-902 \$120.00
Call For OEM Quantity Pricing	

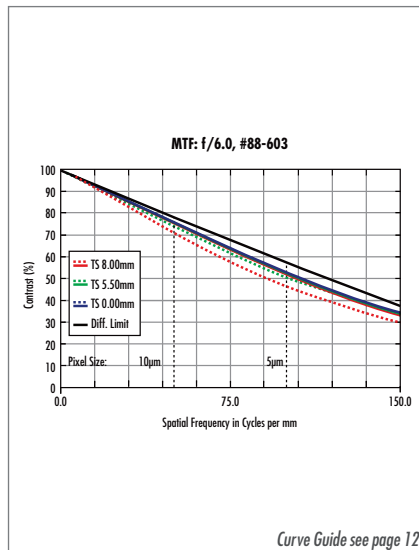
*C-Mount Version is 1" Max Format



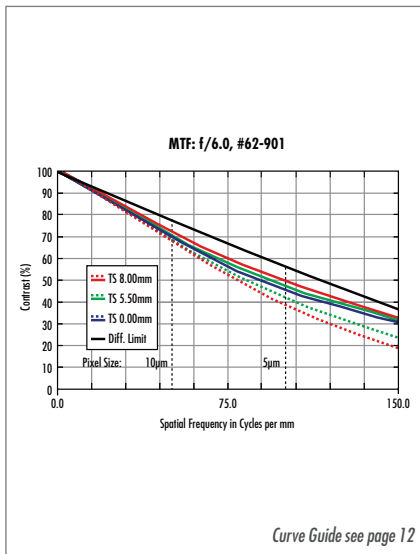
0.55X
1" Format



Primary Magnification:	0.55X, 1"
Maximum Camera Sensor Format:	1"
Field of View, 1" Sensor (mm):	23.3mm
Field of View, 2/3" Sensor:	16mm
Working Distance:	150mm
Depth of Field (20 lp/mm, f/10):	±2.6mm @ 20%
Aperture (f/#):	f/6 - f/16
Numerical Aperture NA, Object Side:	0.018
Resolution (@72 lp/mm, Full Field):	>40%
Typical Telecentricity @ 588nm:	<0.030°
Typical Distortion @ 588nm:	<0.007%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	650g
C-Mount (17.5mm Flange)	#88-603 \$1,995.00
Color Filter - Red / Price	#54-765 \$47.50
Color Filter - Green / Price	#54-771 \$47.50
UV Protective Filter / Price	#54-046 \$33.00
Linear Polarizing Filter / Price	#36-443 \$39.00
IR Cut-off Filter (KG-3) / Price	#54-747 \$185.00
UV/IR-Cut Filter / Price	#54-751 \$205.00
UV/VIS-Cut Filter (R-72) / Price	#54-754 \$87.50
Call For OEM Quantity Pricing	



PlatinumTL™ Telecentric Lenses



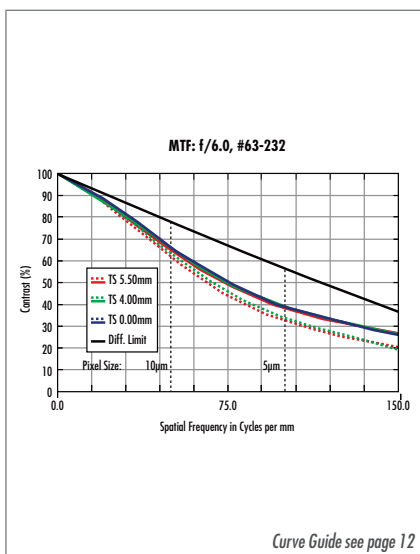
Primary Magnification:	0.9X, Large Format
Maximum Camera Sensor Format:	28.7mm"
Field of View, 28.7mm Sensor:	31.9mm
Field of View, 1/8" Sensor:	20.1mm
Field of View, 1/4" Sensor:	9.8mm
Working Distance:	111mm
Depth of Field (20 lp/mm, f/10):	±0.65mm @ 20%
Aperture (f/#):	f/6 - f/22
Numerical Aperture NA, Object Side:	0.045
Resolution (@72 lp/mm, Full Field):	>40%
Typical Telecentricity @ 588nm:	<0.070°
Typical Distortion @ 588nm:	<0.035%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	<400g
C-Mount (17.5mm Flange) / Price	#62-901 \$1,995.00
F-Mount (46.5mm Flange) / Price	#62-902 \$2,295.00
M42 x 1.0 (19.53mm Flange) / Price	#62-904 \$2,295.00
M42 x 1.0 (6.56mm Flange) / Price	#62-903 \$2,295.00
Color Filter - Red / Price	#89-832 \$255.00
Color Filter - Green / Price	#89-792 \$285.00
Color Filter - Blue / Price	#89-772 \$285.00
UV Protective Filter / Price	#89-802 \$255.00
Linear Polarizing Filter / Price	#36-444 \$39.00

Call For OEM Quantity Pricing

*C-Mount Version is 1" Max Format



28.7mm Format
0.9X



Primary Magnification:	1.7X, 2/3"
Maximum Camera Sensor Format:	2/3"
Field of View, 2/3" Sensor:	5.2mm
Field of View, 1/2" Sensor:	3.8mm
Working Distance:	123mm
Depth of Field (20 lp/mm, f/10):	±0.18mm @ 20%
Aperture (f/#):	f/6 - f/22
Numerical Aperture NA, Object Side:	0.083
Resolution (@72 lp/mm, Full Field):	>25%
Typical Telecentricity @ 588nm:	<0.080°
Typical Distortion @ 588nm:	<0.020%
Coating:	425 - 675nm BBAR
Number of Elements (Groups):	10 (7)
Weight:	<700g
C-Mount (17.5mm Flange) / Price	#63-232 \$1,995.00
Color Filter - Red / Price	#54-765 \$47.50
Color Filter - Green / Price	#54-771 \$47.50
Color Filter - Blue / Price	#54-777 \$47.50
UV Protective Filter / Price	#54-046 \$33.00
Linear Polarizing Filter / Price	#36-443 \$39.00

Call For OEM Quantity Pricing



2/3" Format
1.7X

VIDEO RESOURCES

Join our imaging expert and Director of Machine Vision Solutions, Gregory Hollows, in the EO Imaging Lab as he reviews with you the most important concepts to know when designing or implementing a machine vision system.

- Over 2 Hours of Instruction
- Best Practices and Design Considerations

WWW.EDMUNDOPTICS.COM/IMAGING-LAB



TECHNICAL SUPPORT

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To make sure you never have a question go unanswered, we provide global technical support by telephone, e-mail, and chat. Our expert technical staff of engineers is available to answer your most challenging product and application questions. *Sunday, 8PM - Friday, 8PM, ET.

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800.363.1992 or 856.547.3488



Telecentric Lenses



- Telecentric and Non-Telecentric Designs with Selectable Field of View
- Adjustable Iris for Depth of Field Control
- Fixed Versions Available
- C-Mount Compatible Design with $\frac{2}{3}$ " Sensor Coverage to Ease System Integration
- Produce Low Distortion Images Ideal for Inspection Applications and Factory Automation

Note: Customized fixed versions are available to meet your volume requirements. Please contact technical support to discuss your specific requirements.

DOWNLOAD DATASHEETS

Volume pricing and customization available. An EO-designed and manufactured family.



SPECIFICATIONS

*Horizontal on $\frac{2}{3}$ " sensor

0.15X - 0.5X Non-Telecentric Lens, #87-536

PMAG	0.15X	0.2X	0.3X	0.4X	0.5X
WD (mm)	179.8	133.5	87.3	64	50
FOV (mm)*	58.7	44	29.3	22	17.6

0.5X - 1.0X Non-Telecentric Lens, #87-535

PMAG	0.5X	0.6X	0.7X	0.8X	0.9X	1.0X
WD (mm)	100.1	87.4	78.3	71.3	65.8	61.5
FOV (mm)*	17.6	14.67	12.6	11	9.78	8.8

For Imaging Filters, see page 123



SPECIFICATIONS

*Horizontal on $\frac{2}{3}$ " sensor

0.25X - 0.50X Telecentric Lens, #88-385

PMAG	0.25X	0.30X	0.35X	0.40X	0.45X	0.50X
WD (mm)	145	124.5	112	104	100.2	100.1
FOV (mm)*	35.2	29.3	25.1	22	19.6	17.6

0.5X - 1.0X Telecentric Lens, #88-386

PMAG	0.5X	0.6X	0.7X	0.8X	0.9X	1.0X
WD (mm)	115	106	102	100	100	100
FOV (mm)*	17.6	14.67	12.6	11	9.78	8.8

1.0X - 3.0X Telecentric Lens, #88-387

PMAG	1.0X	1.5X	2.0X	2.5X	3.0X
WD (mm)	71.6	61	55.6	52.4	50.3
FOV (mm)*	8.8	5.87	4.4	3.5	2.93

0.15X - 0.5X
 $\frac{2}{3}$ " Format
Non-Telecentric



Magnification:	0.15X - 0.5X Non-Telecentric	
Maximum Camera Sensor Format:	$\frac{2}{3}$ "	
Field of View, $\frac{2}{3}$ " Sensor:	58.7 - 17.6mm	
Working Distance:	179.8 - 50.0mm	
Resolution:	75 lp/mm @ >20%	
Aperture (f/#):	f/4 - f/22	
Typical Distortion @ 588nm:	<0.1%	
Filter Threading:	M25.5 x 0.5	
Lens Mount:	C-Mount	
Max. Diameter:	32mm	
Length:	59.5mm	
Stock No. / Price	#87-536	\$850.00
Call For OEM Quantity Pricing		

VariMagTL™ Telecentric Lenses

0.5X - 1.0X
2/3" Format
Non-Telecentric



0.25X - 0.5X
2/3" Format
Telecentric



0.5X - 1.0X
2/3" Format
Telecentric



1.0X - 3.0X
2/3" Format
Telecentric



Magnification:	0.5 - 1.0X Non-Telecentric	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	17.6 - 8.8mm	
Working Distance:	100.1 - 61.5mm	
Resolution:	75 lp/mm @ >20%	
Aperture (f/#):	f/4 - f/22	
Typical Distortion @ 588nm:	<0.1%	
Filter Threading:	M25.5 x 0.5	
Lens Mount:	C-Mount	
Max. Diameter:	30mm	
Length:	56.11 - 75.45mm	
Stock No. / Price	#87-535	\$850.00
0.5X Fixed Stock No. / Price	#87-531	\$750.00
0.75X Fixed Stock No. / Price	#87-532	\$750.00
1.0X Fixed Stock No. / Price	#87-533	\$750.00

Call For OEM Quantity Pricing

Magnification:	0.25X - 0.5X Telecentric	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	35.2 - 17.6mm	
Working Distance:	145 - 100.1mm	
Resolution:	75 lp/mm @ >20%	
Aperture (f/#):	f/6 - Closed	
Typical Telecentricity @ 588nm:	<0.1°	
Typical Distortion @ 588nm:	<0.1%	
Filter Threading:	M62 x 0.75	
Lens Mount:	C-Mount	
Max. Diameter:	65mm	
Overall Length:	177.9mm	
Stock No. / Price	#88-385	\$2,295.00

Call For OEM Quantity Pricing

Magnification:	0.5X - 1.0X Telecentric	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	17.6 - 8.8mm	
Working Distance:	115 - 100mm	
Resolution:	75 lp/mm @ >20%	
Aperture (f/#):	f/6 - Closed	
Typical Telecentricity @ 588nm:	<0.1°	
Typical Distortion @ 588nm:	<0.1%	
Filter Threading:	M40.5 x 0.5	
Lens Mount:	C-Mount	
Max. Diameter:	50.8mm	
Overall Length:	175.48mm	
Stock No. / Price	#88-386	\$1,495.00

Call For OEM Quantity Pricing

Magnification:	1.0X - 3.0X Telecentric	
Maximum Camera Sensor Format:	2/3"	
Field of View, 2/3" Sensor:	8.8 - 2.93mm	
Working Distance:	71.6 - 50.3mm	
Resolution:	75 lp/mm @ >20%	
Aperture (f/#):	f/6 - Closed	
Typical Telecentricity @ 588nm:	<0.1°	
Typical Distortion @ 588nm:	<0.1%	
Filter Threading:	M30.5 x 0.5	
Lens Mount:	C-Mount	
Max. Diameter:	48mm	
Overall Length:	90.1 - 153.7mm	
Stock No. / Price	#88-387	\$1,850.00
Replacement 2X - 3X Adapter	#89-409	\$45.00

Call For OEM Quantity Pricing

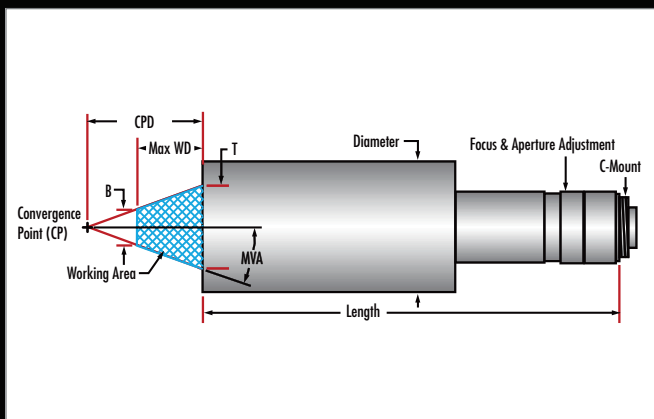


- Simultaneously Image Top and Sides of an Object
- Can Be Used as Long Working Distance Borescopes
- Ideal for Component Inspection

TECHSPEC® Hypercentric Lenses provide a converging view of an object, focusing on the top and surrounding sides simultaneously, and are used to eliminate the need for multiple camera and imaging lens setups in machine vision inspection or identification applications. TECHSPEC® Hypercentric Lenses are ideal for inspecting parts such as pharmaceutical vials, batteries, or automotive parts. These imaging lenses provide a conical-shaped working area, and are optimized for use with

monochromatic light. When 0.5 - 1.5mm spacers are positioned between the lens and camera, TECHSPEC® Hypercentric Lenses can also be used as long working distance borescopes, simultaneously focusing on the internal walls and bottom surface of an object. The borescope working distance is the area past the convergence point (CP) of the standard working area. The use of larger spacers increases the borescope focus distance.

Note: All specifications are defined at 660nm.



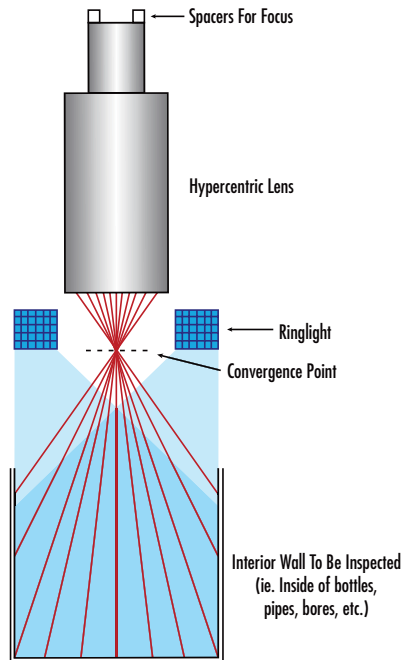
TECHSPEC® HYPERCENTRIC LENSES

*Circular Image is Produced on Maximum Sensor Format

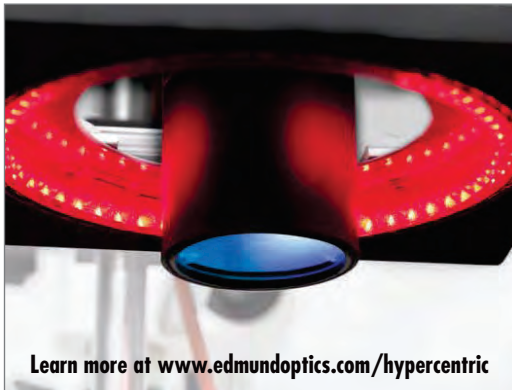
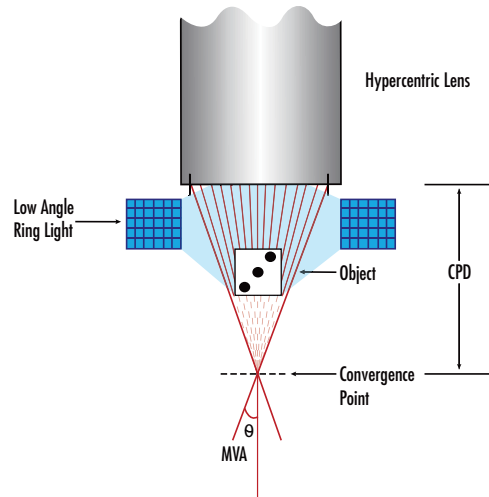
Sensor Format (Vertical)*	1/8"	1/2"	3/8"
Convergence Point Distance (CPD):	28.2mm	28.2mm	28.2mm
T (Near Aperture):	37.2mm	37.2mm	37.2mm
B (Far Aperture):	9.4mm	10.4mm	11.5mm
Max. View Angle (MVA):	33°	33°	33°
Max. Working Distance (WD):	21.1mm	20.1mm	19.5mm
Max. Depth of Field:	18mm	14mm	9.5mm
Dimensions (Dia. x L):	58.9 x 167mm	58.9 x 160mm	58.9 x 158mm
Stock No.	#86-584	#86-585	#86-586
Price	\$2,495.00	\$2,550.00	\$2,595.00

Hypercentric Lenses

Hypercentric Lens Borescope Configuration



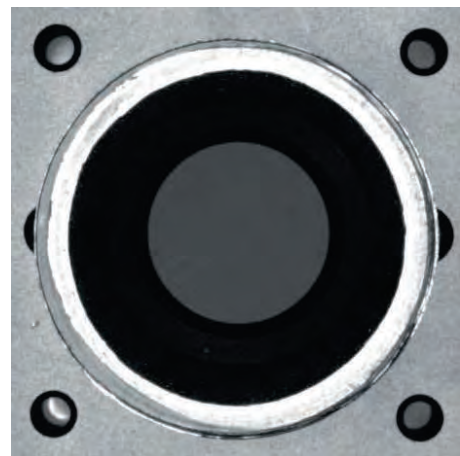
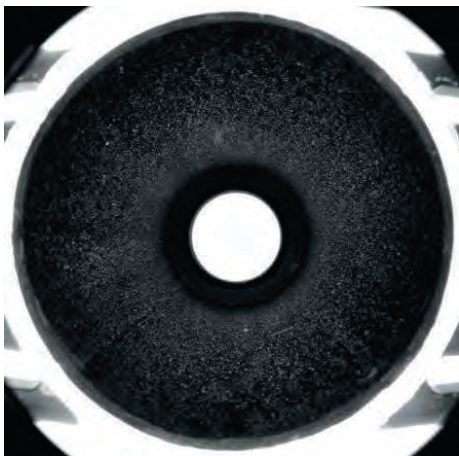
Hypercentric Lens External Viewing Configuration



Learn more at www.edmundoptics.com/hypercentric



Images of dice using a Hypercentric Lens (left) and a Fixed Focal Length Lens (right).



Images of Pipe Using Hypercentric Lens in Borescope Mode (left) and a 25mm Fixed Focal Length Lens (right).

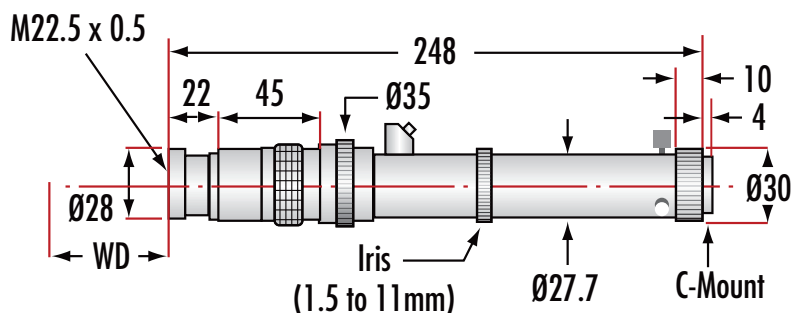
Dynamic Focus VZM™ Lenses



- Electronically Adjust Focus with Integrated Liquid Lens
- Overcomes Depth of Field Limitations
- Includes Software for Focus Tuning

The Dynamic Focus VZM™ Lens utilizes an internal liquid lens to easily and seamlessly adjust focus over a 7X range, from 0.65X to 4.6X, while maintaining the zoom capabilities of the standard VZM™ Zoom Imaging Lenses. The lens also features a lockable iris, zoom control, and a rotatable mount that allows the camera to be properly oriented. Additionally, a removable mounting flange allows the lens to fit into the 50 mm diameter thru hole of the Rack and Pinion Mount #03-609. The liquid lens focus can be controlled via the ruggedized 6-pin Hirose

connector and a USB port, while coarse magnification adjustments can be made manually. The included software allows the Dynamic Focus VZM™ Lens to be programmed to cycle through focus with a square, sinusoidal, or sawtooth waveform or adjustable frequency and focus-shift range. Note: For illumination purposes, it is recommended to use the 1.125" inner diameter fiber optic ring light (#54-175), which can connect to any of our fiber optic illuminators.



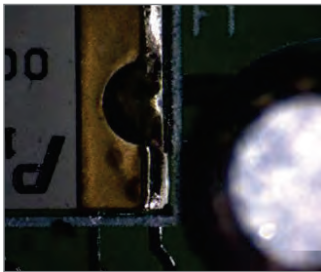
Units: mm

Zoom Lenses

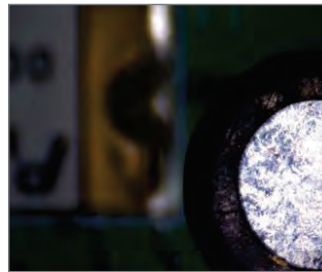
SPECIFICATIONS						
Magnification Setting:	0.75X	1X	2X	3X	4X	4.5X
Magnification Range:	0.65X - 1.15X	0.9X - 1.2X	1.5X - 2.0X	2.4X - 3.0X	3.2X - 4.0X	3.7X - 4.6X
Working Distance (mm):	20 - 101	20 - 100	54 - 90	75 - 90	82 - 90	84 - 90
Horiz. Field of View, $\frac{2}{3}$ " Sensor (mm):	13.5 - 7.7	9.8 - 7.3	5.9 - 4.4	3.7 - 2.9	2.8 - 2.2	2.4 - 1.9
Horiz. Field of View, $\frac{1}{2}$ " Sensor (mm):	9.8 - 5.6	7.1 - 5.3	4.3 - 3.2	2.7 - 2.7	2.0 - 1.6	1.7 - 1.4

DYNAMIC FOCUS VZM™ LENS		
Maximum Sensor Format:	$\frac{2}{3}$ "	
Primary Magnification:	0.65X - 4.6X	
Parfocal Working Distance:	87 ±3mm	
Filter Thread:	M22.5 x 0.5	
Overall Length:	248mm	
Stock No. / Price	#89-999	\$1,850.00

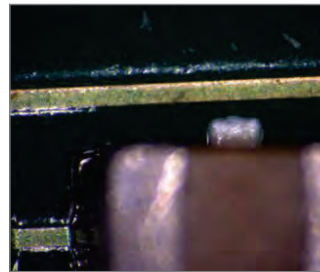
ACCESSORIES		
Description	Stock No.	Price
C-Mount Electrical Lens Driver	#88-940	\$280.00
6-way Male/Female Hirose Cable, 1m	#88-941	\$85.00



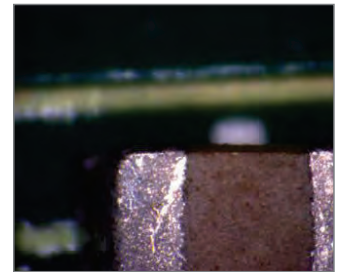
0.75X at Far Focus



0.75X at Near Focus



3.0X at Far Focus



3.0X at Near Focus

TECHNICAL NOTE

AUGMENTING YOUR MACHINE VISION SYSTEM WITH LIQUID LENSES

Attaching a liquid lens to existing fixed focal lenses can be useful in applications that require a large depth of field. The liquid lens will allow you to electronically focus throughout the focus range of the lens. Having the ability to focus both up close and out to infinity in milliseconds can be very useful in applications such as package sorting, security, and barcode reading. Optotune Focus-Tunable Lenses feature large clear apertures of 10mm or 16mm and are offered in many popular machine vision mounting options.

STEP 1: Select a Compatible Lens for Your Application (Recommended Examples Below)

Focal Length	Fixed Focal Length Lenses Applicable Stock Numbers	Camera Sensor Size											
		$\frac{1}{4}$ "		$\frac{1}{3}$ "		$\frac{1}{2.5}$ "		$\frac{1}{2}$ "		$\frac{1}{1.8}$ "		$\frac{2}{3}$ "	
		10mm CA*	16mm CA*	10mm CA*	16mm CA*	10mm CA*	16mm CA*	10mm CA*	16mm CA*	10mm CA*	16mm CA*	10mm CA*	16mm CA*
8.5mm	#58-000												
12mm	#58-001, #86-607 - #86-613												
16mm	#59-870, #85-348 - #85-354, #85-336												
25mm	#85-355 - #85-361, #85-337												
35mm	#85-362 - #85-368, #85-338												
50mm	#86-614 - #86-620												

*Liquid Lens Clear Aperture

Vignetting: ■ Minimal/None ■ Moderate ■ Significant ■ Not Recommended

STEP 2: Select the Necessary C-Mount Adapter

1 Adapter Needed	For #58-000, #58-001, #59-870 use adapter #33-428
	For 12mm, 16mm, 25mm Ci Series Lenses use adapter #33-185
	For 35mm Ci Series Lenses use adapter #33-186
	For 50mm Ci Series Lenses use adapter #33-187

STEP 3: Attach Liquid Lens Components to the Front of the Lens

Optotune Focus-Tunable Liquid Lenses*			
Clear Aperture	Tuning Range (Diopeters)	Male Thread	Stock No.
10mm	-1.5 to +3.5	C-Mount	#88-939
16mm	-2 to +3	C-Mount	#33-494
Accessories			
Optotune Electrical Lens Driver			#88-940
1m 6-Way Hirose Cable			#88-941
3m 6-Way Hirose Cable			#33-468

*For more information, visit our website



For more information about
Fixed Focal Length Lenses, see page 46-53

Zoom Lenses

VZM™ IMAGING LENSES

VZM™ Zoom Imaging Lenses enable inspection of a wide range of objects without the inconvenience of changing working distances. In addition, the par-focal zoom allows magnifications to be easily changed without refocusing. Iris versions (i-series) all have locking iris, front filter thread, removable mounting flange, and optional zoom lock.



Motorized
VZM™ 450



VZM™ 450i
Right Angle

Primary Magnification:
Field of View (1/2" Sensor, Horizontal):
Resolution in Object Space (lp/mm):
Resolution in Image Space (lp/mm):
Filter Thread (i Models Only):
Working Distance:
Weight:
VZM™ Zoom Lens
VZM™ i Zoom Lens
Motorized VZM™ Zoom Lens

ACCESSORIES

VZM™ Extender Lenses



See website for specifications

VZM™ EXTENDER LENSES

Extender Lenses	Stock No.	Price
0.75X for VZM™ 200i	#63-100	\$190.00
0.5X for VZM™ 200i	#54-716	\$125.00
0.5X for VZM™ 450	#55-386	\$95.00
0.5X for VZM™ 450i	#54-670	\$95.00
0.25X for VZM™ 450i	#54-669	\$150.00
VZM™ i-Series Zoom Lock Adapter	#57-831	\$75.00

Mounted Filters (for VZM™ i models)



TECHSPEC® IMAGING FILTERS (M22.5 x 0.5)

NUV	#89-753	\$120.00
Blue	#89-763	\$120.00
Cyan	#89-773	\$120.00
Green	#89-783	\$120.00
UV/IR Cut-Off	#89-793	\$115.00
Orange	#89-803	\$120.00
Light Red	#89-813	\$115.00
Dark Red	#89-823	\$115.00
UV/VIS Cut-Off	#89-833	\$115.00



VZM™ 100i

- 4:1 Zoom Ratio
- Removable Mounting Flange
- Optional Zoom Lock Adapter
- Rotatable Mount for Camera Orientation

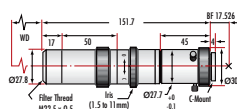
VZM™ 100i

Min.	Max.
0.25X	1X
25.6mm	6.4mm
17.5	32
70	32

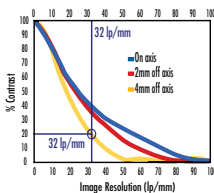
M22.5 x 0.5
175mm ± 3mm
270g

N/A	—
#59-805	\$995.00
N/A	—

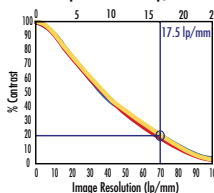
VZM™ 100i



Modulation Transfer Function—1X PMAG Object Resolution (lp/mm)



Modulation Transfer Function—0.25X PMAG Object Resolution (lp/mm)



See Website for
Additional Resolution
& Depth of Field Data
www.edmundoptics.com/vzm



VZM™ 200i

- 4:1 Zoom Ratio
- Removable Mounting Flange
- Optional Zoom Lock Adapter
- Rotatable Mount for Camera Orientation

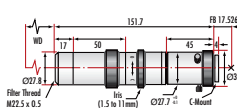
VZM™ 200i

Min.	Max.
0.5X	2.0X
12.0mm	3.0mm
26	88
52	44

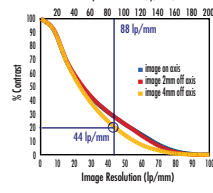
M22.5 x 0.5
90mm ± 3mm
232g

N/A	—
#54-715	\$995.00
N/A	—

VZM™ 200i



Modulation Transfer Function—2X PMAG Object Resolution (lp/mm)



EO logo displayed on a
mobile phone at 0.125X. FOV = 48mm
VZM™ 200i w/ 0.25X extender



U.S. \$100 bill at 0.5X FOV=12mm
VZM™ 200i



VZM™ 300 AND VZM™ 300i

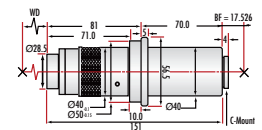
- 4:1 Zoom Ratio
- 2 - 8mm FOV on 1/2" Sensor
- Rugged Mechanical Design

VZM™ 300 (300i)

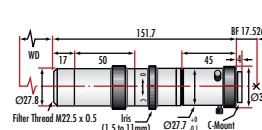
Min.	Max.
0.75X	3X
8.0mm	2.0mm
46.5 (37.5)	105 (111)
62 (50)	35 (37)

M22.5 x 0.5 (300i only)
60mm ± 3mm (56mm ± 3mm)
386g (232g)

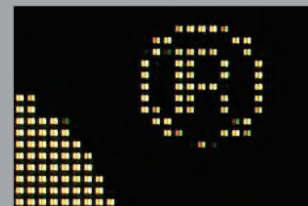
#39-708	\$995.00
#52-571	\$995.00
#57-826	\$2,495.00



VZM™ 300i



Units: mm



EO edge and @ symbol at 0.75X
FOV = 8mm
VZM™ 300



U.S. \$100 bill at 0.75X FOV= 8mm
VZM™ 300i

Zoom Lenses

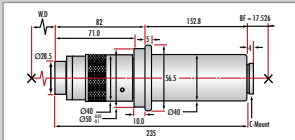
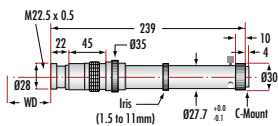
VZM™ IMAGING LENSES



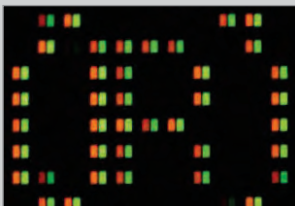
VZM™ 450 AND VZM™ 450i

- **6.4:1 Zoom Ratio**
- **1.4 - 8.8mm FOV on 1/2" Sensor**
- **VZM™ 450 Right Angle Available**

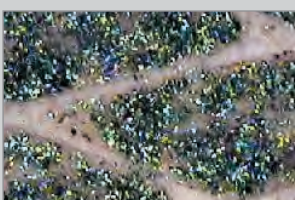
VZM™ 450 (450i)	
Min.	Max.
0.7X (0.75X)	4.5X
8.8mm	1.4mm
30	144
40	32
M22.5 x 0.5 (450i only)	
90mm ± 3mm	
580g (405g)	
#52-347	\$995.00
#54-671	\$995.00
#57-827	\$2,695.00

**VZM™ 450i**

Units: mm



® symbol at 3X FOV = 2mm
VZM™ 450i

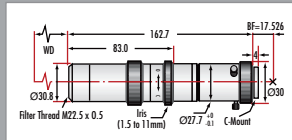


U.S. \$100 Bill at 2.5X FOV= 2.5mm
VZM™ 450i

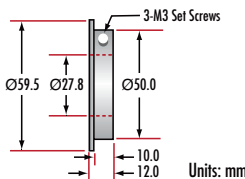
VZM™ 600i

- **6:1 Zoom Ratio**
- **1.0 - 6.4mm FOV on a 1/2" sensor**
- **Removable Mounting Flange**

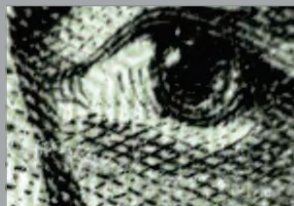
VZM™ 600i	
Min.	Max.
1.0X	6.0X
6.4mm	1.0mm
87	176
87	29
M22.5 x 0.5 60mm ±3mm 250g	
N/A	—
#88-399	\$995.00
N/A	—



Removable Mounting Flange for all i-Series (Fits Rack and Pinion #03-609)



Units: mm



U.S. \$20 bill at 1.0X FOV = 0.64mm
VZM™ 600i

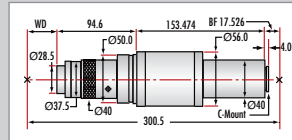
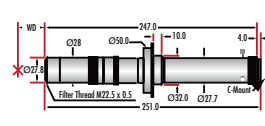


U.S. \$20 bill at 6.0X FOV = 1.0mm
VZM™ 600i

VZM™ 1000 AND VZM™ 1000i

- **4:1 Zoom Ratio**
- **35mm Working Distance**
- **0.64 - 2.5mm FOV on 1/2" Sensor**

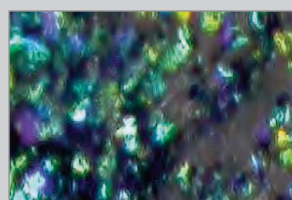
VZM™ 1000 (1000i)	
Min.	Max.
2.5X	10X
2.56mm	0.64mm
102.5	228
41	22.8
M22.5 x 0.5 (1000i only)	
35mm ±1mm	
770g (326g)	
#54-396	\$995.00
#55-834	\$995.00
#57-828	\$2,895.00

**VZM™ 1000i**

Units: mm



Bottom right of ® symbol at 10X
FOV = 0.64mm
VZM™ 1000

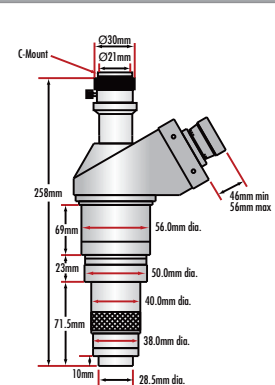


U.S. \$100 bill at 10X FOV= 0.6mm
VZM™ 1000i

VZM™ 1000 TRINOCULAR

- **4:1 Zoom Ratio**
- **25X - 100X Magnification with Included 10X Eyepiece**
- **Compatible with C-Mount Cameras**

VZM™ 1000 Trinocular	
Min.	Max.
2.5X	10X
2.56mm	0.64mm
102.5	228
41	22.8
— 36mm —	
#52-352	\$1,295.00
N/A	—
N/A	—



See website for
VZM™ Imaging Systems

Zoom Lenses

CLOSE FOCUS ZOOM LENSES

- Versatile and Affordable
- Smaller Fields of View & Working Distances than Fixed FL Lenses
- Manual Iris for Light Control

Close Focus Zoom Lenses are ideal for inspection, documentation and testing applications. Due to their large field of view range, these lenses are generally considered the best selection for multi-purpose use.

10X Zoom

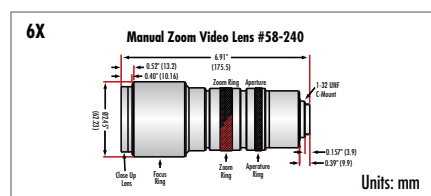
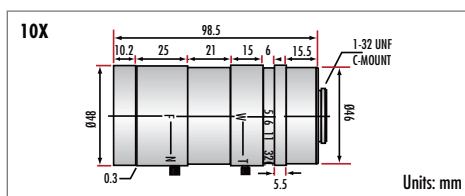


6X Zoom



	10X Zoom C-Mount Lens		6X Zoom C-Mount Lens	
Focal Length:	13 - 130mm (10:1 zoom ratio)		18 - 108mm (6:1 zoom ratio)	
Max Sensor Format:	1/2"		2/3"	
Aperture (f/#):	f/5.6 - f/32		f/2.5 - f/28	
Total Field of View Range:	7.8 - 280mm		5.8mm - ∞	
Working Distance (WD) Range:	152 - 457mm		127 - 305mm (300 - ∞)*	
Max. Dia. x L (mm):	48 x 98.5		62 x 176	
Weight:	233g		540g	
Front Filter Size (Dia. x Pitch):	M46 x 0.75		M52 x 0.75	
Working Distance:	Min 152mm	Max 457mm	Min 127mm	Max 305mm
Primary Magnification:	0.82X - 0.085X	0.23X - 0.023X	1.1X - 0.2X	0.4X - 0.067X
Field of View Zoom Range:	7.8 - 75mm	28 - 280mm	5.8 - 35mm	16 - 96mm
Stock No. / Price	#54-363	\$495.00	#58-240	\$495.00

*Without removable close up lens



HIGH RESOLUTION MACRO ZOOM C-MOUNT LENSES

- Full Zoom, Focus and Iris Control
- Up to 100 lp/mm Resolution
- Working Distances from 100mm to ∞



HIGH RESOLUTION MACRO ZOOM C-MOUNT LENSES				*Horizontal on Max. Sensor **With close up lens attached		
Focal Length (mm):	8.5 - 90.0 (10.6X)		11.5 - 69.0 (6X)		8.0 - 48.0 (6X)	
Sensor Format:	1/3"		2/3"		1/2"	
Working Distance:	300mm - ∞ (150 - 300mm)**		1000mm - ∞ (10mm in Macro)		1000mm - ∞ (10mm in Macro)	
Aperture (f/#):	f/2.5 - Closed		f/1.4 - Closed		f/1.0 - Closed	
Angular Field of View*:	3.2° - 31.3°		7.3° - 41.9°		7.7° - 43.6°	
Resolution (Center, Corner):	100 lp/mm, 60 lp/mm		100 lp/mm, 60 lp/mm		100 lp/mm, 60 lp/mm	
Weight:	437g		300g		280g	
Dimensions (Dia. x L):	60 x 130mm		48 x 102.7mm		50.5 x 92.8mm	
Filter Thread:	M48 x 0.75		M46 x 0.75		M46 x 0.75	
Stock No. / Price	#68-679	\$495.00	#68-678	\$695.00	#68-677	\$695.00

MANUAL ZOOM IMAGING LENSES

- Manual Focus, Zoom & Aperture Control
- Features Locking Set Screws
- C-Mount



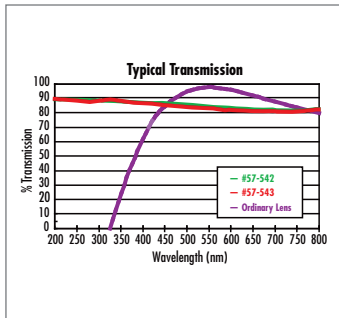
For Mounted Filters
See page 123-125



MANUAL ZOOM IMAGING LENSES			*Horizontal on Max. Sensor	
Focal Length (mm):	8.0 - 48.0 (6X)		12.5 - 75.0 (6X)	
Max. Sensor Format:	1/2"		2/3"	
Camera Mount:	C-Mount		C-Mount	
Aperture (f/#):	f/1.2 - f/16		f/1.2 - f/16	
Angular Field of View*:	44.6° - 8.0°		27.8° - 4.9°	
Field of View* (@ min. WD):	984 - 168mm		495 - 86mm	
Working Distance (WD):	1.2m to ∞		1.0m to ∞	
Max. Dia. x Max. L (mm):	51 x 97		57 x 114.5	
Weight:	305g		475g	
Front Filter Size (Dia. x Pitch):	M49.0 x 0.75		M55.0 x 0.75	
Stock No. / Price	#53-152	\$450.00	#53-153	\$495.00

Specialty Lenses

UV FIXED FOCAL LENGTH LENSES



- **Transmission from 230 - 1200nm**
- **Compact Size for Easy System Integration**
- **Ideal for Use with Mounted Color Filters**

UV Fixed Focal Length Lenses are ideal for use in a variety of applications, including the surface inspection of circuits or fiber optics, quality control of semiconductor materials, or for locating oil contamination or leakage. Additional applications include forensic, pharmaceutical, or biomedical imaging, fluorescence, security, or counterfeit detection. UV Fixed Focal Length Lenses are manufactured from fused silica elements to provide excellent transmission from the ultraviolet to the near-infrared. **Note:** These lenses are not corrected for chromatic aberration, and require refocusing when using an illumination source with a spectral bandwidth greater than 10nm. A monochromatic light source and narrow bandpass filter are recommended to improve the overall performance of the lens. The 78mm lens (#57-543) has a removable C-mount adapter, enabling it to be used with M42 x 0.75 (T2) mounts.



UV FIXED FOCAL LENGTH LENSES

*Horizontal Field of View; calculated for 1/2" format sensor

Focal Length (mm)	Max Sensor Format	Aperture f/#	Angular* FOV (Horiz.)	FOV* at Min. WD	Minimum WD	Spectral Range (nm)	Dimensions (mm)		Weight (g)	Filter Thread (Dia. x Pitch)	Stock No.	Price
							Max Dia.	Length				
25	1"	f/2.8 - f/16	14.0°	58.9mm	0.23m	230 - 1200	30.0	25.4	33	M25.5 x 0.5	#57-542	\$1,495.00
78	1"	f/3.8 - f/16	4.4°	36.1mm	0.44m	230 - 1200	62.5	109.3	446	M49.0 x 0.75	#57-543	\$3,495.00

VARIFOCAL LENSES

- **Large Field of View**
- **C and CS-Mount Lenses**

Vari focal lenses provide a flexible solution to applications that previously would have required multiple fixed focal length lenses. Simply adjust through the indicated focal length range for the desired field of view, within the specified working distance range, and then set focus for best image. They have a different, simplified optical and mechanical design that is more cost-efficient to produce than zoom lenses. **Note: CS-Mount lenses are not compatible with C-Mount cameras.**



VARIFOCAL IMAGING LENSES

*FOV=Field of View; calculated for 1/2" or max. 1/3" format sensor. **High resolution, low distortion lens for megapixel cameras. † Maximum

Focal Length (mm)	Mount	Max Sensor Format	Aperture (f/#)	Angular FOV* Horizontal	FOV* (Hor.) at Min WD (mm)	Min. Working Distance (m)	Dimensions (mm)			Filter Thread (Dia. x Pitch)	Stock No.	Price
							Max. Dia.	Length	Rear Prot.			
1.8 - 3.6	CS	1/8"	f/1.6 - f/16	144.2° - 79.4°	1236 - 332	0.2	37.4	51.0	0	—	#55-254	\$250.00
2.8 - 12.0	CS	1/8"	f/1.3 - f/16	98.2° - 23.8°	692 - 126	0.3	40.7	56.0	2.3	—	#57-675	\$155.00
2.9 - 8.2	CS	1/8"	f/1.0 - f/16	98.3° - 35.2°	1156 - 317	0.5	36.5	44.3	0	—	#59-915	\$150.00
3.5 - 10.5	CS	1/8"	f/1.0 - Closed	81.6° - 27.2°	518 - 145	0.3	41.7	48.8	2.5	—	#59-916	\$150.00
4.0 - 8.0	C	1/2"	f/1.4 - f/16	90.4° - 47°	1007 - 435	0.5	41.6	48.8	4.1	—	#59-917	\$250.00
4.0 - 12.0	C	1/2"	f/1.2 - f/16	93.6° - 31.2°	639 - 168	0.3	40.0	50.3	4.6†	—	#58-365	\$195.00
5.0 - 50.0	C	1/8"	f/1.3 - f/16	51.8° - 5.6°	777 - 78	0.8	47.0	57.7	0	M37.5 x 0.5	#55-256	\$195.00
10.0 - 30.0	CS	1/2"	f/1.4 - f/16	35.7° - 12.5°	387 - 131	0.6	47.0	57.5	0	M37.5 x 0.5	#57-677	\$250.00
12.0 - 36.0**	C	2/3"	f/2.8 - f/16	30.2° - 10°	107 - 35	0.2	41.6	53.0	0	M35.5 x 0.5	#57-680**	\$299.00
20.0 - 100.0	CS	1/3"	f/1.6 - f/16	13.6° - 28°	238 - 49	1.0	50.0	110.0	0	—	#58-440	\$250.00

55mm FL PARTIALLY-TELECENTRIC VIDEO LENS

- **Manual Iris**
- **Ideal for Measurement Applications**
- **±12.5mm Depth of Field at 0.5X**

Telecentric lenses yield constant magnification over a range of working distances, virtually eliminating viewing angle error. The 55mm focal length telecentric lens allows ±12.5mm of object movement (at 0.5X magnification) before a 1% error in image scale occurs. Conventional lenses typically permit ±1.7mm of movement under the same conditions. The lens' protective window (at C-Mount end) needs to be removed for use with adapter lenses. This lens is only partially telecentric, since it has both a telecentric and non-telecentric range.

These lenses are ideal in machine vision applications requiring accurate measurement of three-dimensional objects with slight height variations. By eliminating the perspective distortion and magnification error inherent in conventional lenses, they yield dimensionally accurate images that are easily interpreted by software.

For mounting these lenses, the Industrial Boom Stands and mounting adapters are recommended as workstation platforms. Ring light guides cannot be mounted directly on this lens because of the front focusing adjustment.



TELECENTRIC SPECIFICATIONS

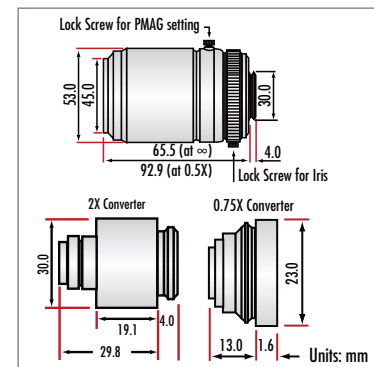
(Lens is not telecentric with the 0.75X Converter) *Horiz. 1/2" Sensor

	Lens Alone	Lens with 2X Converter	
Primary Magnification PMAG:	0.5X - 0.4X	1.0X - 0.4X (full range)	
Field of View*:	12.8 - 16.0mm	6.4 - 16.0mm	
Working Distance:	5.0" - 6.25"	5.25" - 11.25"	
Focal Length:	55mm	110mm	
Aperture (f/#):	f/2.8 - f/32		
Max. Sensor Format:	2/3"	Filter Size:	M43 x 0.75
Distortion:	<1.0%	Weight:	11.1 oz.
Lens Mount:	C-Mount		

NON-TELECENTRIC SPECIFICATIONS

*Horizontal for 1/2" format sensor

	Lens Alone	With 2X Converter	With 0.75X Converter
Primary Magnification PMAG:	0.5X - 0X	1.0X - 0X	0.375X - 0X
Field of View*:	12.8mm - 6.7°	6.4mm - 3.3°	17.0mm - 8.9°
Lens Working Distance:	5" to ∞	5.25" to ∞	5" to ∞
55mm Partially-Telecentric Video Lens		#52-271	\$575.00
2X Converter for #52-271		#52-272	\$175.00
0.75X Converter for #52-271		#52-273	\$175.00



Specialty Lenses

LOW DISTORTION WIDE ANGLE LENSES



- **High 3 MegaPixel Resolution**
- **No Refocusing from 100mm to Infinity**
- **Lightweight Design**

The optical design of these low-distortion wide angle lenses enables users to achieve less than 3% distortion over a 125° field of view or less than 1% over a 110° field of view. Originally targeted for security applications, these lenses maintain high resolution and can accommodate camera sensors up to 3 MegaPixels, making them an ideal replacement for machine vision or factory automation applications. No refocusing is needed from 100mm to Infinity. Locking screw for manual iris enables lenses to be used in high vibration environments.

LOW DISTORTION WIDE ANGLE LENSES

*Horizontal for 1/3" format sensor

Focal Length	Max. Sensor Format	Camera Mount	Distortion*	Aperture (f/#)	Angular Field of View*	Min. Working Distance	Dimensions (Dia. x L)	Weight	Manual Iris		Auto Iris	
									Stock No.	Price	Stock No.	Price
1.28mm	1/3"	CS	<3%	f/1.8 - Closed	125°	10mm	36.0 x 65.0mm	110g	#62-046	\$595.00	#68-696	\$595.00
1.28mm	1/3"	C	<3%	f/1.8 - Closed	125°	10mm	36.0 x 65.1mm	110g	#62-050	\$595.00	N/A	—
1.67mm	1/2.5"	CS	<1%	f/1.8 - Closed	110°	100mm	36.0 x 56.0mm	80g	#64-105	\$365.00	#68-697	\$425.00
1.67mm	1/2.5"	C	<1%	f/1.8 - Closed	110°	100mm	36.0 x 56.0mm	80g	#68-695	\$495.00	N/A	—
1.8 - 3.0mm	1/2.5"	CS	<1%	f/1.8 - Closed	105° - 77°	500mm	39.0 x 50.0mm	70g	#85-162	\$385.00	#85-163	\$395.00
1.8 - 3.0mm	1/2.5"	C	<1%	f/1.8 - Closed	105° - 77°	500mm	39.0 x 50.0mm	70g	#89-524	\$675.00	N/A	—

FISHEYE VIDEO LENSES



- **Wide Field of View (185°)**
- **Fixed Focus**
- **Lockable Iris Control**

The Fisheye Video Lens is designed to support MegaPixel resolution cameras across a 185° field of view. The large depth of field eliminates the need for focus adjustment and allows the lens to be sharply focused between 100mm and infinity. A lockable iris adjustment enables control over the exposure without changing integration time, and stays locked in place to prevent accidental alteration. This lens is excellent for space-constrained applications where large fields of view are required at short working distances.

FISHEYE VIDEO LENS

*Horizontal for 1/2" format sensor

Focal Length	Max. Sensor Format	Camera Mount	Aperture (f/#)	Angular Field of View*	Min. Working Distance	Dimensions (Dia. x L)	Weight	Stock No.	Price
1.8mm	2/3"	C-Mount	f/1.4 - f/16	185° x 154°	100mm	56.5 x 52.1mm	135g	#62-274	\$695.00

SCHNEIDER FAST C-MOUNT LENSES



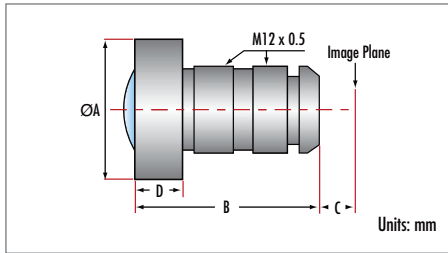
- **Helical Focus Movement**
- **Click-Stop Free Iris Setting**
- **External Iris & Focus Lock**

Designed for extremely low light situations, the high aperture (f/0.95) of these lenses provides excellent image quality even under low light conditions. These lenses are designed to cover the visible spectrum (400 - 700nm). Locking focus and iris prevent change in stressful environments. The front filter thread allows the use of color filters to increase contrast, for increased accuracy of sorting, picking or measuring applications, or reducing glare with polarizing filters.

SCHNEIDER FAST C-MOUNT LENSES

Focal Length (mm)	Max. Sensor Format	Aperture f/#	Angular FOV (°)	Geometric Distortion (%)	FOV at Min. WD (mm)	Min. Working Distance (mm)	Filter Thread	Stock No.	Price
17.0	2/3"	f/0.95 - f/11	29	< -3	56.5	150	M35.5 x 0.5	#59-832	\$2,495.00
25.0	1"	f/0.95 - f/11	20	< -3	76.8	300	M39 x 0.5	#59-833	\$1,995.00

INFINITE CONJUGATE μ -VIDEO™ IMAGING LENSES



- 1.68 to 50.0mm Focal Length Options
- M12 x 0.5 Mounting Thread
- Multi-Element Design

Designed for use in micro board-level cameras, these lenses provide excellent image quality in a small, versatile package. Optimized to cover up to $\frac{1}{4}$ " sensors, they are an ideal choice for wide angle and close focus applications. All lenses are threaded for M12 x 0.5. All glass lens element designs. Lenses are designed for the 400nm to 700nm range.



INFINITE CONJUGATE μ -VIDEO™ IMAGING LENSES									*Horizontal at max. Sensor format. **Filter at 650nm † Values for ¼" Sensor								
Focal Length (mm)	Max. Sensor Format	f/#	Angular FOV* (°)	Min. Working Distance (mm)	Distortion Diag. at Full Field (%)	Max. Res. @ 20% Contrast (lp/mm)			Dimensions (mm)				No-IR Cut Stock No.	IR Cut** Stock No.	Price		
						On-Axis	0.7 Field	Full Field	A	B	C	D			1-10	11-24	25+
1.68	¼"	f/2.5	132.9	400	-83.90	160	80	—	15.0	13.2	3.3	2.8	#59-776	#66-880	\$49.50	\$40.50	Call For OEM Quantity Pricing
1.74	¼"	f/2.8	114.4	400	-60	124	87	30	21.0	19.6	3.3	3.2	#56-774	#66-881	\$49.50	\$40.50	
1.9	¼"	f/2.0	118	400	—	—	—	—	15.0	13.1	4.4	2.8	#64-106	#66-882	\$49.50	\$40.50	
2.1	⅓"	f/2.0	131	400	-82.4	100†	63†	40†	17.0	18.3	4.8	3.7	#55-569	#66-883	\$49.50	\$40.50	
2.5	⅓"	f/2.5	115.8	400	-60	63	48	30	17.0	19.1	4.4	3.7	#57-681	#66-884	\$49.50	\$40.50	
2.9	⅓"	f/2.0	98.6	400	-36.0	63	63	40	15.0	17.4	5.2	5.8	#55-570	#66-885	\$49.50	\$40.50	
3.0	⅓"	f/2.0	97.8	300	-52.10	97	62	35	14.0	15.3	5.3	3.9	#59-778	#66-886	\$49.50	\$40.50	
6.05	⅓"	f/1.8	46	400	-10	72	55	46	15.0	15.26	8.0	6.0	#57-684	#66-890	\$49.50	\$40.50	
6.37	⅓"	f/2.4	42.2	400	-2.40	80	63	25	14.8	13.12	5.3	3.3	#55-573	#66-891	\$49.50	\$40.50	
8.0	⅓"	f/2.5	30.9	800	-3.0	80	63	63	15.0	13.5	5.8	3.0	#55-574	#66-892	\$49.50	\$40.50	
10.1	½"	f/2.8	36	400	-0.57	81	54	64	15.0	13.4	6.1	3.2	#63-762	#59-779	\$49.50	\$40.50	
10.4	½"	f/2.8	35	400	-2.00	93	90	88	14.0	12.0	6.4	4.0	#65-251	#64-107	\$49.50	\$40.50	
12.0	⅓"	f/2.0	22.2	800	-0.15	63	60	60	14.0	12.1	6.2	4.0	#56-775	#66-893	\$49.50	\$40.50	
16.0	⅓"	f/2.0	17	400	-2.50	75	65	60	14.0	14.4	8.0	4.5	#64-108	#66-894	\$49.50	\$40.50	
25.0	⅓"	f/2.5	10.7	200	-0.46	83	58	58	25.0	23.2	8.1	6.7	#56-776	#66-895	\$59.50	\$51.50	
35.0	⅔"	f/2.0	13.6	200	-1.10	160	100	80	25.0	23.4	15.8	6.0	#59-780	#66-896	\$59.50	\$51.50	
50.0	½"	f/2.5	6.8	400	-1.20	160	100	80	27.0	52.8	4.1	8.0	#59-781	#66-897	\$59.50	\$51.50	

HIGH RESOLUTION INFINITE CONJUGATE μ-VIDEO™ IMAGING LENSES											*Horizontal at max. sensor format				
Focal Length (mm)	Max. Sensor Format	f/#	Angular FOV* (°)	Working Distance (mm)	TV Distortion (%)	Contrast at 100 lp/mm Resolution			Dimensions (mm)			Stock No.	Price		
						On-Axis	0.7 Field	Full Field	A	B	C		1-10	11-24	25+
2.5	1/2.8"	f/2	125	400 - ∞	-36%	85%	67%	34%	20	17.97	4.57	#34-711	\$59.50	\$51.50	Call for OEM Quantity Pricing
3.0	1/2.7"	f/2	114.5	400 - ∞	-53.0%	69.0%	44.0%	37.0%	15	15.4	5.2	#88-587	\$59.50	\$51.50	
3.5	1/2.7"	f/2.5	102.8	400 - ∞	-46.2%	59.0%	46.0%	28.0%	15	15.4	6.9	#88-588	\$59.50	\$51.50	
4.0	1/2.7"	f/2	101	400 - ∞	-32.3%	75.0%	62.0%	34.0%	15	16.1	5.9	#88-589	\$59.50	\$51.50	
4.3	1/2.7"	f/2	68	400 - ∞	-0.4%	72.0%	56.0%	46.0%	22	21.5	5.5	#88-590	\$59.50	\$51.50	
4.6	1/2.8"	f/2	74	400 - ∞	-27.1%	72.0%	38.0%	29.0%	12	13.1	1.9	#88-591	\$59.50	\$51.50	
5.6	1/2.8"	f/2	50	400 - ∞	-1.5%	67.0%	51.0%	49.2%	17	22.2	5.3	#88-592	\$59.50	\$51.50	
6.0	1/2.7"	f/2	57	400 - ∞	-16.0%	66.0%	62.0%	51.6%	14	15.1	6.7	#89-750	\$59.50	\$51.50	
8.0	1/2.7"	f/2	42	400 - ∞	-9.9%	65.0%	54.0%	43.5%	15	14.4	6.8	#89-751	\$59.50	\$51.50	
12.0	1/2.7"	f/2	27	400 - ∞	-2.4%	75.0%	73.0%	65.7%	15	14.3	5.7	#89-752	\$59.50	\$51.50	



See pages 74-81 for additional TECHSPEC® μ -video Imaging Lenses

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Filtering in Machine Vision

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Filter Technology



Figure 1

RGB Color Filters

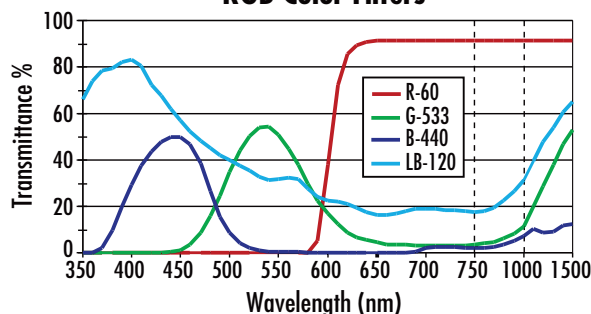


Figure 1: Transmission curves for several different colored glass filters.

For more information on various types of **colored filters** that are available, visit WWW.EDMUNDOPTICS.COM/FILTERS



For recommended Imaging Filters, see **pages 123-125**.

For a **complete listing** of EO Filters, visit WWW.EDMUNDOPTICS.COM/FILTERS

There are many different types of filters in machine vision that can be utilized to improve or change the image of the object under inspection. It is important to understand the different technologies behind the various types of filters in order to understand their advantages and limitations. Although there is a wide variety of filters, almost all can be divided into two primary categories: colored glass filters and coated filters.

Colored Glass Filters

Colored glass filters are incredibly common in machine vision, and are created by doping glass materials with elements that selectively change their absorption and transmission spectra. The dopants vary based on which wavelengths are considered for transmission, and the manufacturing process is then nearly identical to standard optical glass manufacturing. Colored glass filters are advantageous for a couple different reasons: they are of relatively low cost when compared to interference filters and, more importantly, they do not demonstrate any shift in wavelength transmission when used with wide angle lenses or at an angle. However, colored glass filters also typically feature wide cut-on wavebands, do not have curves that are as sharp or accurate as coated interference filters, and do not have transmission throughput levels (percentages) as high as interference filters. *Figure 1* shows the transmission curves for several common colored glass filters. Note that the filters feature wide cut-on wavebands and have relatively shallow slopes describing their transmission functions.

Infrared (IR) cut-off filters can be either colored glass filters or a type of coated filter that is useful for both monochrome and color cameras in machine vision applications. Since the silicon sensors in most machine vision cameras are responsive to wavelengths up to approximately 1 μ m, any IR light incident on the sensor that may have been caused by overhead fluorescent lights or other unwanted sources can create inaccuracies on the sensor. On a color camera, IR light will create a false color on the sensor that can degrade overall color reproduction. For this reason, many color imaging cameras come standard with IR-cut filters over the sensor. With monochrome cameras, the presence of IR light will degrade the contrast of the overall image.

There are a multitude of other types of colored glass filters. For instance, daylight blue filters can be used for color balancing when polychromatic light sources and color sensors are used.

Coated Interference Filters

Coated filters typically offer sharper cut-on and cut-off transitions, higher transmissions, and better blocking than colored glass filters. In addition to colored glass filters, there are a range of coated filters, they range from hard coated fluorescent filters to dichroic filters to polarization filters. Each coated filter undergoes a unique manufacturing process to ensure the proper performance. Wavelength-selective optical filters are manufactured by depositing dielectric layers on a specific substrate of alternating high and low indices of refraction. The surface quality and uniformity of the substrate establishes the baseline optical quality for the filter, along with setting wavelength limits where the transmission of the substrate material falls off. The dielectric layers produce the detailed spectral structure of a filter by creating constructive and destructive interference across a range of wavelengths, as well as providing much sharper cut-off and cut-on bands when compared to colored glass filters.

(Continued on page 121)

Many types of hard coated filters exist, such as bandpass, longpass, shortpass, and notch filters, each with a specified blocking range and transmission range. Longpass filters are designed to block short wavelengths and pass long wavelengths. Shortpass filters are the opposite, passing shorter wavelengths and blocking longer. Bandpass filters pass a band of wavelengths, while blocking longer and shorter wavelengths. The inverse of a bandpass filter is a notch filter, which blocks a band of wavelengths and passes the longer and shorter. Transmission curve shapes for these filter types are shown in *Figure 2*.

Filters designed for deep blocking (high Optical Density) and steep slopes (sharp transition from blocking to transmission) are used in applications where precise light control is critical. Most machine vision applications do not require this level of precision; typically, any filter with an Optical Density (OD) of 4 or greater is more precise than required and adds unnecessary cost.

Because hard coated filters utilize optical interference to achieve such precise transmission and rejection bands, they introduce some difficulties

when used in machine vision applications. All interference filters are designed for a specific Angle of Incidence (AOI), generally 0° unless specifically defined otherwise. When used in machine vision, these filters are generally placed in front of the lens; doing such causes the filter to accept light coming from angles dictated by the angular field of view of the lens. Especially in the case of short focal length (large angular field of view) lenses, the light that is transmitted through the filter will often display an unwanted effect known as blue shift. For example, a 4.5mm focal length lens (wide angle) will have a much larger blue shift than a 50mm focal length lens (narrow angle). As the AOI on an interference filter increases, the optical path length through the filter layers increases, which causes the cut-on and cut-off wavelengths to decrease (*Figure 3*). Therefore, at different field points in the image, the filter will behave differently by transmitting different wavelength ranges: the farther out in the field, the more pronounced the blue shift. In most cases, interference filters can still provide better filtering control over a colored glass filter, but be aware of the potential pitfalls when using an interference filter with a wide-angle lens.

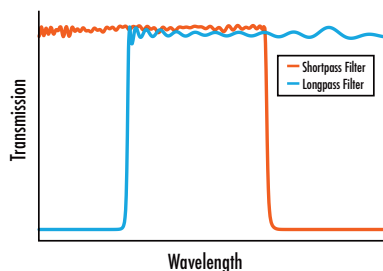
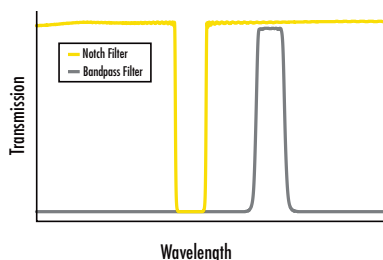
Figure 2a**Figure 2b**

Figure 2: Transmission curve examples of longpass and shortpass (a) and bandpass and notch filters (b).

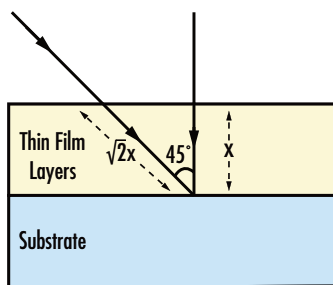
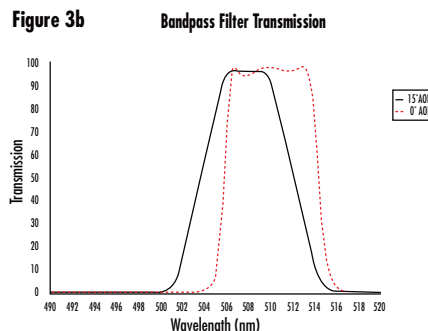
Figure 3a**Figure 3b**

Figure 3a: Interference filters function based on the distance that light incident upon the filter travels. At the correct angle of incidence, the light waves incident on the filter destructively interfere, disallowing them from making it through the filter. At a different angle, the destructive interference is not as effective, effectively changing the type of filter.

Figure 3b: An example of blue shift, shown with a bandpass filter used at a 15° angle of incidence. Note not only the shift towards a lower center wavelength, but the shallowing of the slope as well. The dashed curve is ideal, when the filter is used at a 0° angle of incidence.

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Applications with Machine Vision Filtering

When designing a machine vision system, it is important to enhance the contrast of the inspected object's features of interest. For an introduction to contrast, see *Section 2.3*. Filtering provides a simple way to enhance the contrast of the image while blocking out unwanted illumination. There are many different ways filters can enhance contrast, and the filter type is dependent on the application. Some common filters used in machine vision are colored glass, interference, Neutral Density (ND), and polarization.

Colored glass bandpass filters are some of the simplest filters available for drastically improving image quality. These filters work incredibly well at narrowing the waveband that is visible by the vision system, and are often less expensive than comparable interference filters. Colored glass filters work best when used to block out colors on the opposite side of the color wheel (*Figure 4*).

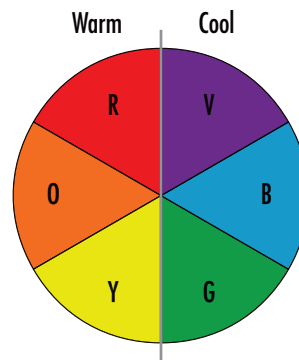
Figure 4

Figure 4: Color wheel demonstrating that warm colors should be used to filter out cool colors on the opposite side of the wheel.

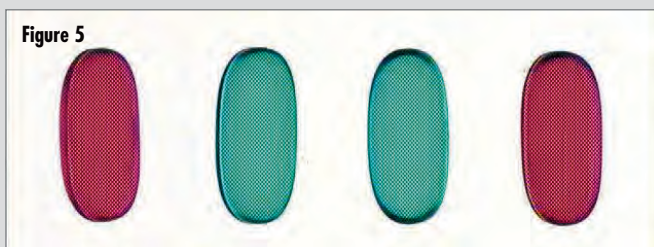


Figure 5: Four liquid capsules under inspection with the same vision system, shown here in color.

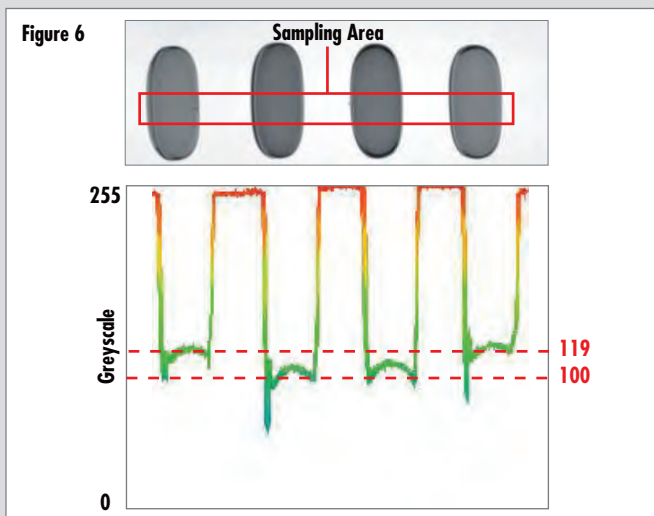


Figure 6: Capsules being viewed with a monochromatic camera, yielding a contrast of 8.7%.

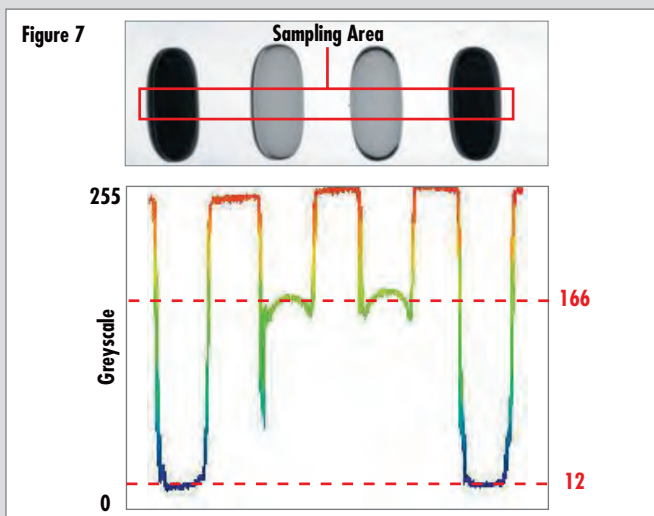


Figure 7: Capsules being viewed with a monochromatic camera and green colored glass filter yielding a contrast of 86.5%.

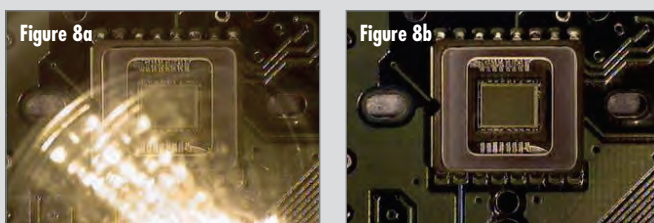


Figure 8: Images taken with no filter (a) showing high glare and with polarization filters (b) which reduce glare.

Color Filters

Consider the example shown in *Figure 5*, where gel capsules are being inspected. As shown, two red capsules are on the outer sides of a pair of green capsules and under a white light backlight. This is a sorting application where the pills need to be separated by color to reach their respective locations. Imaging the capsules with a monochrome camera (*Figure 6*) provides a contrast between the green and red capsules of only 8.7%, which is below the minimum advisable contrast of 20%.

In this particular example, minor fluctuations in ambient light, such as individuals walking past the system, can decrease the already low contrast value of 8.7% enough so that the system is no longer capable of operating properly. Several solutions to this problem exist: a bulky and costly light baffling system can be built to completely enclose the inspection system, the entire lighting scheme of the system can be reworked, or a filter can be added to enhance the contrast between the green and red pills. In this instance, the simplest and most cost effective solution is to utilize a green colored glass filter in order to improve the contrast between the two different colored capsules. As shown in *Figure 7*, the contrast improves from 8.7% to 86.5%: an increase of nearly a factor of 10.

Neutral Density Filters

Neutral density filters are used in certain applications where it is advantageous to have additional control over the brightness of an image without changing the exposure time or adjusting the $f/\#$. Although there are two primary types of neutral density filters (absorbing and reflecting), their overall responsibility is the same: uniformly lower the light that is transmitted through the lens and onto the sensor. For applications like welding where the imager can be overloaded regardless of the exposure time, neutral density filters can provide the necessary drop in throughput without needing to change the $f/\#$ (which can impact the resolution of the system). Specialty neutral density filters, like apodizing filters, exist to help with hotspots in the center of an image caused by a harsh reflection from an object, but the optical density decreases with radial distance away from the center of the filter.

Polarizing Filters

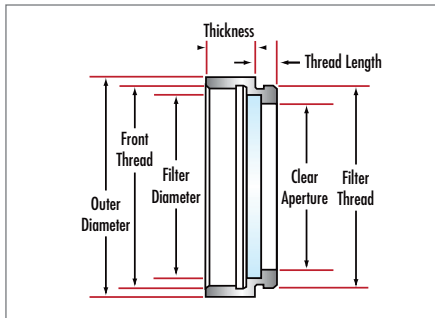
Polarization filters are another common type of filter used in machine vision applications as they allow better imaging of specular objects. In order to properly use polarizing filters, it is important that both the light source and the lens have polarization filters on them. These filters are called the polarizer and the analyzer, respectively. *Figure 8* shows an example of how polarization filters can make a difference when viewing specular objects. In the *Figure 8a*, a CCD imager is being inspected with brightfield illumination and *Figure 8b* shows the same illumination setup with a polarizer on the light source and an analyzer on the lens.

As shown in *Figure 8b*, augmenting the system with polarizers provides superior performance as the harsh reflections are absorbed by the filter on the lens. To ensure the maximum extinction of unwanted glare, the polarizer on the light source must be aligned with its polarization axis 90° from the polarization axis of the polarizer on the lens, otherwise, the lens will still transmit some of the harshly reflected light into the system, causing glare.

It is critical to understand that filters exist to manipulate the contrast of an image in order to help increase the accuracy of the imaging system. Whether it is simple color filtering or polarization filtering, each filter exists to solve a unique problem; it is important to understand what filters should be used for specific applications.

More information on filters, including **technical content** and **transmission curves**, can be found on each TECHSPEC® filter's product page
WWW.EDMUNDOPTICS.COM/FILTERS

TECHSPEC® IMAGING FILTERS



- Optimized for Use with Popular LEDs
- Multiple Mounting Sizes and Threads Available to Ease System Compatibility
- Extremely High and Flat Transmission Profiles Provide Even Illumination

TECHSPEC® Imaging Filters are designed and manufactured for the most demanding machine vision and imaging applications. TECHSPEC® Imaging Filters pass or block specific UV, visible, or IR wavelengths and provide extremely wide angles of incidence. Compared to traditional filters, these hard coated filters provide superior blocking of unwanted light and greater durability for longer lifetimes. Additionally, these filters can be used to improve image contrast and isolate spectral regions and colors.



DIMENSIONS

Filter Thread	Outer Diameter (mm)	Front Thread (to allow for stacking)	Filter Diameter (mm)	Thickness (mm)	Thread Length (mm)	Clear Aperture CA (mm)
M22.5 x 0.50	24.5	M22.5 x 0.50	20.1	4.5	2.0	18.5
M25.5 x 0.50	27.5	M25.5 x 0.50	23.0	4.5	2.0	21.5
M30.5 x 0.50	32.5	M30.5 x 0.50	28.0	5.0	2.0	26.5
M34.0 x 0.50	36.0	M34.0 x 0.50	31.6	5.0	1.5	30.0
M35.5 x 0.50	37.0	M35.5 x 0.50	33.1	5.0	2.0	31.5
M40.5 x 0.50	42.0	M40.5 x 0.50	38.0	5.0	2.0	36.5
M43.0 x 0.75	45.0	M43.0 x 0.75	40.2	5.0	2.0	39.2
M46.0 x 0.75	48.0	M46.0 x 0.75	43.2	4.8	2.2	41.5
M55.0 x 0.75	57.0	M55.0 x 0.75	52.2	4.8	2.2	50.5
M62.0 x 0.75	65.0	M62.0 x 0.75	59.2	5.5	2.5	57.5

COATING SPECIFICATIONS

Filter	Center Wavelength (nm)	Full Width Half Max (nm)	Average Transmission (%)	Absolute Blocking Range (nm)	
				OD ≥ 3.0	OD ≥ 4.0
NUV	330	95	74	400 - 650	200 - 250
Blue	470	85	95	200 - 400	550 - 1200
Cyan	518	95	89	600 - 1000	200 - 450
Green	524	92	94	200 - 450	600 - 1000
UV/IR Cut-Off	548	290	95	200 - 370	750 - 1100
Orange	590	79	89	700 - 1050	200 - 500
Light Red	634	70	93	200 - 550	700 - 1050
Dark Red	660	66	94	200 - 550	720 - 1120
UV/VIS Cut-Off	880	135	96	200 - 750	1000 - 1200

TECHSPEC® IMAGING FILTERS

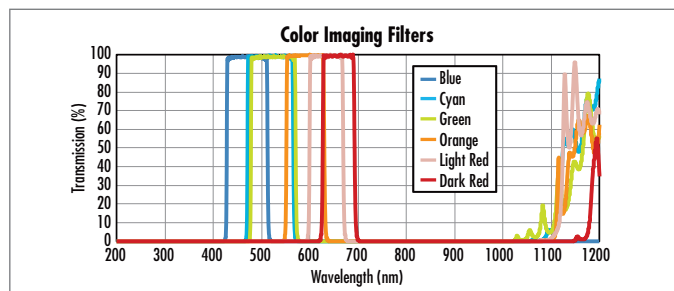
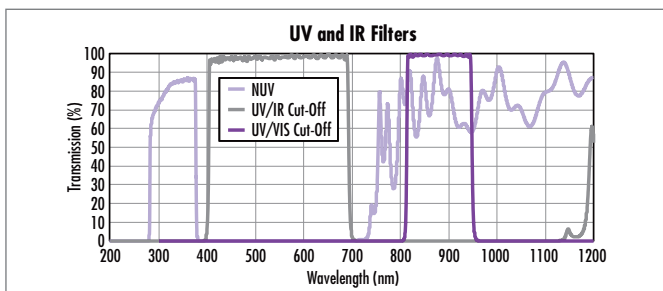
Filter Thread	NUV		Blue		Cyan		Green	
	Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price
M22.5 x 0.50	#89-753	\$120.00	#89-763	\$120.00	#89-773	\$120.00	#89-783	\$120.00
M25.5 x 0.50	#89-754	\$125.00	#89-764	\$125.00	#89-774	\$125.00	#89-784	\$125.00
M30.5 x 0.50	#89-755	\$135.00	#89-765	\$135.00	#89-775	\$135.00	#89-785	\$135.00
M34.0 x 0.50	#89-756	\$145.00	#89-766	\$145.00	#89-776	\$145.00	#89-786	\$145.00
M35.5 x 0.50	#89-757	\$149.00	#89-767	\$149.00	#89-777	\$149.00	#89-787	\$149.00
M40.5 x 0.50	#89-758	\$170.00	#89-768	\$170.00	#89-778	\$170.00	#89-788	\$170.00
M43.0 x 0.75	#89-759	\$175.00	#89-769	\$175.00	#89-779	\$175.00	#89-789	\$175.00
M46.0 x 0.75	#89-760	\$189.00	#89-770	\$189.00	#89-780	\$189.00	#89-790	\$189.00
M55.0 x 0.75	#89-761	\$225.00	#89-771	\$225.00	#89-781	\$225.00	#89-791	\$225.00
M62.0 x 0.75	#89-762	\$285.00	#89-772	\$285.00	#89-782	\$285.00	#89-792	\$285.00

Call For OEM Quantity Pricing

TECHSPEC® IMAGING FILTERS

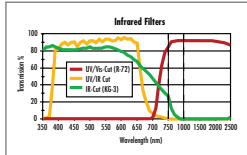
Filter Thread	UV/IR Cut-Off		Orange		Light Red		Dark Red		UV/VIS Cut-Off	
	Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price
M22.5 x 0.50	#89-793	\$115.00	#89-803	\$120.00	#89-813	\$115.00	#89-823	\$115.00	#89-833	\$115.00
M25.5 x 0.50	#89-794	\$118.00	#89-804	\$125.00	#89-814	\$118.00	#89-824	\$118.00	#89-834	\$118.00
M30.5 x 0.50	#89-795	\$125.00	#89-805	\$135.00	#89-815	\$125.00	#89-825	\$125.00	#89-835	\$125.00
M34.0 x 0.50	#89-796	\$130.00	#89-806	\$145.00	#89-816	\$130.00	#89-826	\$130.00	#89-836	\$130.00
M35.5 x 0.50	#89-797	\$135.00	#89-807	\$149.00	#89-817	\$135.00	#89-827	\$135.00	#89-837	\$135.00
M40.5 x 0.50	#89-798	\$155.00	#89-808	\$170.00	#89-818	\$155.00	#89-828	\$155.00	#89-838	\$155.00
M43.0 x 0.75	#89-799	\$160.00	#89-809	\$175.00	#89-819	\$160.00	#89-829	\$160.00	#89-839	\$160.00
M46.0 x 0.75	#89-800	\$169.00	#89-810	\$189.00	#89-820	\$169.00	#89-830	\$169.00	#89-840	\$169.00
M55.0 x 0.75	#89-801	\$199.00	#89-811	\$225.00	#89-821	\$199.00	#89-831	\$199.00	#89-841	\$199.00
M62.0 x 0.75	#89-802	\$255.00	#89-812	\$285.00	#89-822	\$255.00	#89-832	\$255.00	#89-842	\$255.00

Call For OEM Quantity Pricing



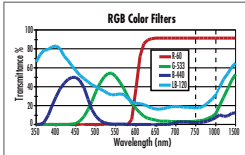
Filters

MOUNTED IMAGING LENS FILTERS



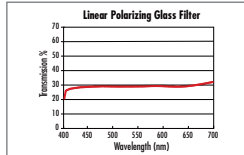
INFRARED FILTERS

- UV/IR Cut: Pass Only Visible, Block UV & NIR
- KG-3: Pass Visible, Block IR
- UV/VIS Cut: Block UV & Visible, Pass NIR



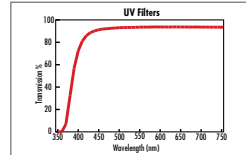
COLOR FILTERS

- Improve Contrast
- Isolate Spectral Regions/Colors
- Like Colors Lighten Like Colors
- Colored Glass for Wider Angles vs. Dichroic Filter



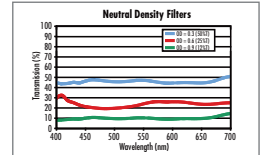
LINEAR POLARIZING FILTERS

- Eliminate Hot Spots
- Improve Illumination Contrast
- Stackable for Variable Control
- Rotating Mount



UV FILTERS

- Blocks UV & Transmits Visible
- Ideal to Protect Lenses & Filters
- Use as Dust Cover



NEUTRAL DENSITY FILTERS

- Uniform VIS Light Reduction
- Light/Exposure Control
- Stackable for Specific Control

INFRARED FILTERS

Filter Thread	IR-Cut (KG-3)		UV/IR-Cut		UV/VIS-Cut (R-72)	
	Stock No.	Price	Stock No.	Price	Stock No.	Price
M25.5 x 0.50	#49-800	\$160.00	#49-808	\$175.00	#65-796	\$67.50
M30.5 x 0.50	#49-801	\$160.00	#49-809	\$175.00	#65-797	\$67.50
M37.0 x 0.75	#49-802	\$165.00	#49-810	\$180.00	N/A	—
M39.0 x 0.50	#49-803	\$165.00	#49-811	\$180.00	N/A	—
M40.5 x 0.50	#49-804	\$170.00	#49-812	\$185.00	N/A	—
M43.0 x 0.75	#49-805	\$170.00	#49-813	\$185.00	N/A	—
M46.0 x 0.75	#54-744	\$170.00	#54-748	\$185.00	#64-887	\$67.50
M49.0 x 0.75	#54-745	\$175.00	#54-749	\$190.00	#54-752	\$67.50
M52.0 x 0.75	#54-746	\$185.00	#54-750	\$205.00	#54-753	\$77.50
M58.0 x 0.75	#54-747	\$185.00	#54-751	\$205.00	#54-754	\$87.50
M62.0 x 0.75	#49-806	\$230.00	#49-814	\$240.00	#64-888	\$127.50
M72.0 x 0.75	N/A	—	N/A	—	#64-889	\$227.50

COLOR FILTERS

Filter Thread	Red		Green		Blue		Daylight Blue	
	Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price
M22.5 x 0.50	#46-539	\$39.00	#46-540	\$39.00	#46-541	\$39.00	N/A	—
M25.5 x 0.50	#46-542	\$39.00	#46-543	\$39.00	#46-544	\$39.00	N/A	—
M30.5 x 0.50	#46-545	\$45.00	#46-546	\$45.00	#46-547	\$45.00	N/A	—
M37.0 x 0.75	#58-642	\$47.50	#58-643	\$47.50	N/A	—	N/A	—
M39.0 x 0.50	#49-797	\$47.50	#49-798	\$47.50	#49-799	\$47.50	N/A	—
M46.0 x 0.75	#54-762	\$47.50	#54-768	\$47.50	#46-571	\$47.50	#54-780	\$47.50
M49.0 x 0.75	#54-763	\$47.50	#54-769	\$47.50	#54-775	\$47.50	#54-781	\$47.50
M52.0 x 0.75	#54-764	\$47.50	#54-770	\$47.50	#54-776	\$47.50	#54-782	\$47.50
M58.0 x 0.75	#54-765	\$47.50	#54-771	\$47.50	#54-777	\$47.50	#54-783	\$47.50
M62.0 x 0.75	#46-532	\$51.50	#46-533	\$51.50	N/A	—	#46-534	\$51.50
M72.0 x 0.75	#46-535	\$57.50	#46-536	\$57.50	N/A	—	#46-537	\$57.50

UV / PROTECTIVE FILTERS

Filter Thread	Stock No.	Price
M22.5 x 0.50	#58-647	\$25.00
M25.5 x 0.50	#46-577	\$30.00
M27.0 x 0.50	#64-891	\$30.00
M30.5 x 0.50	#46-576	\$30.00
M34.0 x 0.50	#64-892	\$30.00
M37.0 x 0.75	#54-039	\$30.00
M37.5 x 0.50	#64-893	\$30.00
M39.0 x 0.50	#46-579	\$31.00
M40.5 x 0.50	#54-725	\$31.00
M43.0 x 0.75	#54-040	\$31.00
M46.0 x 0.75	#54-041	\$31.00
M48.0 x 0.75	#54-042	\$31.00
M49.0 x 0.75	#54-043	\$31.00
M52.0 x 0.75	#54-044	\$33.00
M55.0 x 0.75	#54-045	\$33.00
M58.0 x 0.75	#54-046	\$33.00
M62.0 x 0.75	#54-047	\$36.00
M67.0 x 0.75	#46-578	\$41.00
M72.0 x 0.75	#54-048	\$36.00
M77.0 x 0.75	#64-894	\$59.00
M86.0 x 1.00	#64-895	\$95.00
M105.0 x 1.00	#58-648	\$129.00

LINEAR POLARIZING FILTERS

Filter Thread	Stock No.	Price
M22.5 x 0.50	#58-649	\$29.00
M25.5 x 0.50	#46-575	\$29.00
M27.0 x 0.50	#64-896	\$29.00
M30.5 x 0.50	#46-574	\$31.00
M34.0 x 0.50	#64-897	\$32.00
M35.5 x 0.50	#64-898	\$33.00
M37.0 x 0.75	#52-556	\$33.00
M37.5 x 0.50	#64-899	\$33.00
M40.5 x 0.50	#53-999	\$35.00
M42.0 x 0.75	#52-557	\$35.00
M43.0 x 0.75	#52-558	\$35.00
M46.0 x 0.75	#36-439	\$36.00
M48.0 x 0.75	#52-559	\$37.00
M49.0 x 0.75	#36-440	\$37.00
M52.0 x 0.75	#36-441	\$38.00
M55.0 x 0.75	#36-442	\$38.00
M58.0 x 0.75	#36-443	\$39.00
M62.0 x 0.75	#36-444	\$39.00
M67.0 x 0.75	#64-900	\$43.00
M72.0 x 0.75	#52-560	\$43.00
M77.0 x 0.75	#64-901	\$63.00
M86.0 x 1.00	#64-902	\$120.00
M105.0 x 1.00	#64-903	\$199.00

NEUTRAL DENSITY

Filter Thread	OD 0.3 50%T	OD 0.6 25%T	OD 0.9 12%T	Price
M22.5 x 0.50	#59-162	#59-167	#59-172	\$29.00
M25.5 x 0.50	#59-163	#59-168	#59-173	\$30.00
M30.5 x 0.50	#59-164	#59-169	#59-174	\$32.00
M37.0 x 0.75	#59-165	#59-170	#59-175	\$34.00
M39.0 x 0.50	#59-166	#59-171	#59-176	\$35.00
M46.0 x 0.75	#54-728	#54-734	#54-740	\$37.50
M49.0 x 0.75	#54-729	#54-735	#54-741	\$39.00
M52.0 x 0.75	#54-730	#54-736	#54-742	\$39.00
M55.0 x 0.75	#65-014	#65-018	#65-022	\$41.00
M58.0 x 0.75	#54-731	#54-737	#54-743	\$43.00
M62.0 x 0.75	#65-015	#65-019	#65-023	\$45.00
M72.0 x 0.75	#65-016	#65-020	#65-024	\$60.00
M77.0 x 0.75	#65-017	#65-021	#65-025	\$65.00

Kit including all 11 M25.5 x 0.5 Filters

#66-156 \$495.00



TECHSPEC® M25.5 AND M30.5 MOUNTED FILTERS

- Mounts Available Separately to Hold any 25mm Diameter Filter
- Mounted ND, Shortpass, and Longpass Filters Available

We've specially designed our M25.5 x 0.5 and M30.5 x 0.5 diameter mounts to hold any of our 25 or 25.4mm diameter filters. Mounts allow for up to 6.5mm filter thickness, making them ideal for stacking multiple ND filters, or for creating custom band-pass filters from longpass and shortpass filter combinations. M25.5 x 0.5 Mounted Filters are ideal for use with our TECHSPEC® C Series Fixed Focal Length Lenses; the M30.5 x 0.5 Mounted Filters are well-suited to our MegaPixel Fixed Focal Length Lenses. See website for more options.



	M25.5	M30.5	1-5	6-25
Empty Mount for 25mm Filters	#65-800	#65-801	\$35.00	\$29.75

SHORTPASS FILTERS				
Cut-Off Wavelength	Transmission Band	M25.5 Filter	M30.5 Filter	Price
400nm	250 - 385nm	#66-639	#66-654	\$125.00
450nm	250 - 430nm	#66-640	#66-655	\$125.00
500nm	250 - 480nm	#66-641	#66-656	\$125.00
550nm	400 - 530nm	#66-642	#66-657	\$125.00
600nm	400 - 580nm	#66-643	#66-658	\$125.00
650nm	400 - 630nm	#66-644	#66-659	\$125.00
700nm	400 - 680nm	#66-645	#66-660	\$125.00
750nm	400 - 725nm	#66-646	#66-661	\$125.00
800nm	400 - 775nm	#66-647	#66-662	\$125.00
850nm	400 - 820nm	#66-648	#66-663	\$125.00
900nm	425 - 865nm	#66-649	#66-664	\$125.00
950nm	450 - 910nm	#66-650	#66-665	\$125.00

LONGPASS FILTERS				
Cut-On Wavelength	Transmission Band	M25.5 Filter	M30.5 Filter	Price
400nm	420 - 2000nm	#66-669	#66-684	\$125.00
450nm	470 - 2000nm	#66-670	#66-685	\$125.00
500nm	420 - 2000nm	#66-671	#66-686	\$125.00
550nm	475 - 2000nm	#66-672	#66-687	\$125.00
600nm	625 - 2000nm	#66-673	#66-688	\$125.00
650nm	675 - 2000nm	#66-674	#66-689	\$125.00
700nm	725 - 2000nm	#66-675	#66-690	\$125.00
750nm	780 - 2000nm	#66-676	#66-691	\$125.00
800nm	830 - 2000nm	#66-677	#66-692	\$125.00
850nm	880 - 2000nm	#66-678	#66-693	\$125.00
900nm	935 - 2000nm	#66-679	#66-694	\$125.00
950nm	985 - 2000nm	#66-680	#66-695	\$125.00

ABSORPTIVE ND FILTERS - VISIBLE SPECTRUM				
Optical Density	Average Transmission %	M25.5 Filter	M30.5 Filter	Price
0.10	79	#66-699	#66-714	\$59.00
0.15	70	#66-700	#66-715	\$59.00
0.20	63	#66-701	#66-716	\$59.00
0.30	50	#66-702	#66-717	\$59.00
0.40	40	#66-703	#66-718	\$59.00
0.50	32	#66-704	#66-719	\$59.00
0.60	25	#66-705	#66-720	\$59.00
0.70	20	#66-706	#66-721	\$59.00
0.90	12.5	#66-707	#66-722	\$59.00
1.00	10	#66-708	#66-723	\$59.00
1.30	5.0	#66-709	#66-724	\$59.00
1.50	3.2	#66-710	#66-725	\$59.00
2.00	1.0	#66-711	#66-726	\$59.00
2.50	0.3	#66-712	#66-727	\$59.00
3.00	0.1	#66-713	#66-728	\$59.00

NON-REFLECTIVE ND FILTERS - NIR SPECTRUM				
Optical Density	Average Transmission %	M25.5 Filter	M30.5 Filter	Price
0.30	50	#66-729	#66-739	\$119.00
0.50	32	#66-730	#66-740	\$119.00
0.60	25	#66-731	#66-741	\$119.00
0.90	12.5	#66-732	#66-742	\$119.00
1.00	10	#66-733	#66-743	\$119.00
1.30	5.0	#66-734	#66-744	\$119.00
1.50	3.2	#66-735	#66-745	\$119.00
2.00	1.0	#66-736	#66-746	\$119.00
2.50	0.3	#66-737	#66-747	\$119.00
3.00	0.1	#66-738	#66-748	\$119.00

Visit www.edmundoptics.com/filters for complete filter specifications.



FILTER HOLDERS FOR IMAGING LENSES

- Holds 2" Diameter or Square Filters
- Provides Male M52 x 0.75 Filter Thread Interface
- Step Down Adapter Options for Other Common Filter Thread

These innovative filter holders enable easy integration of 2" and 50mm filters into imaging applications. Swivel feature on the back end of the holder allows for rotation of the optic while mounted. The holder's male M52 x 0.75 thread can be adapted to other standard mounting threads by using the optional filter thread adapters.



FILTER HOLDERS FOR IMAGING LENSES		
2" Square Threaded Filter Holder	#59-445	\$40.00
2" Diameter Threaded Filter Holder	#83-340	\$40.00

FILTER THREAD ADAPTERS			
Filter Threading	Stock No.	Price	
M58 x 0.75	#59-447	\$25.00	
M55 x 0.75	#59-446	\$25.00	
M49 x 0.75	#59-448	\$25.00	
M48 x 0.75	#59-449	\$25.00	
M46 x 0.75	#59-450	\$25.00	

FILTER THREAD ADAPTERS			
Filter Threading	Stock No.	Price	
M40.5 x 0.5	#59-453	\$40.00	
M39 x 0.5	#59-454	\$45.00	
M37 x 0.75	#59-455	\$45.00	

FILTER ADAPTER RINGS

Step rings allow the attachment of different size filters and accessories to your lens. Step rings are available in step up and step down rings. To determine which type of ring you need, always start with the filter size that fits on your lens and then compare it to the filter size you want to adapt. Choose a "Step Up" ring if the filter size of the lens is smaller than the filter size that you want to adapt.

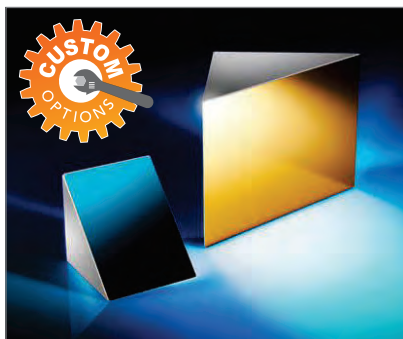


FILTER ADAPTER RINGS - STEP UP RINGS		
Description	Stock No.	Price
M37 to M49 Step Up Ring	#59-015	\$39.00
M52 to M67 Step Up Ring	#59-016	\$39.00

FILTER ADAPTER RINGS - STEP DOWN RINGS		
Description	Stock No.	Price
M43 to M37 Step Down Ring	#56-701	\$39.00
M49 to M43 Step Down Ring	#56-700	\$39.00
M52 to M46 Step Down Ring	#59-019	\$39.00
M58 to M55 Step Down Ring	#59-020	\$39.00

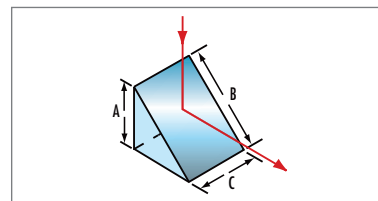
Mirrors

TECHSPEC® RIGHT ANGLE MIRRORS



- Reflects Light at 90°
- Ideal for System Alignment
- Multiple Coatings Available

Available with an enhanced aluminum or protected gold coating, TECHSPEC® Right Angle Mirrors are easily mounted, and are ideal for applications requiring precision alignment and high performance. Right angle mirrors reflect incident light at 90°, and are crucial in many optical systems.



Material: N-BK7
Dimensional Tolerance: ± 0.1 mm
Surface Quality: 40-20
Surface Accuracy: ≤ 25 mm: $\lambda/8$, ≥ 25 mm: $\lambda/4$

Clear Aperture: 90%
Angle Tolerance: ± 2 arcmin
Bevel: Protective as needed
Hypotenuse Coating: As noted

TECHSPEC® RIGHT ANGLE MIRRORS

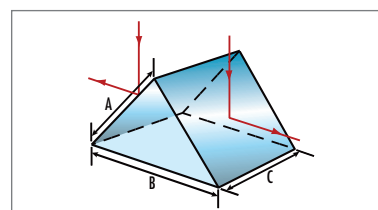
Size (mm) A = C	Size (mm) B	Stock No. Enhanced Aluminum	Enhanced Aluminum			Stock No. Protected Gold	Protected Gold			Stock No. Protected Silver	Protected Silver		
			1-5	6-25	26+		1-5	6-25	26+		1-5	6-25	26+
3.0	4.2	#49-405	\$62.50	\$50.00	Call For OEM Quantity Pricing	#65-844	\$87.50	\$70.00	Call For OEM Quantity Pricing	#89-623	\$77.50	\$62.00	Call For OEM Quantity Pricing
5.0	7.1	#45-591	\$57.50	\$46.00		#47-027	\$82.50	\$66.00		#89-624	\$72.50	\$58.00	
6.25	8.8	#48-383	\$57.50	\$46.00		#48-385	\$82.50	\$66.00		#89-625	\$72.50	\$58.00	
10.0	14.1	#45-592	\$62.50	\$50.00		#47-028	\$87.50	\$70.00		#89-626	\$77.50	\$62.00	
12.5	17.7	#48-384	\$62.50	\$50.00		#48-386	\$87.50	\$70.00		#89-627	\$77.50	\$62.00	
15.0	21.2	#45-593	\$75.00	\$60.00		#48-387	\$100.00	\$80.00		#89-628	\$90.00	\$72.00	
20.0	28.3	#45-594	\$80.00	\$64.00		#47-029	\$105.00	\$84.00		#89-629	\$95.00	\$76.00	
25.0	35.4	#45-595	\$85.00	\$68.00		#47-030	\$110.00	\$88.00		#89-630	\$100.00	\$80.00	
30.0	42.4	#45-687	\$115.00	\$92.00		#47-031	\$140.00	\$112.00		#89-631	\$130.00	\$104.00	
35.0	49.5	#49-406	\$125.00	\$100.00		#65-845	\$150.00	\$120.00		#89-632	\$140.00	\$112.00	
40.0	56.6	#45-688	\$160.00	\$128.00		#65-846	\$185.00	\$148.00		#89-633	\$175.00	\$140.00	
50.0	70.7	#45-689	\$210.00	\$168.00		#47-032	\$235.00	\$188.00		#89-634	\$225.00	\$180.00	
75.0	106.1	#47-307	\$255.00	\$204.00		#47-308	\$280.00	\$224.00		#89-635	\$270.00	\$216.00	

TECHSPEC® 90° SPECIALTY MIRRORS



- Splits Input Image Into Two Paths Separated by 180°
- Variety of Sizes and Broadband Coatings Available
- Additional Right Angle Prism Options Available

TECHSPEC® 90° Specialty Mirrors are constructed from right angle prisms with a mirror coating on the two legs and an uncoated hypotenuse. The mirrored surfaces form a precise 90° angle, ideal for splitting an image from a single imaging lens onto two different cameras, or for combining two images onto a single camera.



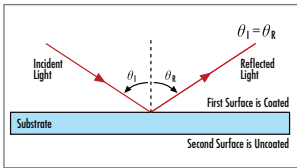
Material: N-BK7
Dimensional Tol.: ± 0.1 mm
Surface Quality: 40-20
Clear Aperture: 90%

Angle Tolerance: ± 2 arcmin
Bevel: Protective, as needed
Coating: As noted

TECHSPEC® 90° SPECIALTY MIRRORS

Size (mm) A = C	Size (mm) B	Surface Accuracy	Stock No. Enhanced Aluminum	Enhanced Aluminum			Stock No. Protected Gold	Protected Gold		
				1-5	6-25	26+		1-5	6-25	26+
5.0	7.1	$\lambda/8$	#49-412	\$85.00	\$68.00	Call	#65-847	\$95.00	\$76.00	Call
10.0	14.1	$\lambda/8$	#47-004	\$99.00	\$80.00		#47-237	\$109.00	\$88.00	
15.0	21.2	$\lambda/8$	#49-413	\$110.00	\$88.00		#65-848	\$120.00	\$96.00	
20.0	28.3	$\lambda/8$	#49-414	\$120.00	\$96.00		#65-849	\$130.00	\$104.00	
25.0	35.4	$\lambda/8$	#47-005	\$130.00	\$104.00		#47-238	\$140.00	\$112.00	
50.0	70.7	$\lambda/4$	#47-006	\$295.00	\$236.00		#47-239	\$300.00	\$240.00	
75.0	106.1	$\lambda/4$	#47-309	\$375.00	\$300.00		#47-310	\$390.00	\$312.00	

TECHSPEC® FIRST SURFACE MIRRORS

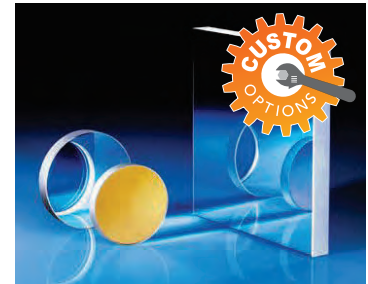


- Wide Variety of Shapes and Sizes Available
- Enhanced Aluminum, Protected Silver, and Protected Gold Coatings
- Contact Us for Custom Sizes

When using our TECHSPEC® First Surface Mirrors, the coated surface is to be facing the incident light in order to minimize energy loss by not allowing light to pass through the glass substrate. The mirrors are available in circular, square, and rectangular dimensions. Rectangular first surface mirrors are ideal for applications requiring the mirror to be mounted at 45° in order to produce a 90° bend in the light path.

Substrate: Float Glass
Dimensional Tolerance: ±0.25mm
Thickness Tolerance: Nominal
Surface Accuracy: 4-6λ per inch

Surface Quality: 60-40
Circular Edges: Ground, 0.5mm max. edge chip
Rectangular Edges: Seamed, 0.5mm max. edge chip
Coating: As Noted



TECHSPEC® FIRST SURFACE MIRRORS

1/2mm Thick

Dimensions (mm)	Thickness (mm)	Enhanced Aluminum				Protected Silver				Protected Gold			
		Stock No.	1-5	6-25	26+	Stock No.	1-5	6-25	26+	Stock No.	1-5	6-25	26+
5.0 Dia.	2.00	#32-940	\$17.00	\$13.50	Call For OEM Quantity Pricing	#89-463	\$21.00	\$16.50	Call For OEM Quantity Pricing	#43-728	\$29.50	\$24.00	Call For OEM Quantity Pricing
6.0 x 6.0	2.00	#43-866	\$17.00	\$13.50		#89-464	\$21.00	\$16.50		#43-877	\$29.50	\$24.00	
6.0 x 8.5	2.00	#43-867	\$17.00	\$13.50		#89-465	\$21.00	\$16.50		#43-878	\$29.50	\$24.00	
6.35 Dia.	2.00	#45-610	\$17.00	\$13.50		#89-466	\$21.00	\$16.50		#45-611	\$29.50	\$24.00	
10.0 Dia.	2.00	#32-941	\$17.00	\$13.50		#89-467	\$21.00	\$16.50		#43-729	\$29.50	\$24.00	
10.0 x 10.0	2.00	#45-517	\$17.00	\$13.50		#89-468	\$21.00	\$16.50		#45-518	\$29.50	\$24.00	
10.0 x 14.0	2.00	#48-449	\$17.00	\$13.50		#89-469	\$21.00	\$16.50		#48-454	\$29.50	\$24.00	
12.5 Dia.	2.00	#32-942	\$17.00	\$13.50		#89-470	\$17.00	\$13.50		#43-730	\$17.00	\$13.50	
12.5 x 12.5	2.00	#43-790	\$17.00	\$13.50		#89-471	\$17.00	\$13.50		#43-791	\$17.00	\$13.50	
12.5 x 17.5	2.00	#43-869	\$17.00	\$13.50		#89-472	\$21.00	\$16.50		#43-880	\$29.50	\$24.00	
12.7 Dia.	2.00	#83-483	\$17.00	\$13.50	Call For OEM Quantity Pricing	*	—	—	Call For OEM Quantity Pricing	#83-493	\$29.50	\$24.00	Call For OEM Quantity Pricing
12.7 x 12.7	2.00	#83-484	\$17.00	\$13.50		*	—	—		#83-494	\$29.50	\$24.00	
15.0 Dia.	3.00	#32-943	\$17.00	\$13.50		#89-475	\$21.00	\$16.50		#43-731	\$29.50	\$24.00	
15.0 x 15.0	3.00	#43-870	\$17.00	\$13.50		#89-476	\$21.00	\$16.50		#43-881	\$29.50	\$24.00	
15.0 x 21.0	3.00	#43-871	\$17.00	\$13.50		#89-477	\$21.00	\$16.50		#43-882	\$29.50	\$24.00	
18.0 Dia.	3.00	#45-521	\$17.00	\$13.50		*	—	—		#45-522	\$29.50	\$24.00	
20.0 Dia.	3.00	#32-944	\$19.00	\$15.50		#89-479	\$23.50	\$18.50		#43-732	\$35.50	\$28.50	
20.0 x 20.0	3.00	#43-872	\$19.00	\$15.50		#89-480	\$23.50	\$18.50		#43-883	\$35.50	\$28.50	
20.0 x 28.0	3.00	#43-873	\$19.00	\$15.50		#89-481	\$23.50	\$18.50		#43-884	\$35.50	\$28.50	
25.0 Dia.	3.00	#32-945	\$19.00	\$15.50		#89-482	\$23.50	\$18.50		#43-733	\$29.00	\$23.50	
25.0 x 25.0	3.00	#43-792	\$19.00	\$15.50	Call For OEM Quantity Pricing	#89-483	\$23.50	\$18.50	Call For OEM Quantity Pricing	#43-793	\$30.00	\$24.00	Call For OEM Quantity Pricing
25.0 x 35.0	3.00	#43-875	\$19.00	\$15.50		#89-484	\$23.50	\$18.50		#43-886	\$35.50	\$28.50	
25.4 Dia.	3.00	#83-485	\$19.00	\$15.50		*	—	—		#83-495	\$35.50	\$28.50	
25.4 x 25.4	3.00	#83-486	\$19.00	\$15.50		*	—	—		#83-496	\$35.50	\$28.50	
30.0 Dia.	3.00	#46-025	\$22.00	\$18.00		#89-487	\$27.50	\$22.00		#46-026	\$59.00	\$47.50	
35.0 Dia.	3.00	#46-027	\$22.00	\$18.00		#89-488	\$27.50	\$22.00		#46-028	\$59.00	\$47.50	
35.0 x 35.0	3.00	#45-519	\$22.00	\$18.00		#89-489	\$27.50	\$22.00		#45-520	\$59.00	\$47.50	
35.0 x 50.0	3.00	#48-450	\$22.00	\$18.00		#89-490	\$27.50	\$22.00		#48-455	\$59.00	\$47.50	
38.1 Dia.	3.00	#83-487	\$22.00	\$18.00		*	—	—		#83-497	\$59.00	\$47.50	
38.1 x 38.1	3.00	#83-488	\$22.00	\$18.00		*	—	—		#83-498	\$59.00	\$47.50	
40.0 Dia.	3.00	#45-612	\$28.00	\$22.50	Call For OEM Quantity Pricing	*	—	—	Call For OEM Quantity Pricing	#45-613	\$59.00	\$47.50	Call For OEM Quantity Pricing
50.0 Dia.	3.00	#45-614	\$28.00	\$22.50		#89-494	\$35.00	\$28.00		#45-615	\$50.00	\$40.00	
50.0 x 50.0	3.00	#43-876	\$28.00	\$22.50		#89-495	\$35.00	\$28.00		#43-887	\$58.00	\$46.50	
50.0 x 75.0	3.00	#48-451	\$28.00	\$22.50		#89-496	\$35.00	\$28.00		#48-456	\$68.00	\$54.50	
50.8 Dia.	3.00	#83-489	\$28.00	\$22.50		*	—	—		#83-499	\$68.00	\$54.50	
50.8 x 50.8	3.00	#83-490	\$28.00	\$22.50		*	—	—		#83-500	\$68.00	\$54.50	
60.0 x 85.0	3.00	#64-410	\$34.00	\$27.50		*	—	—		#64-411	\$68.00	\$54.50	
75.0 Dia.	3.00	#45-616	\$34.00	\$27.50		*	—	—		#45-617	\$90.00	\$72.00	
75.0 x 75.0	3.00	#48-452	\$34.00	\$27.50		*	—	—		#48-457	\$90.00	\$72.00	
75.0 x 100.0	3.00	#48-453	\$34.00	\$27.50		*	—	—		#48-458	\$90.00	\$72.00	
76.2 Dia.	3.00	#83-491	\$34.00	\$27.50	Call For OEM Quantity Pricing	*	—	—	Call For OEM Quantity Pricing	#83-501	\$90.00	\$72.00	Call For OEM Quantity Pricing
76.2 x 76.2	3.00	#83-492	\$34.00	\$27.50		*	—	—		#83-502	\$90.00	\$72.00	

TECHSPEC® 45° REFLECTIVE DICHROIC COLOR FILTERS

Substrate: N-BK7
Thickness: 12.5mm, 35 x 35mm: 3.0 ±0.20mm
 25.0mm, 50 x 50mm: 4.0 ±0.20mm
Dimensional Tolerance: ±0.25mm
Clear Aperture: >90%
Surface Quality: 60-40
Surface Accuracy: λ/4
Parallelism: <1 arcmin
Angle of Incidence: 45°
Coating Tolerances: ±15nm

- Reflects Stated Color While Transmitting Remaining Visible Spectrum
- Ideal for Color Separation Applications
- Precision N-BK7 Substrate

Our Reflective Dichroic Color Filters are designed to be used at a 45° angle of incidence and will reflect the stated color while transmitting the remaining visible wavelengths. EO's Reflective Dichroics boast higher performance and a better quality substrate than other readily available color processing filters. Each filter provides greater than 98% reflection over the specified color range and greater than 90% transmission of the remaining wavelengths.



TECHSPEC® 45° DICHROIC COLOR FILTERS

Color	R _{avg} > 98%	R _{avg} = 50%	12.5mm Diameter	25.0mm Diameter	35 x 35mm	50 x 50mm
Red	640 - 750nm	615nm	#47-263	#47-266	#49-471	#47-948
Blue	400 - 475nm	510nm	#47-264	#47-267	#49-472	#47-949
Green	535nm	FWHM = 65nm	#47-265	#47-268	#49-473	#47-950
Cyan	400 - 565nm	590nm	#66-242	#66-245	#66-248	#66-251
Yellow	550 - 725nm	520nm	#66-243	#66-246	#66-249	#66-252
Magenta	400 - 465nm & 635 - 725nm	495 & 605nm	#66-244	#66-247	#66-250	#66-253
Price (1-10)			\$65.00	\$75.00	\$99.00	\$125.00
Price (11-25)			\$50.00	\$60.00	\$80.00	\$100.00
Price (26+)			Call For OEM Quantity Pricing			

InfiniProbe™ TS-160 Universal Macro/Micro System



Camera not included.



Camera not included.

- High Resolution Design for up to 35mm Sensors
- 0X - 4X Macro and 4X - 16X Micro Configurations
- Internally Focuses from 18mm to Infinity

The InfiniProbe™ TS-160 Universal Macro/Micro System is a universal lens system that redefines on-the-go adaptability. The InfiniProbe™ TS-160 Universal Macro/Micro System is designed to transform almost any machine vision, scientific-grade, or DSLR camera into an ultra-portable, continuously-focusable microscope that is ideal for forensic, industrial, or biological applications such as entomological microscopy. Additionally, the TS-160 is optimized for up to 35mm sensors and is compatible with CS-, C-, T-, and F-mount cameras. To maximize adaptability, the TS-160 can internally focus from 18mm to infinity and internally accept any 25mm filter. When not being used in the field, the TS-160 can be mounted to stands or fixtures for use in the lab. InfiniLight™ adapters are available for mounting popular brand-name flash units directly onto the TS-160. Note: The main body and an objective are required for operation. **Please contact technical support to discuss your specific requirements.**



Wasp Image taken with
InfiniProbe™ TS-160 in the Field

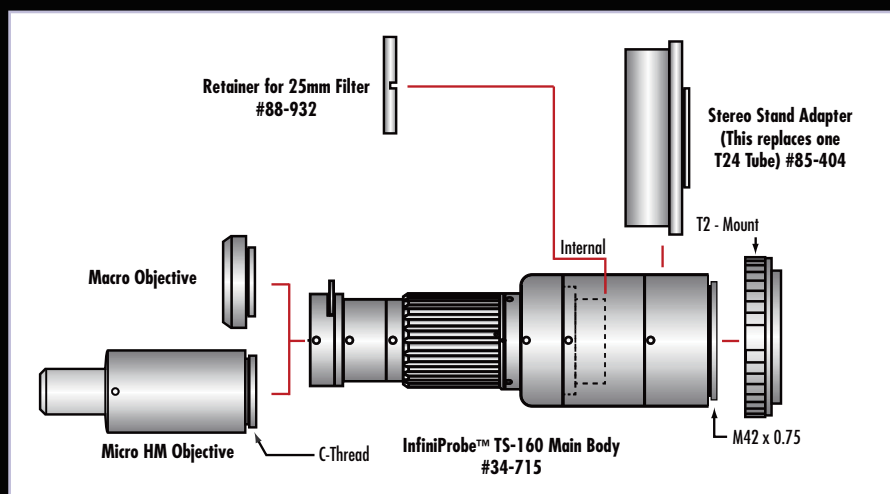


Image of Bullet Casing taken with
InfiniProbe™ TS-160 in the Lab

InfiniProbe™ TS-160 Universal



InfiniProbe™ TS-160 with Macro Objective and Mounting Bar



Many Configuration Options



InfiniLight™ T24 Spacer for Canon and Nikon Macro Flash



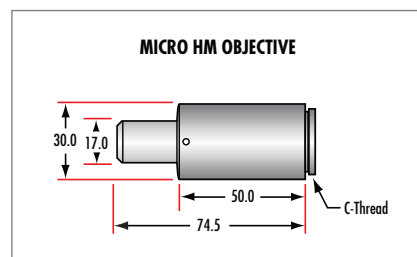
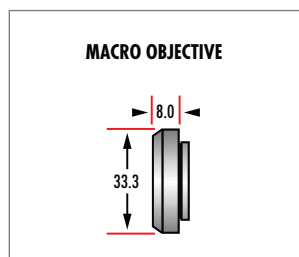
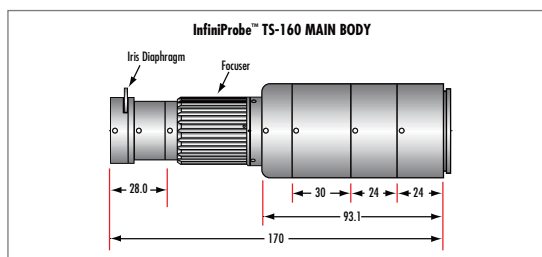
Can be mounted directly to your DSLR for field use



Put your DSLR and Flash Directly on the TS-160 and Mount in a Stand, just one of many configurations

InfiniProbe™ TS-160 UNIVERSAL		
Main Assembly with M42 x 0.75 Thread (Required)		
N InfiniProbe™ TS-160 (Includes Micro HM and Macro Objectives and T24 and T30 tubes)	#34-715	\$3,125.00
Optional Accessories		
Compressor Lens	#85-408	\$295.00
C-Mount Adapter	#88-956	\$45.00
T2 (M42 x 0.75) to Canon EOS Adapter	#85-401	\$30.00
T2 (M42 x 0.75) to Olympus Camera Adapter	#85-402	\$30.00
T2 (M42 x 0.75) to Nikon F-Mount Camera Adapter	#85-403	\$30.00
Mounting Clamp	#85-400	\$85.00
Mounting Bar	#86-888	\$95.00
Microscope Stand	#59-418	\$170.00
Microscope Stand Adapter for #59-418	#85-404	\$135.00
InfiniLight™ T24 Spacer for Canon Macro Flash	#88-576	\$195.00
InfiniLight™ T24 Spacer for Nikon Macro Flash	#88-577	\$195.00

OBJECTIVE MAGNIFICATION TABLE (ALL COVER 35mm SENSOR)								
Macro (One T24 Tube)			Macro (Two T24 Tubes and Compressor Lens)			Micro (One T24 Tube)		
WD (mm)	Magnification	FOV (mm)	WD (mm)	Magnification	FOV (mm)	WD (mm)	Magnification	FOV (mm)
32	4.0X	9.0	21	4.0X	9.0	18	16.0X	2.3
44	2.8X	12.9	24	3.5X	10.3	20	12.0X	3.0
66	2.0X	18.0	28	3.0X	12.0	21	10.0X	3.6
94	1.5X	24.0	32	2.75X	13.1	24	5.0X	7.2
139	1.0X	36.0	49	2.0X	18.0	27	4.0X	9.0
189	0.75X	48.0	69	1.5X	24.0	—	—	—
214	0.66X	54.5	107	1.0X	36.0	—	—	—
239	0.6X	60.0	—	—	—	—	—	—
284	0.5X	72.0	—	—	—	—	—	—



Visit our website for the InfiniProbe MS™, for your C-Mount needs with up to 1" sensors

Infinity Photo-Optical Lenses

InfiniTube™ STANDARD

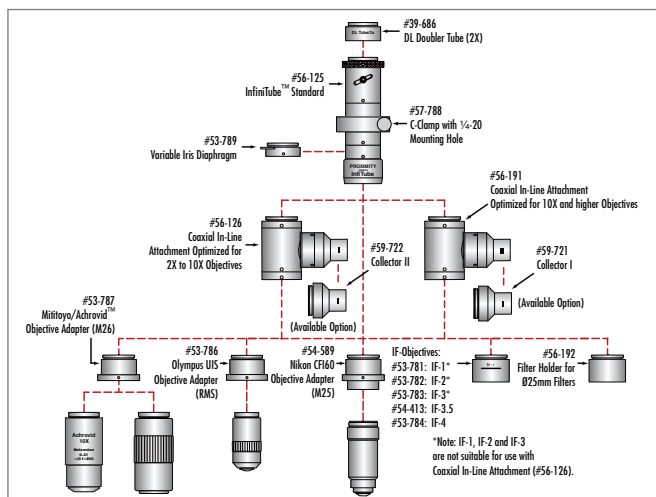


- Max. Format $\frac{3}{8}$ "
- Direct to Video CS / C-Mount
- Internal Focusing
- Conventional / In-Line Illumination Option
- Requires Achrovid™ / Mitutoyo Olympus / Nikon Objectives
- Optional 25mm Filter Holder

InfiniTube™ STANDARD

Description	Stock No.	Price
ONE REQUIRED		
Standard (no In-Line Attachment)	#56-125*	\$895.00
Standard with Iris	#65-607*	\$1,075.00
Standard 1.5X Magnification	#65-608*	\$1,075.00
Standard 1.5X Magnification with Iris	#65-609*	\$1,150.00
Standard Dual Port	#65-610	\$1,735.00
Standard Right Angle	#65-611	\$1,535.00
$\frac{3}{8}$ " In-Line Assembly (#56-125 & #56-191)	#54-590*	\$1,775.00
ONE REQUIRED for In-Line Illumination		
Standard In-Line (Optimized for 10X and higher objectives)	#56-191	\$895.00
Standard In-Line (Optimized for 2X to 10X objectives)	#56-126	\$895.00
ONE REQUIRED		
Mitutoyo / Achrovid™ Objective Adapter (M26)	#53-787	\$150.00
Nikon CF160 Objective Adapter (M25)	#54-589	\$160.00
Olympus UIS Objective Adapter (RMS)	#53-786	\$150.00
OPTIONAL		
Filter Holder 24 - 25mm (2 - 12mm thickness)	#56-192	\$85.00
C-Clamp with $\frac{1}{4}$ -20 Mounting Hole (not included with some lenses)	#57-788	\$95.00
DL Doubler Tube	#39-686	\$195.00

*Includes Mounting Clamp #57-788



InfiniTube™ FM



- Best Value
- Direct to CS / C-Mount to $\frac{1}{2}$ " Format
- Ultra-Compact
- Mini Low Priced PL-Series Long WD Objectives Mount Directly
- Internal Focusing
- In-Line Coaxial Illumination Option
- Accepts 9mm Filters
- Rotatable Polarization-Capable
- Adaptable to Achrovid™ / Mitutoyo / Olympus and Nikon Objectives

InfiniTube™ FM

Description	Stock No.	Price
ONE REQUIRED		
FM-50 Main Body (0.25X)*	#62-832	\$525.00
FM-75 Main Body (0.33X)*	#62-833	\$525.00
FM-100 Main Body (0.5X)	#58-309	\$525.00
FM-200 Main Body (1X)	#58-310	\$525.00
Combined $\frac{1}{2}$ " In-Line Assembly and FM-200 (#58-310 & #58-312)	#58-311	\$995.00
OPTIONAL		
In-Line Attachment (Optimized for 10X and higher objectives)	#58-312	\$525.00
In-Line Attachment (Optimized for 2X to 10X objectives)	#58-313	\$525.00
Collector I - LM. Turns #58-312 into #58-313	#59-471	\$95.00
Collector II - HM. Turns #58-313 into #58-312	#59-472	\$95.00
ONE REQUIRED		
PL-SERIES OBJECTIVES (Directly Attach to FM-body)		
Regular PL's can be used In-line.		
On FM-50 Main body, multiply objective rated power by 1X		
On FM-75 Main body, multiply objective rated power by 1.5X		
On FM-100 Main body, multiply objective rated power by 2X		
On FM-200 Main body, multiply objective rated power by 4X		
PL-94mm WD/0.50X	#55-405	\$150.00
PL-68mm WD/0.66X	#55-404	\$150.00
PL-44mm WD/1.0X	#55-403	\$150.00
PL-18mm WD/2.0X	#55-402	\$150.00
PL/FD-390mm WD/0.125X (not for In-line use)	#59-117	\$325.00
PL/FD-295mm WD/0.165X (not for In-line use)	#59-116	\$325.00
PL/FD-195mm WD/0.25X (not for In-line use)	#59-115	\$325.00
ADAPTERS FOR LARGER INFINITY-CORRECTED OBJECTIVES		
Mitutoyo/Achrovid™ Objective Adapter (M26)	#58-316	\$75.00
Mitutoyo/Achrovid™ 2X (only) Objective Adapter (M26)	#58-949	\$75.00
Nikon CF160 Objective Adapter (M25)	#58-315	\$95.00
Olympus UIS-2 Objective Adapter (RMS)	#58-314	\$85.00
OPTIONAL		
DL Doubler Tube (2X additional magnification)	#39-686	\$195.00
C-Clamp with $\frac{1}{4}$ -20 Mounting (not supplied with main bodies)	#57-788	\$95.00
Complete $\frac{1}{2}$ " In-Line System	#58-348	\$3,835.00

*When using FM-50 and 75 with inline, DL Doubler tube is recommended for sensors larger than $\frac{1}{2}$ "

OBJECTIVES

Magnification	Numerical Aperture	FOV ($\frac{3}{8}$ " Camera Sensor)	FOV ($\frac{1}{2}$ " Camera Sensor)	Working Distance	Focal Length	Depth of Focus	Resolving Power	Stock No.	Price
MITUTOYO M PLAN APO OBJECTIVES									
2X	0.055	4.40 x 3.30mm	3.20 x 2.40mm	34.0mm	100mm	91.0µm	5.0µm	#46-142	\$935.00
5X	0.14	1.80 x 1.32mm	1.28 x 0.96mm	34.0mm	40mm	14.0µm	2.0µm	#46-143	\$705.00
7.5X	0.21	1.17 x 0.88mm	0.85 x 0.64mm	35.0mm	26.67mm	6.2µm	1.3µm	#66-383	\$1,365.00
10X	0.28	0.88 x 0.66mm	0.64 x 0.48mm	33.5mm	20mm	3.5µm	1.0µm	#46-144	\$885.00
20X	0.42	0.44 x 0.33mm	0.32 x 0.24mm	20.0mm	10mm	1.6µm	0.7µm	#46-145	\$2,055.00
50X	0.55	0.18 x 0.13mm	0.13 x 0.10mm	13.0mm	4mm	0.9µm	0.5µm	#46-146	\$2,675.00
100X	0.70	0.09 x 0.07mm	0.06 x 0.05mm	6.0mm	2mm	0.6µm	0.4µm	#46-147	\$3,495.00
ACHROVID™ OBJECTIVES									
2X	0.054	4.40 x 3.30mm	3.20 x 2.40mm	37.0mm	100mm	91.0µm	6.2µm	#56-121	\$450.00
2.5X	0.064	3.52 x 2.64mm	2.56 x 1.92mm	37.0mm	80mm	75.0µm	5.2µm	#56-122	\$450.00
3.3X	0.077	2.67 x 2.00mm	1.94 x 1.45mm	37.0mm	60mm	45.0µm	4.3µm	#56-123	\$450.00
4X	0.09	2.20 x 1.65mm	1.60 x 1.20mm	37.0mm	50mm	25.0µm	3.7µm	#56-124	\$450.00
5X	0.12	1.80 x 1.32mm	1.28 x 0.96mm	37.0mm	40mm	16.0µm	2.8µm	#55-790	\$450.00
10X	0.21	0.88 x 0.66mm	0.64 x 0.48mm	17.5mm	20mm	4.5µm	1.6µm	#55-791	\$495.00

Infinity Photo-Optical Lenses

INFINITY K2 / DistaMax™ LONG DISTANCE VIDEO MICROSCOPE

- **Most Advanced Research-Grade Tube System**
- **3X Greater Magnification than Other Coaxial In-line Systems**
- **Focus from Infinity to 54mm**
- **CentriTel® Focuser Available**

Recognized as the standard in Long-Distance microscopes, the K2 DistaMax™ now incorporates a patented IVS focus system, further improving what was already a top performer, and making the K2 DistaMax™ easier to use than previous models. To begin using the K2 DistaMax™, simply choose an objective for the front and a camera mount for the rear. The K2 DistaMax™ offers high magnifications and a dynamic working distance range, covering all sensors up to 35mm (43mm diagonal) formats. The K2 DistaMax™ Single-Port package includes a manual iris for light level and depth of field control. The Dual-Port package includes a right angle mirror for switching between views (not simultaneous viewing), in addition to the parts included in the Single-Port package. The K2 DistaMax™ is ideal for applications ranging from remote vacuum chamber viewing to on-line process control.

The NWE Objective allows focus from infinity to as near as 675mm. Perhaps the most versatile K2 DistaMax™ objective, the NWE also can be used with the Microscope Objective Adapter Disc and other accessories. All objectives attach directly to a front dovetail. When combined with NWE Objective, Microscope Objective Adapter Disc, and Objective Adapter, the K2 DistaMax™ can interface common infinity-corrected microscope objectives, even when the Coaxial In-line Illuminator is used, making it a powerful direct coaxial in-line system. To enable CentriTel® for all formats simply add the CentiTel® Focuser, #87-430. For viewing through an eyepiece (not included), adapter #58-796 is required. The recommended eyepiece is #37-692, which accepts 19mm diameter reticles.



One Main Body Required		
K2 Single Port	#87-426	\$5,450.00
K2 Dual Port	#87-427	\$6,780.00
One Required		
C-Mount Camera Adapter	#88-956	\$45.00
Nikon F-Mount Camera Adapter	#42-835	\$55.00
62mm Eyepiece Tube (for viewing)	#58-796	\$85.00
Optional Amplifiers		
CF Tube (1.66x)	#65-041	\$425.00
DL Doubler Tube (2X Video)	#39-686	\$195.00
Lockable Doubler Tube (2X Video)	#57-714	\$275.00
NTX Tube 2X	#86-892	\$475.00
Zoom Module (1X - 2.2X)	#59-238	\$1,450.00
Optional		
CentriTel® Focuser	#87-430	\$1,995.00
Mounting Bar	#86-888	\$95.00

One Required		
Standard and Close-Focus Range		
K2 Objective NWE	#87-428	\$665.00
K2 Objective STD	#39-339	\$665.00
K2 Objective CF-1	#39-340	\$665.00
K2 Objective CF-1/B	#57-721	\$695.00
K2 Objective CF-2	#39-341	\$795.00
K2 Objective CF-3	#39-342	\$795.00
K2 Objective CF-4	#52-829	\$695.00
High-Power Micro Range		
K2 Microscope Adapter Disc	#87-429	\$150.00
Mitutoyo/Achrovid Objective Adapter (M26)	#53-787	\$150.00
Nikon CF160 Objective Adapter (M25)	#54-589	\$160.00
Olympus UIS Objective Adapter (RMS)	#53-786	\$150.00
Polarizer Set for #56-191	#59-768	\$110.00
Coaxial In-Line Illuminator	#56-191	\$895.00

Eyepiece:	Not Included, see table
Depth of Field:	Continuously variable
Image:	Inverted (straight); Erect, right to left reverse (top dual port)
Objective Filter:	Accepts 49 x 0.75mm Dia. Filters
Thread:	(M27 x 0.5 for CF-4)
Iris:	Variable 30 - 1.2mm
Dimensions:	66mm Max Dia. x 290mm L (without objective)
Weight:	3.5 lbs
Mounting:	Ring clamp with 1/4-20 (x1) and M4 (x2)

K2 OBJECTIVE OPTIONS

*It is no coincidence that the NWE Objective's initials were chosen by Infinity Photo-Optical to honor the memory of EO's inspirational founder, Norman W. Edmund® - Jay Margolis, President of Infinity Photo-Optical.

	NWE*	STD (w/o S Lens)	CF-1	CF-1/B	CF-2	CF-3	CF-4
Primary Magnification:	0.6X - 0.12X	0.95X - 0.31X	1.5X - 0.5X	2.13X - 0.71X	2.29X - 1.36X	3.05X - 2.06X	5.33X - 4.27X
Field of View (1/2" sensor) (mm):	10.7 - 53.3	6.74 - 20.5	3 - 12.2	4.3 - 9.0	2.8 - 4.7	2.1 - 3.1	1.20 - 1.50
Working Distance (mm):	675 - ∞	360 - 980	265 - 580	222 - 418	138 - 205	92 - 125	55 - 63
Size (Dia. x L) (mm):	58 x 53	58 x 53	58 x 65	58 x 53	58 x 41	58 x 68	48 x 54.7

InfiniTube™ ULTIMA MICROSCOPE TUBE LENSES

- **Enables Dynamic Optical Focusing**
- **Compatible with Full-Frame 35mm Sensors**
- **Color-Matched for all Infinity Corrected Objectives**

InfiniTube™ Ultima Microscope Tube Lenses utilize the optics and accessories of the InFocus™ objective line, with simplified mounting capabilities for greater flexibility. An added feature allows for integration to larger full frame camera sensors for higher resolution imaging. These dynamic optical focusing systems eliminate the need for correction collars and expensive motorized actuators. Available in three versions, these modules are simplified by maintaining plan fields and mechanical dimensions across each option. InfiniTube™ Ultima Microscope Tube Lenses are ideal for high powered microscope applications such as confocal microscopy and imaging of thick biological specimens. **Note:** One objective and adapter are required for use.



NEW

InfiniTube™ ULTIMA MICROSCOPE TUBE LENSES

Description	Stock No.	Price
ONE MAIN BODY REQUIRED		
InfiniTube™ Ultima - Nikon/Olympus/Mitutoyo	#34-482	\$1,599.00
InfiniTube™ Ultima - Zeiss	#34-483	\$1,599.00
InfiniTube™ Ultima - Leica	#34-484	\$1,599.00
ONE REQUIRED		
C-Mount Camera Adapter	#88-956	\$45.00
Nikon F-Mount Camera Adapter	#85-403	\$30.00
Canon EOS Camera Adapter	#85-401	\$30.00
Olympus Camera Adapter	#85-402	\$30.00
Description		
ONE REQUIRED		
Mitutoyo Objective	336-137, web	
Olympus Objective	138, web	
Nikon Objective	139, web	
Achrovid Objective	130	
Male T-Mount to Female C-Mount Adapter*	#58-753	\$30.00

*Adapter Required for Use

InfiniTube™ ULTIMA ADAPTERS AND ACCESSORIES

Description	Stock No.	Price
OPTIONAL AMPLIFIERS		
DL Doubler Tube	#39-686	\$195.00
NTX Tube 2X	#86-892	\$475.00
OPTIONAL MICROSCOPE OBJECTIVE ADAPTERS		
RMS Objective Adapter	#53-786	\$150.00
Mitutoyo/Edmund/Achrovid Adapter	#53-787	\$150.00
Nikon (M25) Objective Adapter	#54-589	\$160.00
OPTIONAL MICROSCOPE STAND ADAPTERS		
Olympus Stand Adapter	#34-485	\$195.00
Nikon Stand Adapter	#34-486	\$195.00
Leica Stand Adapter	#34-487	\$245.00
Zeiss Axio Stand Adapter	#34-488	\$195.00
Zeiss Standard Adapter	#34-489	\$195.00
OPTIONAL ACCESSORIES		
Coaxial Illuminator (for 2X to 10X objectives)	#56-126	\$895.00
Coaxial Illuminator (for 10X and greater)	#56-191	\$895.00
Mounting Bar	#86-888	\$95.00
Large Mounting Clamp	#85-400	\$85.00

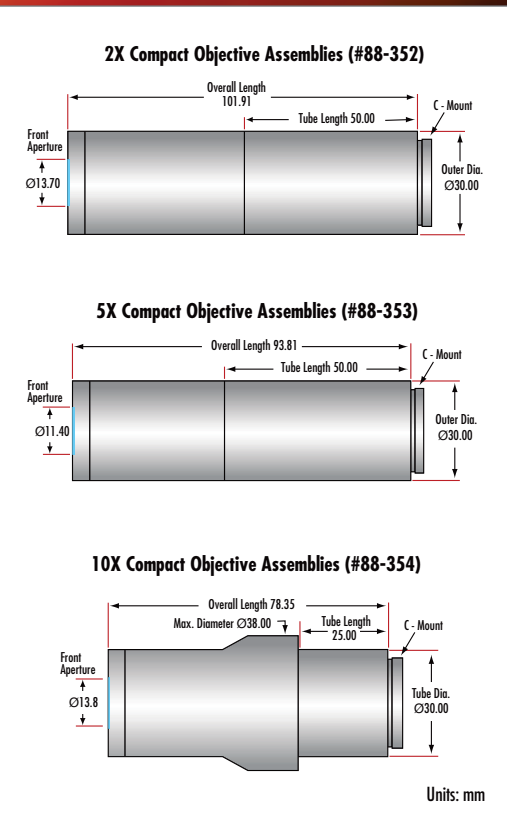
Compact Objective Assemblies



- Lightweight Design with Compact Form Factor
- Configurable Magnification Using Spacers
- Optimized For Long Working Distances
- Easily Increase Magnification by Adding Spacers to Increase Tube Length
- Broadband AR Coating is Optimized for Visible Light Transmission
- Now Featuring Liquid Lens Technology on Select Magnifications

Note: A variety of magnifications and numerical aperture options are available upon request to accommodate various resolution, throughput, and depth of field requirements. To ensure a lens is a proper fit for your application, additional contrast, resolution, magnification, and tube length data is available upon request. Please contact technical support to discuss your specific requirements.

Volume pricing and customization available. An EO-designed and manufactured family.



TECHSPEC® COMPACT OBJECTIVE ASSEMBLIES											Price		
Magnification	Numerical Aperture	Working Distance (mm)	Maximum Sensor Size	Front Aperture (mm)	Dimensions (mm) (L x Dia)	Tube Length (mm)	Field of View $\frac{2}{3}$ " Sensor (mm)	Field of View $\frac{1}{2}$ " Sensor (mm)	Mount	Stock No.	1-5	6-10	11+
2X	0.12	31.3	$\frac{2}{3}$ "	13.7	101.91 x 30	50.0	4.4 x 3.3	3.2 x 2.4	C-Mount	#88-352	\$450.00	\$400.00	C
5X	0.15	16.2	$\frac{2}{3}$ "	11.4	93.81 x 30	50.0	1.8 x 1.32	1.28 x 0.96	C-Mount	#88-353	\$550.00	\$500.00	
10X	0.17	13.5	$\frac{2}{3}$ "	13.8	78.35 x 38	25.0	0.88 x 0.66	0.64 x 0.48	C-Mount	#88-354	\$650.00	\$600.00	

Compact Objective Assemblies

INCREASE MAGNIFICATION BY ADDING TUBE LENGTH			*Approximate. Spacer rings may be needed to dial in magnification
Stock No.	Additional Tube Length Needed	Magnification*	Image
#88-352	None (Base Magnification)	2X	
	70mm	4X	
	104mm	5X	
	191mm	7.5X	
#88-353	None (Base Magnification)	5X	
	40mm	7.5X	
	78mm	10X	
	155mm	15X	
	230mm	20X	
#88-354	None (Base Magnification)	10X	
	30mm	15X	
	60mm	20X	

TECHSPEC® TUNABLE COMPACT OBJECTIVE LIQUID LENS ASSEMBLIES			
Magnification:	2X	5X	Image
Numerical Aperture NA:	0.12	0.15	
Working Distance (mm):	31.3	16.2	
Focus Tunable Range (typical) (mm):	±2	±0.5	
Maximum Sensor Size:	2/3"	2/3"	
Field of View, 2/3" Sensor (mm):	4.4 x 3.3	1.8 x 1.32	#34-713
Field of View, 1/2" Sensor (mm):	3.2 x 2.4	1.28 x 0.96	
Mount:	C-Mount	C-Mount	
Liquid Lens Type:	10mm, VIS Coated, -1.5 - 3.5 diopter range	10mm, VIS Coated, -1.5 - 3.5 diopter range	
Stock No.	 #34-712	 #34-713	
1-5	\$950.00	\$1,050.00	
6-10	\$875.00	\$975.00	
+11	Call for OEM Quantity Pricing		

TECHSPEC® EXTENSION TUBES

TECHSPEC® C-MOUNT EXTENSION TUBES		
Length	Stock No.	Price
5mm	#54-628	\$22.50
10mm	#54-629	\$22.50
15mm	#54-630	\$25.00
25mm	#58-736	\$30.00
40mm	#54-631	\$35.00
50mm	#54-632	\$40.00
100mm	#54-633	\$65.00
111.5mm	#53-838	\$65.00

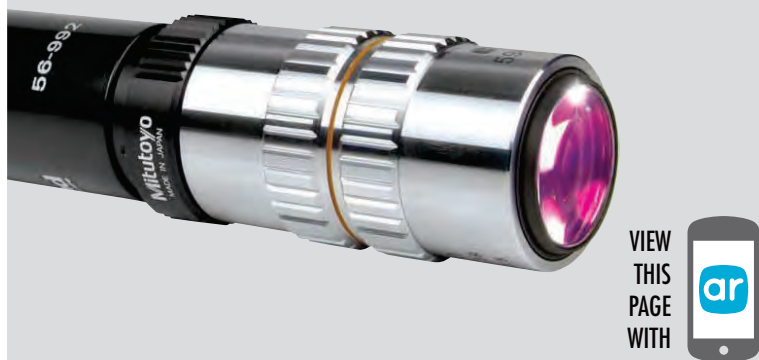


TECHSPEC® BRASS SPACER RINGS

TECHSPEC® C-MOUNT BRASS SPACER RINGS		
Description	Stock No.	Price
0.25mm Spacer Ring	#54-450	\$7.50
0.50mm Spacer Ring	#03-631	\$7.50
1.00mm Spacer Ring	#03-632	\$7.50
1.25mm Spacer Ring	#54-451	\$7.50
1.50mm Spacer Ring	#54-452	\$7.50
2.00mm Spacer Ring	#03-633	\$7.50
Spacer Ring Kit (2 of Each)	#54-461	\$70.00



Using Infinity Corrected Objectives



Microscopy, in its simplest form, allows users to view samples and items that cannot be resolved by the human eye. The technical field of microscopy can be segmented into three separate fields: optical, electron, and physical scanning probe microscopy. Optical microscopy, the focus of this article, relies heavily on properties known as diffraction and refraction. Optical microscopy can be further segmented into a number of techniques: brightfield, darkfield, phase contrast, differential interference contrast (DIC), fluorescence, and confocal based systems. Each technique has a number of similarities and differences; the type of objective used in the system addresses many of these differences.

More information on **infinity corrected objectives** can be found at WWW.EDMUNDOPTICS.COM/OBJECTIVES

Types of Objectives

Microscope objectives are typically grouped under two categories: **finite conjugate** and **infinite conjugate (infinity corrected)**.

In a **finite conjugate** optical design, light from a source (not at infinity) is focused down to a spot. In the case of a microscope, the image of the object under inspection is magnified and projected onto the eyepiece (or sensor if using a camera). The particular distance through the system is characterized by either the DIN or JIS standard; all finite conjugate microscopes are either one of these two standards. These types of objectives account for the majority of basic microscopes, such as systems used for general inspection or assembly purposes. Finite conjugate designs are used in applications where cost and ease of design are major concerns. Additionally, these objectives are typically used for brightfield techniques only.

In an **infinite conjugate**, or infinity-corrected, optical design, light from a source placed at infinity is focused down to a small spot. In an objective, the spot is the object under inspection and infinity points toward the eyepiece (or sensor if using a camera). This type of modern design utilizes an additional tube lens between the object and eyepiece in order to produce an image. Though this design is much more complicated than its finite conjugate counterpart, it allows for the introduction of optical components such as filters, polarizers, and beamsplitters into the optical path (Figure 2). As a result, additional image analysis can be performed in complex systems. For example, adding a filter between the objective and the tube lens allows one to view specific wavelengths of light or to block unwanted wavelengths that would otherwise interfere with the setup. Fluorescence microscopy applications utilize this type of design.

Figure 1

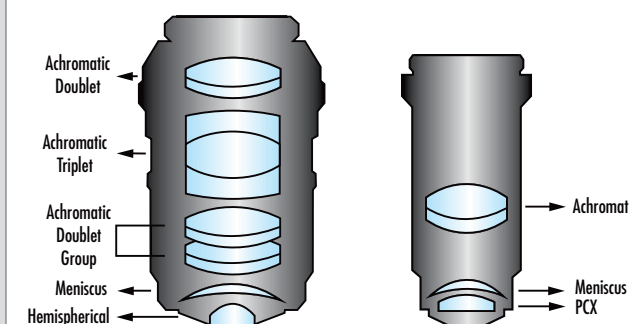


Figure 1: Setup for an Infinity Corrected Objective System.

Another benefit of using an infinite conjugate design is the ability to vary magnification according to specific application needs. Since the objective magnification is the ratio of the tube lens focal length to the objective focal length, increasing or decreasing the tube lens focal length changes the objective magnification. Typically, the tube lens is an achromatic lens with a focal length of 200mm, but other focal lengths can be substituted as well, thereby customizing a microscope system's total magnification. Infinity corrected objectives often incorporate multi element designs and correct for a number of optical errors such as flatness, chromatic aberration, spherical aberration, and polarization. These objectives can be used for almost all microscopy techniques.

Infinity corrected objectives are often designed to address spherical and/or chromatic aberration. Achromatic, apochromatic, planar, and semi-planar objective designs each address a specific optical need. Achromatic objectives are among the simplest and least expensive objectives that account for chromatic aberration. The correction occurs at the red and blue wavelengths, and also account for spherical aberrations at green wavelengths. Limited correction for chromatic aberration and lack of flatness in the field make these suited for simple applications and entry-level users. Apochromatic objectives provide much higher precision and are chromatically corrected for the entire visible spectrum. In addition, they provide spherical aberration correction for two to three wavelengths

Figure 2

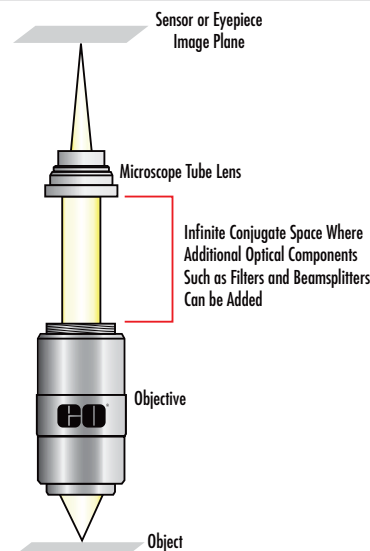


Figure 2: Basic Infinity Corrected Objective Configuration.

and tend to have higher numerical apertures, longer working distances, and typically address field flatness/curvature issues by incorporating semi-planar or planar designs. *Figure 1* illustrates the internal structure differences between apochromatic and achromatic objectives.

Figure 2 illustrates the most basic infinity corrected objective configuration. The objective collects light, which is then focused by the secondary tube lens to the eyepiece or sensor. The image shows a real life microscope system composed of only four components: an infinity corrected objective, a secondary tube lens, an extension tube for stray light control, and a USB camera. Although simple, this system offers little adaptability. As seen in *Figure 3*, a seven-component system can be implemented to create a fluorescent system or to maximize contrast and resolution; in-line illumination ensures there will be less noise in the system and minimizes glaring as well as ghosting in the system.

The seven-component setup can be complicated, but the following explanation aims to make the process as simple as possible. To start, #58-329 MT-1/ MT-2 C-mount Adapter can be opened up and the MT-1 or MT-2

Tube Lenses fit inside. Since the tube lenses themselves have no threads, this adapter provides the necessary C-threads on both sides. Between this adapter and the C-mount camera, an additional 190mm of extension tubes is required. Since the tube lens does not attach directly to the objective, use #55-743 Mitutoyo to C-Mount 10mm Adapter to attach the objective (this adapter adds 10mm of length and adapts the M26 thread to a C-thread). An additional 76.5mm of space between the tube lens and objective is optimal, but it is common to only use about 56.5mm of space between #55-743 and #58-329 since each adapter adds about 10mm of space. With this 56.5mm of space, use extension tubes or add other optical components such as beamsplitters, optical filters, or polarizers as needed.

It is important to note that 76.5mm is the recommended distance since these objectives are infinity corrected. However, if the distance is too short, the system may experience vignetting; if the distance is too long, the resultant image will be dim because of insufficient light. To summarize, refer to *Figure 3* for an illustration of the seven-component digital video microscope system.

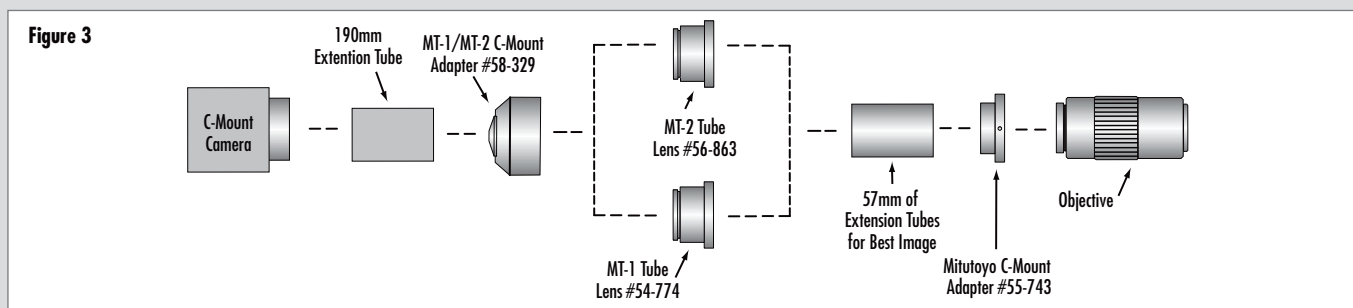


Figure 3: Seven-Component Infinity Corrected Digital Video Microscope System.

Fluorescence Filters for Microscopy

Fluorescence microscopy is an optical microscopy technique that utilizes fluorescence, which is induced using fluorophores, as opposed to absorption, scatter, or reflection. A fluorophore is a type of fluorescent dye used to mark proteins, tissues, and cells with a fluorescent label for examination by fluorescence microscopy. A fluorophore works by absorbing energy of a specific wavelength region, commonly referred to as the excitation range, and re-emitting that energy in another specific wavelength region, commonly referred to as the emission range.

Fluorescence microscope systems can range from very simple, such as an epifluorescent microscope, to extremely complex, such as confocal or multiphoton systems. Whether simple or complex, fluorescence microscopes share the same basic concept: excitation energy is used to illuminate a sample which then produces emission energy, albeit weak, that is quantifiable. The excitation and emission wavelengths do not share the same center wavelength, and this allows specialized optical filters to increase overall contrast and signal.

The most basic concept and schematic can be seen in the *Figure 4*. A filter arrangement is constructed out of three very specific filters: an excitation filter, a dichroic filter, and an emission filter. The excitation filter is placed within the illumination path of a fluorescence microscope, and filters out all wavelengths of the light source except for the excitation range of the fluorophore or specimen under inspection. The dichroic filter is placed between the excitation filter and emission filter at a 45° angle, and reflects the excitation signal towards the fluorophore under inspection while transmitting the emission signal towards the detector. The emission filter is placed within the imaging path of a fluorescence microscope, and filters out the entire excitation range of the fluorophore under inspection while transmitting the emission range of the fluorophore.

A typical excitation and emission profile is shown in *Figure 5*. It is clearly visible that the absorption and emission profiles share common wavelengths, which is one of the main reasons why high quality filters are required with high transmission, narrow bandwidths, high optical densities, and extremely sharp cut-on and cut-off bands. Using low quality filters can ultimately damage the sample, specimen, or expensive sensors.

Figure 4

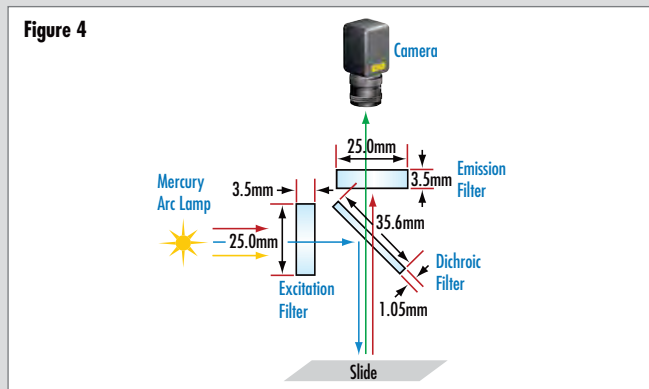


Figure 4: Basic Fluorescence Microscope Setup.

Figure 5

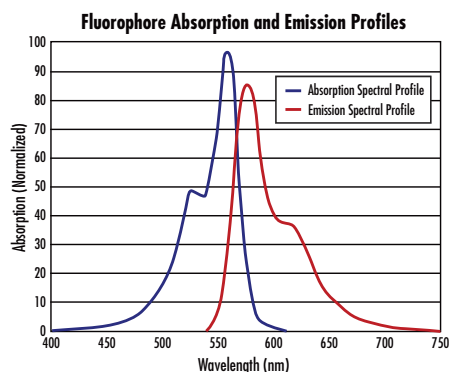


Figure 5: Typical excitation and emission profile.

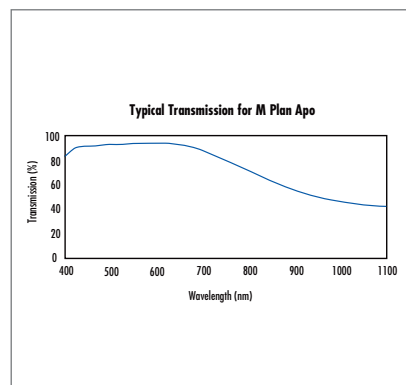
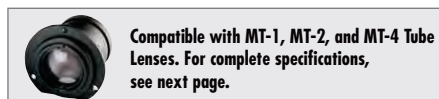
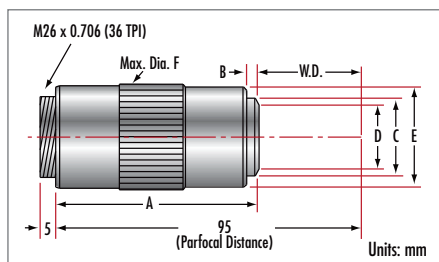
Objectives

MITUTOYO INFINITY CORRECTED LONG WORKING DISTANCE OBJECTIVES



- Long Working Distance, 6mm for 100X
- High Quality Plan Apochromat Design
- Flat Image Surface Over Entire Field of View

Mitutoyo's objectives are world-renowned for setting the standard of excellence for long working distance microscope optics. They have achieved the best combination of working distance and optical performance by using a new approach and avoiding outdated conventions used by competitors. In order to maintain as high an NA and contrast as possible, the lenses are all Plan Apochromats. An apochromatic objective lens is chromatic aberration corrected for red, blue, and yellow. Optimized for bright field illumination (incident illumination parallel to optical axis), these lenses are ideal for in-line illumination applications. For an infinity correction system, a tube lens is required. M Plan APO HR series objectives offer increased resolving power. All stated magnifications are based on a tube lens focal length of 200mm.



M Plan Apo	A	B	C	D	E	F
1X	84.0	0.0	38.0	38.0	41.0	34.0
2X	61.0	1.4	27.5	24.7	32.2	34.0
5X	61.0	1.6	25.0	23.0	32.2	34.0
7.5X	60.0	0.0	25.0	24.0	32.2	34.0
10X	61.0	0.0	28.2	28.2	32.2	34.0
20X	75.0	0.0	29.2	29.2	32.2	34.0
50X	82.0	0.0	29.2	29.2	32.2	34.0
100X	89.0	4.7	29.2	17.8	32.2	34.0
M Plan Apo HR	A	B	C	D	E	F
10X	80.0	0.2	29.0	26.0	37.0	39.0
50X	89.8	0.0	28.2	28.2	32.2	34.0
100X	93.7	0.0	28.2	28.2	32.2	34.0
M Plan Apo SL	A	B	C	D	E	F
20X	64.5	1.2	25.2	23.5	32.2	34.0
50X	74.5	3.9	25.2	24.2	32.2	34.0
80X	80.0	2.5	25.2	21.6	32.2	34.0
100X	82.0	4.4	25.2	22.0	32.2	34.0
200X	82.0	0.5	29.4	27.0	37.0	39.0

M PLAN APO SERIES

	M Plan Apo 1X	M Plan Apo 2X	M Plan Apo 5X	M Plan Apo 7.5X	M Plan Apo 10X	M Plan Apo 20X	M Plan Apo 50X	M Plan Apo 100X
Numerical Aperture, NA:	0.025	0.055	0.14	0.21	0.28	0.42	0.55	0.70
Working Dist., WD (mm):	11.0	34.0	34.0	35.0	33.5	20.0	13.0	6.0
Focal Length (mm):	200.0	100.0	40.0	26.67	20.0	10.0	4.0	2.0
Resolving Power (μm):	11.0	5.0	2.0	1.3	1.0	0.7	0.5	0.4
Depth of Focus (μm):	440.0	91.0	14.0	6.2	3.5	1.6	0.9	0.6
Field of View (mm):								
2/3" Sensor (H x V):	8.8 x 6.6	4.4 x 3.3	1.8 x 1.32	1.17 x 0.88	0.88 x 0.66	0.44 x 0.33	0.18 x 0.13	0.09 x 0.07
1/2" Sensor (H x V):	6.4 x 4.8	3.2 x 2.4	1.28 x 0.96	0.85 x 0.64	0.64 x 0.48	0.32 x 0.24	0.13 x 0.10	0.06 x 0.05
Weight (g):	300	220	230	240	240	270	290	320
Stock No.	#58-235	#46-142	#46-143	#66-383	#46-144	#46-145	#46-146	#46-147
Price	\$2,450.00	\$935.00	\$705.00	\$1,365.00	\$885.00	\$2,055.00	\$2,675.00	\$3,495.00

M PLAN APO SL SERIES

- Super-Long Working Distance for Bright Field Inspection
- High Quality Apochromat Design
- Flat Image Surface Over Entire Field of View

M PLAN APO HR SERIES

- Increased Resolving Power and Numerical Aperture
- Ideal for Brightfield Observation
- Apochromat Design with Flat Image Across Entire Field of View

M PLAN APO SL SERIES						M PLAN APO HR SERIES			
	M Plan Apo SL 20X	M Plan Apo SL 50X	M Plan Apo SL 80X	M Plan Apo SL 100X	M Plan Apo SL 200X	M Plan Apo HR N 5X	M Plan Apo HR 10X	M Plan Apo HR 50X	M Plan Apo HR 100X
Numerical Aperture, NA:	0.28	0.42	0.5	0.55	0.62	0.21	0.42	0.75	0.90
Working Dist., WD (mm):	30.5	20.5	15.0	13.0	13.0	25.5	15.0	5.2	1.3
Focal Length (mm):	10	4	2.5	2	1	40.0	20.0	4.0	2.0
Resolution Power (μm):	1.0	0.7	0.6	0.5	0.4	1.3	0.6	0.3	0.3
Depth of Focus (μm):	3.5	1.6	1.1	0.9	0.7	6.2	1.55	0.5	0.3
Field of View: (mm):									
2/3" Sensor (H x V):	0.44 x 0.33	0.18 x 0.13	0.11 x 0.08	0.09 x 0.07	0.04 x 0.034	1.80 x 1.32	0.88 x 0.66	0.18 x 0.13	0.09 x 0.07
1/2" Sensor (H x V):	0.32 x 0.24	0.13 x 0.10	0.08 x 0.06	0.06 x 0.05	0.03 x 0.025	1.28 x 0.96	0.64 x 0.48	0.13 x 0.10	0.06 x 0.05
Weight (g):	240	280	280	290	490	285	460	400	410
Stock Number	#46-398	#46-399	#46-400	#46-401	#56-072	#34-247	#58-236	#58-237	#58-238
Price	\$3,095.00	\$3,425.00	\$4,050.00	\$4,795.00	\$11,175.00	\$4,750.00	\$8,125.00	\$5,725.00	\$6,175.00

Tube Lenses

MITUTOYO TUBE LENSES



MT-4/MT-40 TUBE LENS

- Use #56-992 or #55-743 Accessory Tubes
- Recommended to use MT-4 for 1-20X and MT-40 on >20X



MT-1 TUBE LENS

- Permits Introduction of Beamsplitter
- Use #58-329 Accessory Tube with #55-743
- 1X Magnification



MT-2 TUBE LENS

- Permits Introduction of Beamsplitter
- Use #58-329 Accessory Tube with #55-743
- 2X Magnification

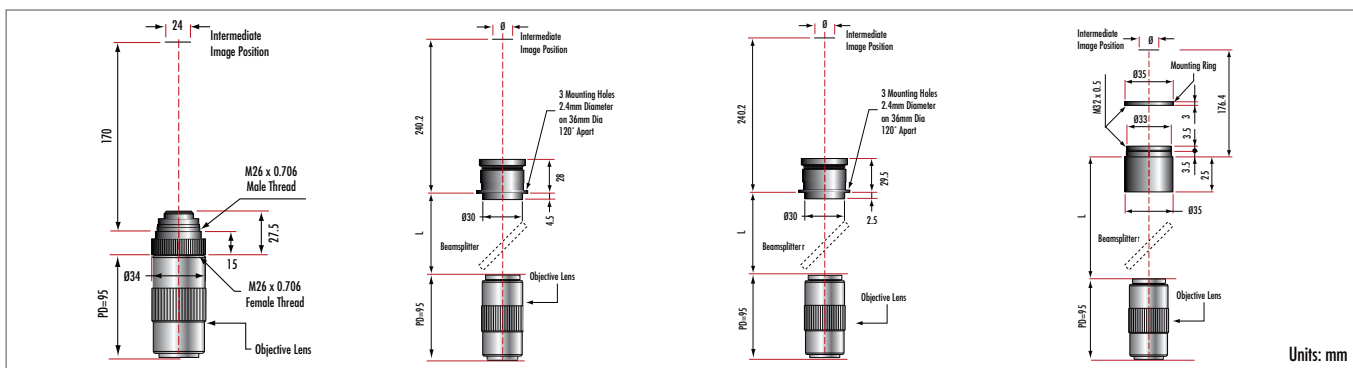


MT-L/MT-L4 TUBE LENS

- MT-L Tube Lens for NUV and NIR Objectives
- MT-L4 Tube Lens for UV Objectives
- 1X Magnification

MITUTOYO TUBE LENSES

	MT-4/MT-40		MT-1		MT-2		MT-L/MT-L4	
Focal Length (mm):	200		200		400		200/200	
Design Wavelength (nm):	436 - 656		436 - 656		436 - 656		355 - 1064/266 - 620	
Image Formation Mag.:	1X		1X		2X		1X/1X	
Image Circle Covered (mm):	30 (MT-4), 24 (MT-40)		30 (@L=76.5mm)		30 (@L=76.5mm)		24/24 (@L=134mm)	
Entrance Pupil Dia. (mm):	11.2		24		18		22/23	
Dimensions = (Dia. x L) (mm):	34 x 27 (MT-4), 34 x 27.5 (MT-40)		40 x 32.5		40 x 32.0		35 x 32.0/35 x 30.6	
Mounting:	M26 x 36 TPI		three 2.4mm holes		three 2.4mm holes		M32 x 0.5/M32 x 0.5	
Stock No./Price	(MT-4) #54-428	\$695.00	#54-774	\$725.00	#56-863	\$835.00	(MT-L) #56-073	\$1,750.00
	(MT-40) #83-911	\$1,195.00					(MT-L4) #56-864	\$3,675.00



TECHNICAL NOTE

USING TUBE LENSES WITH INFINITY CORRECTED OBJECTIVES

In order to create an image with an infinity corrected objective, a tube lens must be used to focus the image. One advantage to using an infinity corrected objective with a tube lens is that there can be a space between the objective and tube lens. The space allows additional optical components to be inserted into the system, such as filters or beamsplitters. The distance between the objective and the tube lens (L) can be varied, but this will affect the image field diameter (Ø). Equations 1 and 2 are approximation formulas to determine the relation between Ø and L.

Equation 1: $\text{Ø}_1 \text{ (mm)} = 2 \times F_1 \times \text{NA}$

Equation 2: $L \text{ (mm)} = \frac{(\text{Ø}_2 - \text{Ø}_1) \times F_2}{\text{Ø}}$

Ø₁ (mm) = exit pupil of the objective
 Ø₂ (mm) = entrance pupil of the tube lens
 F₁ (mm) = focal length of the objective
 F₂ (mm) = focal length of the tube lens
 NA = Numerical Aperture of the objective

Example:

Using an M Plan APO 10X objective (#46-144), MT-1 tube lens (#54-774), and a 2/3" sensor camera, what is the maximum spacing between the tube lens and objective without vignetting? The focal length of the objective (F₁) is 20mm and NA is 0.28, so the exit pupil diameter can be calculated:

$\text{Ø}_1 = 2 \times 20 \times 0.28 = 11.2\text{mm}$

A 2/3" image sensor features an 11mm diagonal, therefore Ø needs to be at least 11mm. The focal length of the MT-1 tube lens is 200mm and the entrance pupil diameter is 24mm. Therefore, $L = ((24 - 11.2) \times 200) / 11 = 232.7\text{mm}$

As long as the spacing between the tube lens and objective is less than 232.7mm, there will be no vignetting.

TECHSPEC® ACCESSORIES AND ADAPTERS FOR MITUTOYO OBJECTIVES

- Camera Extension Tube Allows Integration of C-Mount Cameras
- Adapters Ease Integration of MT-1 and MT-2 Tube Lenses
- Connect with C-Mount or RMS Threaded Components



TECHSPEC® ACCESSORIES AND ADAPTERS FOR MITUTOYO OBJECTIVES

*Requires Mitutoyo C-Mount Adapter #55-743

Objective Thread Adapters	Tube Length	Stock No.	Price	Accessory Tubes	Notes	Stock No.	Price
Mitutoyo to C-Mount Adapter	10mm	#55-743	\$35.00	MT-1/MT-2 C-Mount Adapter*	Requires 190mm of Tube Length on a C-Mount Camera	#58-329	\$169.00
Mitutoyo to RMS Adapter	14mm	#58-296	\$85.00	MT-L/MT-L4 C-Mount Adapter*	Requires 150mm of Tube Length on a C-Mount Camera	#66-027	\$159.00
C-Mount Camera Extension Tube	152.5mm	#56-992	\$139.00	Filter Holder	Accepts 24.15-25.4mm Dia Filters	#56-993	\$75.00

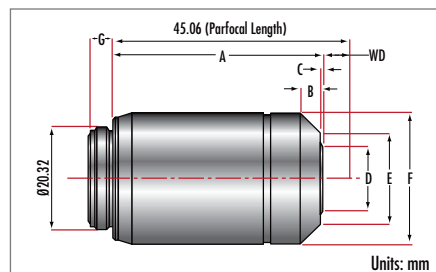
Objectives

OLYMPUS PLAN ACHROMATIC OBJECTIVES



- Ideal for Brightfield, Darkfield, or Fluorescence Microscopy
- Excellent Price-to-Performance Ratio
- Suitable for Introductory and Advanced Optical Microscopy Applications

Olympus Plan Achromatic Objectives are designed for clinical laboratory or examination applications. When using brightfield observation in a transmitted illumination system, Olympus Plan Achromatic Objectives provide excellent field flatness of up to F.N.22.



Dimensions	A	B	C	D	E	F	G
PLN 4X	26.4	4.4	0.0	15.8	15.8	24.0	4.5
PLN 10X	34.3	4.1	1.6	10.5	16.0	24.0	4.5
PLN 20X	43.7	4.2	2.4	6.1	15.6	24.0	4.8
PLN 40X	44.3	4.2	3.0	7.5	15.6	24.0	4.5
PLN 100X	44.7	4.2	2.5	6.6	15.6	24.0	4.5

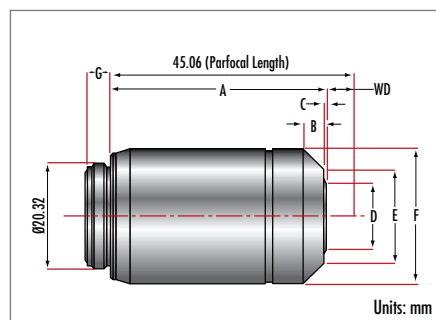
OLYMPUS PLAN ACHROMATIC OBJECTIVES					*Oil Immersion
	PLN 4X	PLN 10X	PLN 20X	PLN 40X	PLN 100X*
Numerical Aperture, NA:	0.1	0.25	0.4	0.65	1.25
Working Distance (mm):	18.5	10.6	1.2	0.6	0.15
Field Number:	22	22	22	22	22
Dimensions (Dia x L, mm):	24 x 26.5	24 x 34.3	24 x 43.7	24 x 44.3	24 x 44.7
Stock No.	#86-812	#86-813	#86-814	#86-815	#86-816
Price	\$140.00	\$315.00	\$375.00	\$575.00	\$995.00

OLYMPUS PLAN FLUORITE OBJECTIVES



- Ideal for Brightfield, Darkfield, DIC, Fluorescence, or Polarization Microscopy
- Excellent Transmission in the UV
- High Numerical Apertures and Oil Immersion Options Available

Olympus Plan Fluorite Objectives are multi-purpose objectives that utilize advanced multi-coatings to provide excellent flat field images from the UV to NIR. Offering high signal-to-noise ratios, excellent resolution, and high contrast imaging capability, Olympus Plan Fluorite Objectives are ideal for brightfield microscopy or Nomarski differential interference contrast (DIC) observations, in addition to darkfield or fluorescence microscopy, or specific polarization techniques.



Dimensions	A	B	C	D	E	F	G
UPLFLN 4X	27.9	2.8	0.0	18.0	18.0	24.0	4.5
UPLFLN 10X	34.9	10.1	0.0	13.6	13.6	24.0	4.5
UPLFLN 20X	42.8	5.3	2.3	9.4	15.8	26.0	4.5
UPLFLN 40X	44.4	5.1	4.0	8.5	16.0	26.0	4.5
UPLFLN 40XO	44.7	4.0	1.7	9.4	19.3	30.0	4.7
UPLFLN 60X	44.7	5.2	2.7	8.6	17.0	29.0	4.7
UPLFLN 100X	44.7	5.5	3.0	7.0	17.2	28.0	4.5

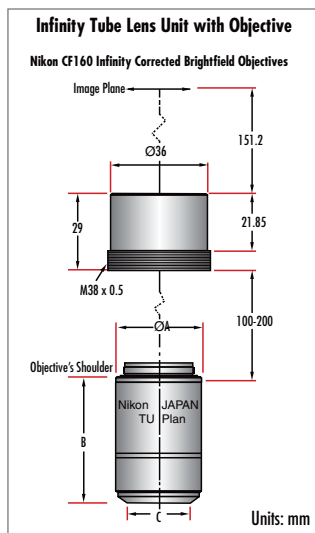
OLYMPUS PLAN FLUORITE OBJECTIVES							*Oil Immersion
	UPLFLN 4X	UPLFLN 10X	UPLFLN 20X	UPLFLN 40X	UPLFLN 40XO*	UPLFLN 60X	UPLFLN 100X*
Numerical Aperture, NA:	0.13	0.3	0.5	0.75	1.3	0.9	1.3
Working Distance (mm):	17	10	2.1	0.51	0.2	0.2	0.2
Field Number:	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Dimensions (Dia x L, mm):	24 x 27.9	24 x 34.9	26 x 42.8	26 x 44.4	30 x 44.7	31 x 44.7	28 x 44.7
Stock No.	#86-817	#86-818	#86-819	#86-820	#86-821	#86-822	#86-823
Price	\$495.00	\$895.00	\$995.00	\$1,195.00	\$5,295.00	\$2,995.00	\$2,450.00

OLYMPUS ACCESSORIES



OLYMPUS ACCESSORIES		
Description	Stock No.	Price
Low Auto Fluorescence Immersion Oil	#86-834	\$49.00
Single Port Tube Lens, 180mm Focal Length	#86-835	\$495.00
1X Camera Coupler	#89-605	\$85.00
C-Mount Adapter	#89-606	\$175.00
Empty Filter Cube for Olympus BX2 Microscopes	#86-832	\$450.00

NIKON CFI60 INFINITY CORRECTED BRIGHTFIELD OBJECTIVES



- **Excellent Color Reproduction**
- **Long Working Distance and High NA**
- **Strain Free**

Designed to meet the most advanced imaging requirements, the CFI60 objectives represent the culmination of Nikon's optical technology. Relying on a 60mm parfocal distance and a much larger barrel diameter allows these objectives to offer increased brightness and the highest possible combination of working distance and numerical aperture (for light gathering ability). Designed to correct lateral and axial chromatic aberrations over the entire field of view, these objectives produce images that are crisp, flat and clear with high contrast and high resolution. Mounting thread: M25 x 0.75.

The accessory tube lens (#58-520) can be used to focus light from the infinity corrected objective onto the image plane. For optimal performance, the distance between the tube lens and the objective's shoulder should be kept within 100 - 200mm. This spacing allows accessories to be inserted in the optical path to accommodate specific needs.



DIMENSIONS				Units: mm
Stock No.	PMAG	A	B	C
#58-515	5X	29.0	36.5	20.0
#58-516	10X	29.0	42.7	18.0
#58-517	20X	29.0	47.0	19.0
#58-518	50X	30.0	49.9	17.7
#58-519	100X	30.0	56.5	14.0

NIKON CFI60 INFINITY CORRECTED OBJECTIVES

	CFI TU Plan Epi 5X	CFI TU Plan Epi 10X	CFI TU Plan Epi ELWD 20X	CFI TU Plan Epi ELWD 50X	CFI TU Plan Epi ELWD 100X
Numerical Aperture:	0.15	0.30	0.40	0.60	0.80
Working Distance (mm):	23.5	17.3	19.0	11.0	3.5
Focal Length (mm):	40.0	20.0	10.0	4.0	2.0
Resolving Power (μm):	2.0	1.0	0.7	0.5	0.3
Depth of Focus (μm):	12.22	3.06	1.72	0.91	0.43
Field of View (mm):					
Eyepiece, 25 Dia. Field:	5.0	2.5	1.25	0.5	0.25
Eyepiece, 22 Dia. Field:	4.4	2.2	1.1	0.44	0.22
2/3" CCD Camera (H x V):	1.76 x 1.32	0.88 x 0.66	0.44 x 0.33	0.18 x 0.13	0.09 x 0.07
1/2" CCD Camera (H x V):	1.28 x 0.96	0.64 x 0.48	0.32 x 0.24	0.13 x 0.10	0.06 x 0.05
Weight (g):	100	125	90	130	215
Stock No.	#58-515	#58-516	#58-517	#58-518	#58-519
Price	\$765.00	\$999.00	\$1,895.00	\$2,250.00	\$4,800.00
Nikon 200mm Tube Lens				#58-520	\$265.00

NIKON INTERFEROMETRY OBJECTIVES

- **Suitable for Non-Contact Optical Profiling**
- **Michelson and Mirau Objectives Available**
- **Infinity Corrected 200mm Tube Lens Design**

Interferometry objectives are used in non-contact optical profile measurement devices to obtain surface maps and surface measurement parameters. They can be used to examine surface topography with very high precision—to within a fraction of the wavelength of light. In these objectives, a light beam passes through a beamsplitter, which directs the light to both the surface of the sample and a built-in reference mirror. The light reflected from these surfaces recombines and a fringe interference pattern is formed. The Michelson objectives provide comparatively longer working distances, wider fields of view and larger depth of focus, whereas the Mirau objectives are used in applications requiring higher magnification and/or numerical apertures. Use of the Nikon 200mm tube lens (#58-520) allows these objectives to be integrated to a C-Mount camera.



	Michelson CF IC Epi Plan TI 2.5X	Michelson CF IC Epi Plan TI 5.0X	Mirau CF IC Epi Plan DI 10X	Mirau CF IC Epi Plan DI 20X	Mirau CF IC Epi Plan DI 50X	Mirau CF IC Epi Plan I-DI 100X
Type:	Michelson	Michelson	Mirau	Mirau	Mirau	Mirau
Numerical Aperture:	0.075	0.13	0.30	0.40	0.55	0.70
Working Distance (mm):	10.3	9.3	7.4	4.7	3.4	2.0
Focal Length (mm):	80.0	50.0	20.0	10.0	4.0	2.0
Resolving Power (μm):	3.7	1.9	0.92	0.69	0.50	0.40
Depth of Focus (μm):	48.6	12.2	3.04	1.71	0.90	0.56
Field of View (mm):						
Eyepiece, 25 Dia. Field:	10.0	5.0	2.5	1.25	0.50	0.25
Eyepiece, 20 Dia. Field:	8.0	4.0	2.0	1.0	0.40	0.20
2/3" Camera (H x V):	3.52 x 2.64	1.76 x 1.32	0.88 x 0.66	0.44 x 0.33	0.18 x 0.13	0.011 x 0.08
1/2" Camera (H x V):	2.56 x 1.92	1.28 x 0.96	0.64 x 0.48	0.32 x 0.24	0.13 x 0.10	0.08 x 0.06
Weight (g):	440	440	125	130	150	200
Stock No.	#59-310	#59-311	#59-312	#59-313	#59-314	#62-788
Price	\$7,400.00	\$3,795.00	\$2,350.00	\$2,625.00	\$4,395.00	\$10,750.00
Nikon 200mm Tube Lens					#58-520	\$265.00

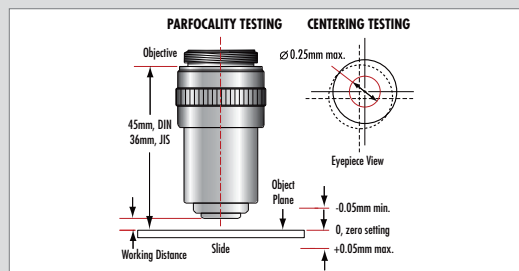
Objective Performance Testing

All objectives are tested to ensure quality and performance to the following specifications.

Centering: Using a customized testing microscope with a pre-calibrated 10X eyepiece, the objective connects to a precisely aligned spinning mount. As objective is turned, the eyepiece reticle is compared to a stage micrometer. The optical to mechanical deviation is determined to be less than the maximum value stated.

Parfocality: Using the same testing microscope, a scale connected to the fine focus knob measures distance moved. As the illustration shows, the standard distance of 45mm for a DIN objective is used as a zero setting. The maximum allowable defocus is stated in the table.

Mechanical: All objective threads are tested to meet the RMS industry standard with go/no-go gauges.



OBJECTIVE PERFORMANCE SPECIFICATIONS		
Objective Magnification	Centering (mm)	Parfocality (mm)
4X	0.15	-0.05 ~ 0
10X	0.03	-0.02 ~ +0.02
20X	0.03	0 ~ +0.03
40X	0.03	0 ~ +0.03
60X	0.25	0 ~ +0.03
100X	0.25	-0.01 ~ +0.05

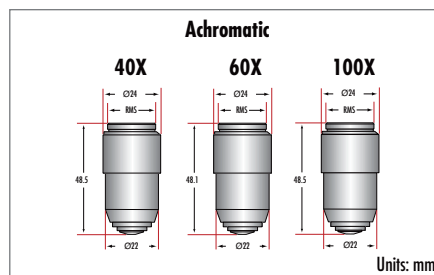
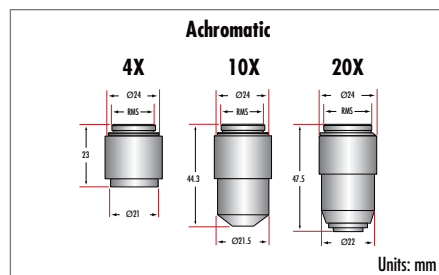
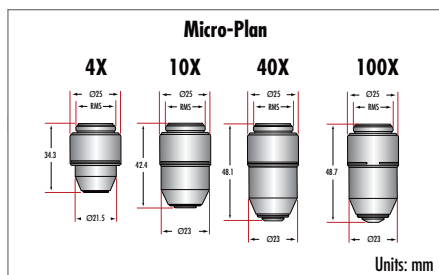
INTERNATIONAL STANDARD MICROSCOPE OBJECTIVES



Our full selection of International Standard Microscope Objectives can be used with most major brands of microscopes that utilize RMS mounting threads. Our product offering features DIN 45mm standard objectives with achromatic and semi-plan designs. The achromatic design ensures proper color correction for broadband white light sources, while semi-plan designs have an added feature to create the flattest image field possible. International Standard Microscope Objectives include AR coated optics to ensure maximum transmission and reduce internal reflections in the optical assembly. All 20X to 100X objectives have spring-loaded (retractable) front ends to prevent slide damage. **Note:** Oil immersion is recommended for all 100X objectives with an NA higher than 1.0 (part number #86-834).

IMMERSION OIL

Description	Stock No.	Price
0.5 oz. Tube of Immersion Oil	#86-834	\$49.00



DIN ACHROMATIC

Magnification	Focal Length (mm)	Field of View (mm)*	Working Distance (mm)	Numerical Aperture (NA)	Stock No.	Price
4X	29.27	4.50	26.00	0.10	#33-436	\$79.00
10X	17.02	1.80	4.40	0.25	#33-437	\$105.00
20X	8.33	0.90	0.80	0.40	#33-438	\$110.00
40X	4.35	0.45	0.60	0.65	#33-439	\$115.00
60X	3.21	0.30	0.15	0.85	#33-440	\$189.00
100X	1.88	0.18	0.20	1.25 (oil immersion)	#33-441	\$255.00

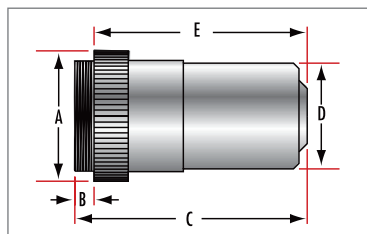
*FOV given for 18mm dia. eyepiece field stop diameter

DIN MICRO-PLAN (SEMI-PLAN)

Magnification	Focal Length (mm)	Field of View (mm)*	Working Distance (mm)	Numerical Aperture (NA)	Stock No.	Price
4X	28.84	5.00	15.10	0.10	#33-469	\$99.00
10X	17.19	2.00	6.40	0.25	#33-470	\$115.00
40X	4.03	0.50	0.65	0.65	#33-471	\$120.00
100X	1.77	0.20	0.22	1.25 (oil immersion)	#33-472	\$195.00

*FOV given for 18mm dia. eyepiece field stop diameter

COMMERCIAL GRADE STANDARD MICROSCOPE OBJECTIVES



Designed for a wide variety of applications, our commercial objectives are provided in both achromatic and plan designs. Using DIN standard, 0.7965" (20.1mm) dia. threads, 36 TPI, 55° Whitworth, these objectives will fit into most microscope and spatial filter assemblies. Used in conjunction with our C- and T-Mounting systems they are an ideal solution for OEM production use.



ACHROMATIC DIMENSIONS (mm)

*40X and 100X versions are spring-loaded. 100X version is also oil immersion-type

Magnification	A	B	C	D	E	Thread
4X	24	3.7	34	19	26	0.7965-36 TPI, 55° Whitworth
10X	24	3.7	43	19	40	0.7965-36 TPI, 55° Whitworth
40X*	24	3.7	48.8	20	45.8	0.7965-36 TPI, 55° Whitworth
100X*	24	3.7	48.8	20	45.8	0.7965-36 TPI, 55° Whitworth

PLAN DIMENSIONS (mm)

*40X and 100X versions are spring-loaded. 100X version is also oil immersion-type

Magnification	A	B	C	D	E	Thread
4X	24	3.7	34	22	30	0.7965-36 TPI, 55° Whitworth
10X	24	3.7	47.6	22	44	0.7965-36 TPI, 55° Whitworth
40X*	24	3.7	49	22	46	0.7965-36 TPI, 55° Whitworth
100X*	24	3.7	48	22	46	0.7965-36 TPI, 55° Whitworth

ACHROMATIC OBJECTIVES

*40X and 100X versions are spring-loaded. 100X version is also oil immersion-type

Magnification	NA	Focal Length (mm)	Working Dist. (mm)	Stock No.	1-24 pcs.	25-49 pcs.	50-74 pcs.	75-100 pcs.
4X	0.10	31.04	18.8	#43-902	\$55.00	\$45.00	\$35.00	\$32.00
10X	0.25	17.13	6.14	#43-903	\$69.00	\$52.00	\$47.00	\$42.00
40X*	0.65	4.65	0.48	#43-904	\$95.00	\$75.00	\$68.00	\$63.00
100X*	1.25	2.91	0.10	#43-905	\$125.00	\$100.00	\$90.00	\$85.00

PLAN OBJECTIVES

*40X and 100X versions are spring-loaded. 100X version is also oil immersion-type

Magnification	NA	Focal Length (mm)	Working Dist. (mm)	Stock No.	1-24 pcs.	25-49 pcs.	50-74 pcs.	75-100 pcs.
4X	0.10	28.91	15.25	#67-706	\$85.00	\$69.00	\$65.00	\$55.00
10X	0.25	15.37	1.50	#43-907	\$110.00	\$89.00	\$82.00	\$78.00
40X*	0.65	4.29	0.49	#43-908	\$160.00	\$139.00	\$129.00	\$119.00
100X*	1.25	2.74	0.10	#43-909	\$245.00	\$205.00	\$185.00	\$165.00

SINGLE TUBE DIN MICROSCOPES FOR OCULAR AND C-MOUNT CAMERA USE

These tube options allow DIN standard objectives to be used directly with either a DIN eyepiece or a C-Mount camera. Tubes are the appropriate length for DIN standard. Any DIN objective can be mounted to either tube. Model #54-869 allows a DIN standard eyepiece to be used with an objective to make an ocular microscope. Model #54-868 allows the DIN objective to be mounted to a C-Mount camera and achieve a primary magnification equal to the magnification of the objective. The field of view of the video system is equal to the sensor size divided by the magnification of the objective. For example, a 4X objective yields a horizontal field of view of 1.6mm on a 1/2" sensor. Objectives and eyepieces are not included with tube assemblies. C-Mount cameras are available in our Imaging section.

Optional mounting ring allows mounting to a 1/4-20 screw. Mounting ring (#52-930) and 1/4-20 fine focus rack and pinion mount (#54-794) are recommended for mounting to boom stands and work station bases.

SINGLE TUBE DIN MICROSCOPES

Description	Stock No.	Price
A) DIN Objective to Camera Tube Assembly	#54-868	\$135.00
B) DIN Objective to Eyepiece Tube Assembly	#54-869	\$135.00
C) Optional 1/4-20 Mounting Ring	#52-930	\$75.00
D) 1/4-20 Rack and Pinion with Fine and Coarse Focus	#54-794	\$375.00

For Option A:

$$\text{Field of View} = \frac{\text{Sensor Size}}{\text{Objective Magnification}}$$

For a 1/4" sensor, the chip size is 3.6mm Horiz.

$$\text{Field of View} = \frac{3.6\text{mm}}{4X} = 0.9\text{mm}$$

For a 1/2" sensor, the chip size is 6.4mm Horiz.

$$\text{Field of View} = \frac{6.4\text{mm}}{4X} = 1.6\text{mm}$$

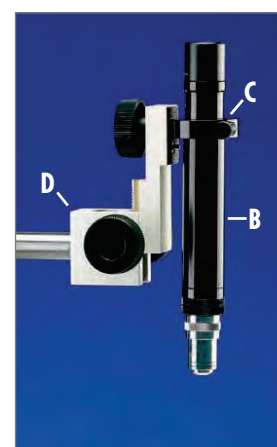
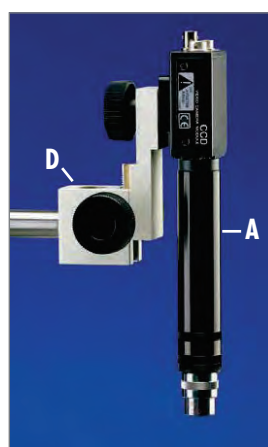


Image of Ronchi Ruling Using 4X Achromatic Objective



Image of Halftone Dots Using 4X Achromatic Objective

Cameras



Digital Camera Interfaces

Digital cameras are available with a variety of interface options that are often dependent on an application's requirements. Some formats, such as the two USB varieties, can greatly simplify the setup process by supplying video output and power via a single interface. Other formats may require an additional power supply but provide advantages such as higher data transfer rates, which affects the frames per second a camera is capable of outputting, or support for a greater number of simultaneous devices. *Table 1* compares the different digital camera interfaces.

For more information on **cameras** go to
WWW.EDMUNDOPTICS.COM/CAMERAS

DIGITAL INTERFACE COMPARISON					
DIGITAL SIGNAL OPTIONS NOTE: images not drawn to scale					
Data Transfer Rate:	5Gb/s	480 Mb/s	1000 Mb/s	up to 3.6Gb/s	800 Mb/s
Max Cable Length:	3m (recommended)	5m	100m	10m	100m (with GOF cable)
# Devices:	up to 27	up to 127	unlimited	1	up to 63
Connector:	USB	USB	RJ45 / Cat5e or 6	26pin	9pin-9pin
Capture Board:	Optional	Optional	Not Required	Required	Optional
External Power:	Optional	Optional	Required (Optional with PoE)	Required	Optional

Table 1: Comparison of Popular Digital Camera Interfaces.

USB (Universal Serial Bus)

USB 3.0 is a popular interface due to its ubiquity among computers. It is high speed and convenient; maximum attainable speed depends upon the number of USB peripheral components, as the transfer rate of the bus is fixed at 5 Gb/s. In USB3 Vision, camera control registers are based on the EMVA GenICam standard. The USB3 standard does not match that of the computer standard of backwards compatibility, but some USB 3.0 cameras are backward compatible making them run at the slower speed of USB 2.0.

USB 2.0 features the plug-and play benefits of USB 3.0, however it is much slower than USB 3.0 with data transmission rates of 480Mb/s. Cables are readily available anywhere computer components are sold for both USB 2.0 and 3.0.

GigE (GigE Vision Standard)

GigE is based on the gigabit ethernet internet protocol and uses standard Cat 5e and Cat 6 cables for a high-speed camera interface. Standard ethernet hardware such as switches, hubs, and repeaters can be used for multiple cameras, although overall bandwidth must be taken into consideration whenever non peer-to-peer (direct camera to card) connections are used. In GigE Vision, camera control registers are based on the EMVA GenICam standard. Optional on some cameras, Link Aggregation (LAG) uses multiple ethernet ports in parallel to increase data transfer rates. Also supported by some cameras, the network Precision Time Protocol (PTP) can be used to synchronize the clocks of multiple cameras connected on the same network, allowing for a fixed delay relationship between their associated exposures.

Camera Link®

Camera Link® is a high speed serial interface standard developed explicitly for machine vision applications. A Camera Link® capture card is required for usage, and power must be supplied separately to the camera. Special cabling is required because, in addition to low-voltage differential pair (LVDP) signal lines, separate asynchronous serial communication channels are provided to retain full bandwidth for data transmission.

The single-cable base configuration allows 255 MB/s transfer dedicated for video. Dual outputs (full configuration) allow for separate camera parameter send/receive lines to free up more data transfer space (680 MB/s) in extreme high-speed applications.

FireWire (IEEE 1394.b/IIDC DCAM Standard)

FireWire, aka IEEE 1394.b, is an isochronous camera interface due to the widespread availability of FireWire ports on computers. FireWire.b allows for the connection of multiple cameras and provides power through the FireWire cable. Hot-swap/hot-plugging is not recommended, as the connector's design may cause power pin shorting to signal pins, potentially damaging the port or the device. FireWire.a is an older, slower version of FireWire and is not used often anymore.

Capture Boards

Image processing typically involves the use of computers, which means a digital interface is necessary when using analog cameras. Capture boards allow users to output analog camera signals into a computer for analysis; for analog signals (NTSC, YC, PAL, CCIR), the capture board contains an analog-to-digital converter (ADC) to digitize the signal for further image processing. Users can then capture images and save them for future manipulation and printing. Basic capturing software is included with capture boards, allowing users to save, open, and view images.

The term capture board also refers to cards that are necessary to acquire and interpret the data from digital camera interfaces, but are not based on standard computer connectors.



TECHSPEC® HP Series
Fixed Focal Length
Lenses on Pages 58-63.

Powering the Camera

Many camera interfaces allow for power to be supplied to the camera remotely over the signal cable (such as USB). When this is not the case, power is commonly supplied either through a Hirose connector (which also allows for trigger wiring and I/O), or a standard AC/DC adapter type connection.

Power over Ethernet (PoE)

Currently, power injectors are available that allow, with particular cameras, the ability to deliver power to the camera over the GigE cable. This can be important when space restrictions do not allow for the camera to have its own power supply. In this case, the injector is added somewhere along the cable line with standard cables running to the camera and computer. However, not all GigE cameras are PoE compatible.

Camera Software

In general, there are two choices when it comes to imaging software: camera-specific Software Development Kits (SDKs) or third-party software. SDKs include application programming interfaces with code libraries for development of user defined programs, as well as simple image viewing and acquisition programs that do not require any coding and offer

Laptops and Cameras

Although many digital camera interfaces are accessible to laptop computers, it is highly recommended to avoid standard laptops for high-performance and/or high-speed imaging applications. Often, the data buses on the laptop will not support full transfer speeds and the resources are not available to take full advantage of high performance cameras and software. In particular, the ethernet network speed interface cards standard in most laptops perform at a much lower level than the PCIe cards available for desktop computers.

simple functionality. With third-party software, camera standards (GenICam, DCAM, GigE Vision) are important to ensure functionality. Third party software includes software such as NI LabVIEW™, MATLAB®, and OpenCV. Often, third-party software is able to run multiple cameras and support multiple interfaces, but it is ultimately up to the user to ensure functionality.

Sensors

Sensor Size

The size of a camera sensor's active area is important in determining the system's Field of View (FOV) and Primary Magnification (PMAG). Given a fixed magnification that is determined by the imaging lens, larger sensors yield greater FOVs. As shown in Figure 1 and in Table 2, there are several standard area-scan sensor sizes. The nomenclature of these standards dates back to the Vidicon vacuum tubes used for television broadcast imagers, so it is important to note that the actual dimensions of the sensors differ. However, most of these standards maintain a 4:3 (Horizontal:Vertical) dimensional aspect ratio.

One issue that often arises in imaging applications is the ability of an imaging lens to support certain sensor sizes. If the sensor is too large for the lens design, the resulting image may appear to fade away and degrade towards the edges because of vignetting (extinction of rays which pass through the outer edges of the imaging lens). This is sometimes referred to as the tunnel effect, since the edges of the field become dark. Smaller sensor sizes do not yield this vignetting issue.

CCD vs. CMOS Sensors

CCD (Charge Coupled Device) and CMOS (Complementary Metal Oxide Semiconductor) are different sensor technologies for converting light into electronic signals. In a CCD, each pixel's charge is converted to voltage, buffered, and transferred through a single node as an analog signal. In a CMOS sensor, the charge-to-voltage conversion is done at the pixel level. Historically, this conversion yielded a less uniform output.

New advances in CMOS technology over the last several years have helped greatly reduce the non-uniformity in low light environments, and in many applications high-end CMOS sensors can outperform the comparable CCD. Additionally, CMOS has lower power consumption than CCD, which makes them useful for any space-constrained application. Lower-end CMOS sensors with pixels smaller than approximately 3 microns are still outperformed by CCD in terms of image quality. Performance differences are highlighted in Table 3.

Figure 1

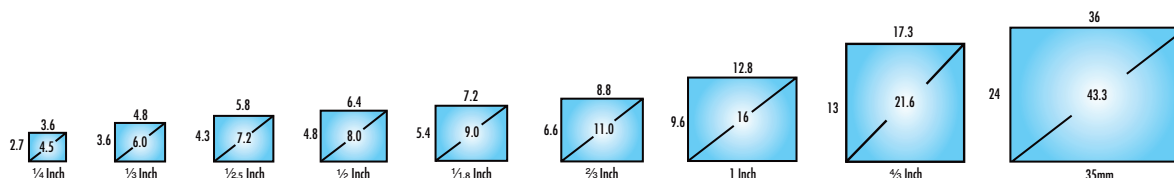


Figure 1: Sensor Size Dimensions for Standard Camera Sensors. Not to Scale.

CAMERA RESOLUTION BY PIXEL SIZE

Pixel Size (µm)	9.9	7.4	5.86	5.5	4.54	3.69	3.45	2.2	1.67
Resolution (lp/mm)	50.5	67.6	85.3	90.9	110.1	135.5	144.9	227.3	299.4
Typical 1/2" Sensor (MP)	0.31	0.56	0.89	1.02	1.49	2.26	2.58	6.35	11.02
Typical 1/3" Sensor (MP)	0.59	1.06	1.69	1.92	2.82	4.27	4.88	12.00	20.83

Table 2: Camera Resolution by Pixel Size.

CCD VS. CMOS SENSORS

	CCD	CMOS		CCD	CMOS
Pixel Signal:	Electron Packet	Voltage	Uniform:	High	Moderate
Chip Signal:	Analog	Digital	Resolution:	Low-High	Low-High
Fill Factor:	High	Moderate	Speed:	Moderate-High	High
Responsivity:	Moderate	Moderate-High	Power Consumption:	Moderate-High	Low
Noise Level:	Low	Low to High	Complexity:	Low	Moderate
Dynamic Range:	High	Moderate to High	Cost:	Moderate	Low

Table 3: CCD vs. CMOS Sensors.

Spectral Properties

Depending on an application's requirements, a camera's ability to reproduce color may or may not be beneficial. A comparison of monochrome, single chip color, and three chip color cameras is shown in *Table 4* and more detail is provided in the following section.

Check out our **Imaging Electronics 101** in the tech resource section at WWW.EDMUNDOPTICS.COM/IMAGING-101

MONOCHROME VS. COLOR		
Monochrome	Color (Single Chip)	3 Chip Color Cameras
- Single Sensor Outputs Grayscale Images 10% Higher Resolution than Comparable Single-Chip Color Cameras - Better Signal-To-Noise Ratio; Greater Contrast - Increased Low-Light Sensitivity	- Uses RGB Bayer Color Filter (Typical) - Low Cost - Lower Resolution (More Pixels Required To Recognize Color) - Standard Cabling; Easily Integrated into Systems	- Utilizes a Prism to Split White Light into 3 Different Sensors - More Costly - Better Color Resolution - Smaller Selection of Lenses - May Require Specially Designed Lenses

Table 4: Monochrome vs. Color.

Monochrome Cameras

CCD and CMOS sensors, being silicon devices, are sensitive to wavelengths from approximately 350 - 1050nm, although the usable range is usually given from 400 - 1000nm. This sensitivity is indicated by the sensor's spectral response curve (*Figure 2*). However, most high-quality color, and some monochrome, cameras provide an infrared (IR) cut-off filter for imaging specifically in the visible spectrum.

Color Cameras

The solid state sensor is based on the photoelectric effect and, as a result, cannot distinguish between colors without additional considerations. There are two types of color CCD cameras: single chip and three-chip. Single chip color CCD cameras offer a common, low-cost imaging solution and use a mosaic (e.g. Bayer) optical filter to make different pixels sensitive to only certain wavelengths of light. A color image is then reconstructed in software using a "de-bayering" algorithm which interpolates true color information from the RGB signals. Since more pixels are required to recognize color, single chip color cameras inherently have lower resolution than their monochrome counterparts. Three-chip color CCD (3CCD) cameras are designed to solve this resolution problem by using a prism to direct each section of the incident spectrum to a different chip. Although 3CCD cameras typically provide extremely high resolutions and more accurate color reproduction, they have lower light sensitivities and can be costly.

Frame Rate and Shutter Speeds

The frame rate refers to the number of full frames composed in a second. In high-speed applications, it is beneficial to choose a faster frame rate to acquire more images of the object as it moves through the FOV.

The shutter speed corresponds to the inverse of the exposure time of the sensor. The exposure time controls the amount of incident light collected by the sensor. Camera blooming (caused by over-exposure) can be controlled by decreasing illumination, or by increasing the shutter speed (decreasing exposure time).

The maximum frame rate for a system depends on the sensor readout speed, the data transfer rate of the interface, and the number of pixels (amount of data transferred per frame). Often, a camera may be run at a higher frame rate by reducing the resolution by binning pixels together or restricting the area of interest. For digital cameras, exposures can be made from tens of microseconds to minutes, although the longest exposures are generally only practical with CCD cameras, which have lower dark currents and noise compared to CMOS.

Electronic Shutter: Global vs. Rolling

A global shutter is analogous to a mechanical shutter, in that all pixels are exposed and sampled simultaneously, with the readout then occurring sequentially; the photon acquisition starts and stops at the same time for all pixels. On the other hand, a rolling shutter exposes, samples, and reads out sequentially; it implies that each line of the image is sampled

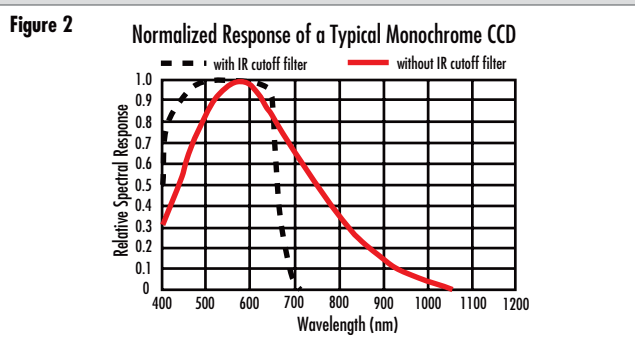


Figure 2: Normalized Spectral Response of a Typical Monochrome CCD.

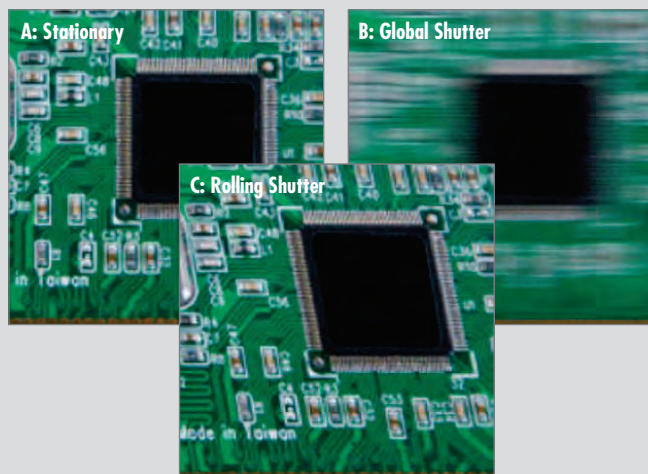


Figure 3: Comparison of Motion Blur. Stationary PCB (A) and images of moving PCB with Continuous Global Shutter (B) and Rolling Shutter (C).

at a slightly different time. Intuitively, images of moving objects are distorted by a rolling shutter; this effect can be minimized with a triggered strobe placed at the point in time where the integration period of the lines overlaps. Note that this is not an issue at low speeds. Implementing global shutter for CMOS requires more complicated sensor architecture than the standard rolling shutter model, and thus they are not available on all CMOS sensors. A comparison of global and rolling shutters is shown in *Figure 3*.

In contrast to global and rolling shutters, an asynchronous shutter refers to the triggered exposure of the pixels. That is, the camera is ready to acquire an image, but it does not enable the pixels until after receiving an external triggering signal. This is opposed to a normal constant frame rate, which can be thought of as internal triggering of the shutter.

Area Scan vs. Line Scan Cameras

Depending on an application's requirements, a system implementer must choose between an area scan or line scan camera. In area scan cameras, an imaging lens focuses the object to be imaged onto the sensor array, and the image is sampled by the pixels all at once for reconstruction (Figure 4). This is convenient if the image is not moving quickly or if the object is not extremely large. With line scan cameras, the pixels are arranged in a linear fashion, and as the object moves past the camera, the image is taken line by line and reconstructed with software (Figure 4). Linear arrays are capable of much higher resolutions than area scan devices, with 2500 pixels being the highest typical horizontal resolution of area scan sensors, while upwards of 12,000 pixels in a linear device is not uncommon. However, with line scan cameras, the object must be precisely moved relative to the camera to construct the image, making integration much more difficult. A brief overview of area scan and line scan cameras is provided in Table 5.

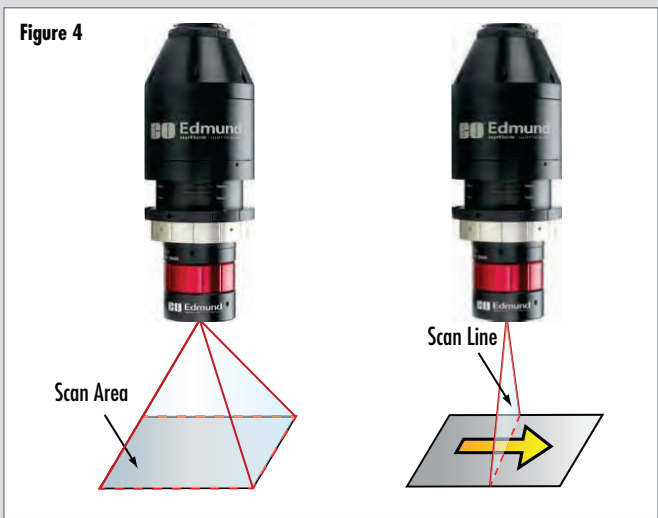


Figure 4: Illustration of Area Scanning Technique (left) and Line Scanning Technique (right).

DIGITAL CAMERA FORMATS	
Area Scan	Line Scan
• 4:3 (H:V) Ratio (Typical) • Large Sensors (Up to 2500-6600 Pixels/Line) • High Speed Applications Up to a Few Hundred FPS • Object is Stationary or Slowly Moving • Shutter Times Slow-to-Fast • Wider Range of Applications • Easier to Set-up • Lower Cost than Line Scan	• Sensor is Linear • Large Sensors (Up to 16,000 Pixels/Line) • High Speed Applications- Line rates Up to 100khz • Constructs Image One Line at a Time • Object Passes in Motion Under Sensor • Ideal for Capturing Wide Objects • Special Alignment & Timing Required • Complex Integration / Simple, but Intense, Illumination

Table 5: Comparison of Digital Camera Formats: Area Scan and Line Scan.

STANDARD CAMERA/LENS MOUNTING CONFIGURATIONS		
C-Mount	F-Mount	CS-Mount
• Threaded Mount • 1" Diameter with 32 TPI (Threads Per Inch) • 17.5mm Back Flange Distance • Most Common Interface	• Some Short FL Lenses Not Compatible • 46.5mm Back Flange Distance • Ideal for Medium Format Line Scan And Full Frame (35mm) Format Applications	• Threaded Mount • 1" Diameter with 32 TPI (Threads Per Inch) • 12.5mm Back Flange Distance • Compatible with C-Mount Lenses using a 5mm Spacer (#03-618)
		Other Common Mounts
		• M12 x 0.5 (S-Mount) • M42 x 1.0 • M72 x 1.0

Table 6: Comparison of Typical Camera Mounting Options.

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Allied Vision Stingray Cameras

Basler Scout Cameras

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Cameras

EO USB 3.0 CMOS MACHINE VISION CAMERAS



- **Compact Designs for Maximum Flexibility**
- **USB 3.0 Interface for Maximum Data Transfer Speed**
- **Lightweight Housing**

EO USB 3.0 CMOS Machine Vision Cameras are lightweight, compact solutions for a range of machine vision applications. Available in 0.4 - 18 MegaPixel options, these cameras utilize USB 3.0 interfaces for maximum data transfer speeds of up to 5Gbits/s. EO USB 3.0 CMOS Machine Vision Cameras feature GPIO trigger/flash and lockable micro USB 3.0 connectors to ensure durability and consistency. **Note:** USB 3.0 cable (sold separately) required for operation.

Type of Sensor:	Progressive Scan CMOS
Dimensions (mm):	29 x 29 x 29 (LE: 47 x 46 x 28)
Weight (g):	52 (LE:41)
Video Output:	USB 3.0
Synchronization:	Internal or Via Software
Mount:	C-Mount (LE: C/CS-Mount)

EO USB 3.0 CMOS MACHINE VISION CAMERAS

Model Number:	EO-0413	EO-0513	EO-1312	EO-13122	EO-2018	EO-2223	EO-2323
Imaging Device:	ON Semi MT9V032STM/C	ON Semi Python 500	e2v EV76C560BB/C	ON Semi PYTHON1300	e2v EV76C570A	CMOSIS CMV2000	ON Semi Python 2000
Camera Sensor Format:	1/3"	1/3.6"	1/1.8"	1/2"	1/1.8"	2/3"	2/3"
Sensing Area, H x V (mm):	4.5 x 2.8	3.84 x 2.88	6.79 x 5.43	6.1 x 4.9	7.2 x 5.4	11.3 x 6.0	9.22 x 5.76
Pixels (H x V):	752 x 480	800 x 600	1280 x 1024	1280 x 1024	1600 x 1200	2048 x 1088	1920 x 1200
Pixel Size, H x V (µm):	6.0 x 6.0	4.8 x 4.8	5.3 x 5.3	4.8 x 4.8	4.5 x 4.5	5.5 x 5.5	4.8 x 4.8
Pixel Depth:	10-bit	10-bit	10-bit	10-bit	10-bit	12-bit	10-bit
Frame Rate (fps):	100	571	60	169	63.4	152	180
Type of Shutter:	Global	Global	Global or Rolling	Global	Global, Multi-Exposure, or Rolling	Global	Global
USB 3.0 Monochrome	#86-752 \$775.00	#34-847 \$675.00	#86-754 \$825.00	#33-520 \$705.00	#88-151 \$1,050.00	#33-522 \$1,095.00	#34-849 \$875.00
USB 3.0 Color	#86-753 \$775.00	#34-848 \$675.00	#86-755 \$825.00	#33-521 \$705.00	#88-152 \$1,050.00	#33-523 \$1,095.00	#34-850 \$875.00
USB 3.0 Lite Edition Monochrome	N/A —	N/A —	#89-733 \$575.00	N/A —	#89-735 \$695.00	N/A —	N/A —
USB 3.0 Lite Edition Color	N/A —	N/A —	#89-734 \$575.00	N/A —	#89-736 \$695.00	N/A —	N/A —

EO USB 3.0 CMOS MACHINE VISION CAMERAS

Model Number:	EO-23121	EO-23122	EO-4010	EO-5012	EO-18112	EO-5310	EO-50231	EO-50232
Imaging Device:	Sony IMX174	Sony IMX249	CMOSIS CMV4000	ON Semi MT9P031/06	ON Semi AR1820HS	ON SEMI PYTHON 500	SONY IMX250	SONY IMX264
Camera Sensor Format:	1/1.2"	1/1.2"	1"	1/2"	1/2"	1"	2/3"	2/3"
Sensing Area, H x V (mm):	11.3 x 7.1	11.3 x 7.1	11.26 x 11.26	5.6 x 4.2	6.1 x 4.6	12.44 x 9.83	8.45 x 7.07	8.45 x 7.07
Pixels (H x V):	1920 x 1200	1920 x 1200	2048 x 2048	2560 x 1920	4912 x 3684	2592 x 2048	2456 x 2054	2456 x 2054
Pixel Size, H x V (µm):	5.86 x 5.86	5.86 x 5.86	5.5 x 5.5	2.2 x 2.2	1.25 x 1.25	4.8 x 4.8	3.45 x 3.45	3.45 x 3.45
Pixel Depth:	12-bit	12-bit	12-bit	12-bit	10-bit	10-bit	12-bit	12-bit
Frame Rate (fps):	161	41	75	15	21	81	77	36
Type of Shutter:	Global	Global	Global	Global Start or Rolling	Rolling	Global	Global	Global
USB 3.0 Monochrome	#33-524 \$925.00	#33-526 \$825.00	#88-153 \$2,995.00	#86-756 \$895.00	N/A —	#34-851 \$1,250.00	#34-853 \$1,720.00	#34-855 \$1,360.00
USB 3.0 Color	#33-525 \$925.00	#33-527 \$825.00	#88-154 \$2,995.00	#86-757 \$895.00	#33-529 \$760.00	#34-852 \$1,250.00	#34-854 \$1,720.00	#34-856 \$1,360.00
USB 3.0 Lite Edition Monochrome	N/A —	N/A —	N/A —	#89-737 \$595.00	N/A —	N/A —	N/A —	N/A —
USB 3.0 Lite Edition Color	N/A —	N/A —	N/A —	#89-738 \$595.00	N/A —	N/A —	N/A —	N/A —

ACCESSORIES

Description	Stock No.	Price
USB 3.0 Locking Cable, 3m	#86-770	\$25.00
USB 3.0 PCIe 2 Port Capture Card	#86-769	\$125.00
GPIO Cable for USB 3.0 EO Camera	#86-758	\$140.00
1/4-20 Mounting Adapter for EO USB 3.0	#86-759	\$45.00
1/4-20 Mounting Adapter for EO USB 3.0 Lite Edition	#89-739	\$45.00

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EO High Dynamic Range Cameras



EO GigE Cameras



EO Autofocusing Cameras



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ALLIED VISION MAKO USB 3.0 CAMERAS



Video Output: USB 3.0
 Lens Mount: C-Mount
 Dimensions (mm): 49.5 x 29 x 29
 Weight (g): 60

- **Compact Housing with Form Factor of 49.5 x 29 x 29mm**
- **Powered Over USB 3.0 Interface**
- **High Frame Rates**

Allied Vision Mako USB 3.0 Cameras offer a variety of sensor choices while maintaining the same compact form factor of 49.5 x 29 x 29mm. Every model is powered over the USB interface and has opto-isolated I/Os. These Allied Vision Mako USB 3.0 Cameras feature GPIOs giving them the maximum flexibility required to adapt to specific needs. The two non-isolated GPIO lines are TTL-based and programmable as input or output. Screw locks ensure a safe electrical connection making these ideal for harsh industrial environments.



ALLIED VISION MAKO USB 3.0 CAMERAS

Model Number:	Mako U-029B	Mako U-051B	Mako U-130B	Mako U-503B
Imaging Device:	ON Semi PYTHON 300	ON Semi PYTHON 500	ON Semi PYTHON 1300	Aptina MT9P031
Sensing Area (H x V) (mm):	3.1 x 2.3	3.8 x 2.9	6.1 x 4.9	5.7 x 4.3
Pixels (H x V):	640 x 480	800 x 600	1280 x 1024	2592 x 1944
Pixel Size, (H x V) (µm):	4.8 x 4.8	4.8 x 4.8	4.8 x 4.8	2.2 x 2.2
Pixel Depth:	8/10 bit	8/10 bit	8/10 bit	8/12 bit
Frame Rate (fps):	550	391	168	14
Monochrome Camera	#34-203	#34-205	#34-207	#34-209
Color Camera	N/A	N/A	N/A	N/A
	\$375.00	\$425.00	\$475.00	\$450.00

ACCESSORIES

Description	Stock No.	Price
1/4-20 Mounting Plate for Allied Vision Mako USB	#34-211	\$40.00
8m USB 3.0 Locking Cable	#34-212	\$130.00
USB 3.0 PCIe 2.0 x1 2 Port Card	#34-213	\$50.00
6-pin GPIO Hirose Cable with Leads, 2m	#34-214	\$70.00
6-pin GPIO Hirose Cable with Leads, 5m	#34-215	\$80.00
6-pin GPIO Hirose Cable with Leads, 10m	#34-216	\$85.00

ALLIED VISION MAKO POWER OVER ETHERNET (PoE) CAMERAS



Pixel Depth: 8/12 Bit
 Type of Sensor: Progressive Scan CCD or CMOS
 Synchronization: External or Via Software
 Video Output: GigE
 Memory (MB): 64
 Power Supply: PoE
 Lens Mount: C-Mount
 Dimensions (mm): 60.5 x 29 x 29
 Weight (g): 80

- **Compact, Robust Metal Housing**
- **One Optocoupled Input, Three Outputs**
- **Power over Ethernet for Increased Flexibility**

Allied Vision Mako Power over Ethernet (PoE) Cameras are ideal digital replacements for analog cameras in a variety of applications, including robots, inspection, or logistics. Allied Vision Mako PoE Cameras feature a precision aligned sensor to maximize image performance, in addition to a 64MB image buffer. To increase adaptability, Allied Vision Mako PoE Cameras also come equipped with multiple smart features, including region of interest readout, programmable exposure and white balance, and easy bandwidth control. Additionally, these PoE cameras utilize a robust metal housing along with camera temperature monitoring to ensure maximum performance in a range of environments. **Note:** GigE cable and power supply (if not using PoE) required for operation.



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ALLIED VISION MAKO POWER OVER ETHERNET (PoE) CAMERAS

Model Number	G-030	G-032	G-125	G-131	G-192	G-223	G-419	G-503
Imaging Device:	CMOSIS CMV300	Sony ICX424	Sony ICX445	e2v EV76C560	e2v EV76C570	CMOSIS CMV2000	CMOSIS CMV4000	ON Semi MT9P031/06
Camera Sensor Format:	1/8"	1/8"	1/8"	1/1.8"	1/1.8"	2/3"	1"	1/2.5"
Sensing Area (H x V) (mm):	4.8 x 3.6	7.9 x 3.6	4.8 x 3.6	6.8 x 5.4	7.2 x 5.4	11.3 x 6.0	11.3 x 11.3	5.7 x 4.3
Pixels (H x V):	644 x 484	658 x 492	1292 x 964	1280 x 1024	1600 x 1200	2048 x 1088	2048 x 2048	2592 x 1944
Pixel Size, H x V (µm):	7.4 x 7.4	7.4 x 7.4	3.75 x 3.75	5.3 x 5.3	4.5 x 4.5	5.5 x 5.5	5.5 x 5.5	2.2 x 2.2
Frame Rate (fps):	309	102	30	62	60	49.5	26.3	14
Monochrome Camera	#33-512	#88-465	#88-467	#33-514	#33-516	#88-469	#88-472	#33-518
Color Camera	#33-513	#88-466	#88-468	#33-515	#33-517	#88-470	#88-473	#33-519
NIR Camera	N/A	N/A	N/A	N/A	N/A	#88-471	#88-474	N/A
	\$695.00	\$575.00	\$595.00	\$550.00	\$625.00	\$1,475.00	\$2,125.00	\$495.00
	\$695.00	\$575.00	\$595.00	\$550.00	\$625.00	\$1,475.00	\$2,125.00	\$495.00
	—	—	—	—	—	\$1,550.00	\$2,225.00	—

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Allied Vision Manta GigE Cameras



Allied Prosilica GigE Cameras



Allied Stingray FireWire.b Cameras



Allied Guppy Pro FireWire.b Cameras



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Cameras

POINT GREY GRASSHOPPER®3 HIGH PERFORMANCE USB 3.0 CAMERAS



- **Feature High Resolution, High Sensitivity CCD Sensors**
- **High Frame Rates Driven by USB 3.0 Interface**
- **Includes Image Capture Software and SDK**

Point Grey Grasshopper®3 High Performance USB 3.0 Cameras are high speed, 14bit imaging cameras designed for demanding machine vision applications including metrology, gauging, or inspection. Point Grey Grasshopper®3 High Performance USB 3.0 Cameras feature a 128MB image buffer along with 2MB of flash memory. In addition to onboard image processing that includes color interpolation, gamma, and lookup table functionality, additional functionality is available using the included image capture software and SDK. USB 3.0 cameras are ideal alternatives for Camera Link® systems. **Note:** USB 3.0 cable (sold separately) is required for operation.

POINT GREY GRASSHOPPER®3 HIGH PERFORMANCE USB 3.0 CAMERAS

Model Number:	GS3-U3-14S5C/M-C	GS3-U3-15S5C/M-C	GS3-U3-23S6C/M-C	GS3-U3-28S4C/M-C	GS3-U3-28S5C/M-C	GS3-U3-32S4M-C	GS3-U3-41S4C/M-C
Type of Sensor:	Progressive Scan CCD	Progressive Scan CCD	Progressive Scan CMOS	Progressive Scan CCD	Progressive Scan CCD	Progressive Scan CMOS	Progressive Scan CCD
Camera Sensor Format:	2/3"	2/3"	1/1.2"	1/1.8"	2/3"	1/1.8"	1/1.8"
Imaging Device:	Sony ICX285	Sony ICX825	Sony IMX174	Sony ICX687	Sony ICX674	Sony IMX252	Sony ICX808
Pixels (H x V):	1384 x 1036	1384 x 1032	1900 x 1200	1928 x 1448	1920 x 1440	2048 x 1536	2016 x 2016
Pixel Size, H x V (µm):	6.45 x 6.45	6.45 x 6.45	5.86 x 5.86	3.69 x 3.69	4.54 x 4.54	3.45 x 3.45	3.1 x 3.1
Frame Rate (fps):	30	45	162	26	26	121	18
Monochrome Camera	#33-530 \$1,695.00	#33-532 \$1,595.00	#88-607 \$1,350.00	#88-049 \$1,350.00	#88-051 \$2,350.00	#33-534 \$1,095.00	#33-536 \$1,450.00
Color Camera	#33-531 \$1,695.00	#33-533 \$1,595.00	#88-608 \$1,350.00	#88-050 \$1,350.00	#88-052 \$2,350.00	N/A —	#33-537 \$1,450.00
NIR Camera	N/A —	N/A —	N/A —	N/A —	N/A —	N/A —	N/A —

POINT GREY GRASSHOPPER®3 HIGH PERFORMANCE USB 3.0 CAMERAS

Model Number:	GS3-U3-41C6C/M-C	GS3-U3-50S5C/M-C	GS3-U3-51S5M-C	GS3-U3-60S6M/C-C	GS3-U3-60QS6C/M-C	GS3-U3-91S6M/C-C	GS3-U3-120S6C/M-C
Type of Sensor:	Progressive Scan CMOS	Progressive Scan CCD	Progressive Scan CMOS	Progressive Scan CCD	Progressive Scan CCD	Progressive Scan CCD	Progressive Scan CCD
Camera Sensor Format:	1"	2/3"	2/3"	1"	1"	1"	1"
Imaging Device:	CMOSIS CMV4000	Sony ICX625	Sony IMX250	Sony ICX694	Sony ICX694	Sony ICX814	Sony ICX834
Pixels (H x V):	2048 x 2048	2448 x 2048	2448 x 2048	2736 x 2192	2736 x 2192	3376 x 2704	4240 x 2824
Pixel Size, H x V (µm):	5.5 x 5.5	3.45 x 3.45	3.45 x 3.45	4.54 x 4.54	4.54 x 4.54	3.69 x 3.69	3.1 x 3.1
Frame Rate (fps):	90	15	75	13	25	9	7
Monochrome Camera	#88-513 \$1,450.00	#89-527 \$2,450.00	#33-538 \$1,550.00	#88-053 \$3,550.00	#33-540 \$3,550.00	#88-055 \$3,850.00	#33-542 \$3,795.00
Color Camera	#88-514 \$1,450.00	#89-528 \$2,450.00	N/A —	#88-054 \$3,550.00	#33-541 \$3,550.00	#88-056 \$3,850.00	#33-543 \$3,795.00
NIR Camera	#89-526 \$1,450.00	N/A —	N/A —	N/A —	N/A —	N/A —	N/A —

ACCESSORIES

Description	Stock No.	Price
4 Port USB 3.0 PCIe Card 2.0 x 1	#89-539	\$135.00
4 Port USB 3.0 Hub with Power	#89-540	\$165.00
USB 3.0 PCIe 2.0 x 1 2 Port Card	#86-769	\$125.00
USB 3.0 Locking Cable, 3m	#86-770	\$25.00
Grasshopper Tripod Mount	#88-057	\$20.00
USB 3.0 Locking Cable, 5m	#88-058	\$35.00
8-pin GPIO Hirose Connector, 1m Cable	#88-059	\$65.00
8-pin GPIO Hirose Connector, 4.5m Cable	#88-060	\$85.00
Flea®3 & Grasshopper®3 Power Supply	#86-784	\$95.00

Pixel Depth:	8, 12, 14, 16 or 24-bit digital data
Type of Shutter:	Global
Electronic Shutter:	See Website
Transfer Speed:	5 Gbit/s
Image Buffer:	128 MB frame buffer
Flash Memory:	2 MB non-volatile memory
Synchronization:	External or Via Software
Video Output:	USB 3.0 interface with screw locks
Lens Mount:	C-Mount
Dimensions:	44 x 29 x 58mm
Operating Temp.:	0° to 50°C
Storage Temp.:	-30° to 60°C
Weight:	90g

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Point Grey Flea3 USB 3 & GigE Cameras



Point Grey Blackfly GigE Cameras



Point Grey Chameleon USB 3



Point Grey Blackfly USB 3



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DALSA GENIE™ NANO POWER OVER ETHERNET (PoE) CAMERAS

- **Fast Frame Rates up to 862 fps**
- **Compact, Robust All Metal Body**
- **Global Electronic Shutter with Exposure Control**

Dalsa Genie™ Nano Power over Ethernet (PoE) Cameras are available in a range of leading CMOS sensors. These PoE cameras provide high speed, low noise, and global electronic shutters. The proprietary TurboDrive™ technology allows the Genie™ Nano to deliver faster frame rates at its full image quality. Dalsa Genie™ Nano PoE Cameras feature high speed and robust quality, making them ideal for electronics inspection, industrial metrology, and Intelligent Traffic Systems (ITS) applications.

Video Output:	Gigabit Ethernet (1000 Mbit/s)	Operating Temperature:	-20° to +60°C
Exposure Control:	Programmable or via external trigger	Power Requirements:	Power Over Ethernet (PoE) or 10 to 36V
I/O Ports:	2 opto-isolated inputs, 2 opto-isolated outputs	Connector:	Standard or RJ-45 screw mount
Dimensions (L x H x W):	38.9 x 29 x 44mm	Conformity:	GigE Vision v1.2
Weight:	46g	Software Platform:	Windows, Linux, or 3rd Party GenICam compliant SDK



NEW

DALSA GENIE™ NANO POWER OVER ETHERNET (PoE) CAMERAS

Model Number:	M/C 640	M/C 1280	M/C 1920	M/C 1940
Camera Sensor Format:	1/4"	1/2"	1/1.2"	1/1.2"
Sensor Type:	ON Semi Python300	ON Semi Python1300	Sony IMX249	Sony IMX174
Pixels (H x V):	640 x 480	1280 x 1024	1920 x 1200	1920 x 1200
Pixel Size, H x V (µm):	4.8 x 4.8	4.8 x 4.8	5.86 x 5.86	5.86 x 5.86
Frame Rate (fps):	862	213	39	84
Lens Mount:	C-Mount	C-Mount	C-Mount	C-Mount
Monochrome Camera	#34-950 \$525.00	#34-952 \$550.00	#34-954 \$550.00	#34-956 \$950.00
Color Camera	#34-951 \$525.00	#34-953 \$550.00	#34-955 \$550.00	#34-957 \$950.00

DALSA GENIE™ NANO POWER OVER ETHERNET (PoE) CAMERAS

Model Number:	M/C 1930	M/C 2020	M/C 2420	M/C 2590
Camera Sensor Format:	2/3"	1/1.8"	2/3"	1"
Sensor Type:	ON Semi Python2000	Sony IMX265	Sony IMX264	ON Semi Python5000
Pixels (H x V):	1920 x 1200	2048 x 1536	2448 x 2048	2592 x 2048
Pixel Size, H x V (µm):	4.8 x 4.8	3.45 x 3.45	3.45 x 3.45	4.8 x 4.8
Frame Rate (fps):	116	55	35	51
Lens Mount:	C-Mount	C-Mount	C-Mount	C-Mount
Monochrome Camera	#34-958 \$695.00	#34-960 \$595.00	#34-962 \$995.00	#34-964 \$995.00
Color Camera	#34-959 \$695.00	#34-961 \$595.00	#34-963 \$995.00	#34-965 \$995.00

ACCESSORIES

Description	Stock No.	Price
1/4-20 Mounting Adapter	#34-966	\$65.00
Cable Kit (12V Power Supply, 2m GigE Cable, and 2m Breakout Cable)	#34-967	\$175.00

Cameras

BASLER ace GIGABIT ETHERNET CAMERA



- Perfect Analog Replacement
- Ultra-Small Form Factor
- Includes Basler Pylon Driver

An ideal upgrade for analog camera users, the Basler ace is an economical Gigabit Ethernet camera. With a small form factor matching that of many analog cameras (29 x 29mm), the ace can be a drop-in replacement in an existing analog system, or a great choice to start a new project with. Optionally able to use Power Over Ethernet (PoE)*, these cameras can have long cable lengths, and are the optimal choice for use on a factory floor. All cameras include the use of the industry proven Basler Pylon Driver. **GigE cable and power supply (if not using PoE) required for operation. Note:** UC Series lens is not included.

Video Output:	Gigabit Ethernet
Synchronization:	Via external trigger, via GigE connection, or free-run
Exposure Control:	Freely programmable
Power Requirements:	Via Power over Ethernet or via Hirose 6-pin connector
Lens Mount:	C-Mount
Housing Size (L x W x H):	54 x 29 x 29mm
I/O Ports:	1 opto-isolated input/output
Software Driver:	Windows®, Linux (32 and 64 bit)
Operating System:	0° to 50°C
Housing Temperature:	GigE Vision compliant, Basler Pylon SDK incl. filter and performance driver
Software Driver:	

BASLER ace GIGABIT ETHERNET CAMERA

Model Number:	acA640-90g	acA640-120g	N acA640-300g	acA645-100g	acA750-30g	acA780-75g	N acA800-200g
Imaging Device:	1/3" CCD	1/4" CCD	1/4" CMOS	1/2" CCD	1/3" CCD	1/2" CCD	1/3.6" CMOS
Sensor Type:	Sony ICX424	Sony ICX618	ON Semi Python300	Sony ICX414	Sony ICX409	Sony ICX415	ON Semi Python500
Pixels (H x V):	658 x 492	659 x 494	640 x 480	658 x 492	752 x 582	728 x 582	800 x 600
Pixel Size, H x V (µm):	7.4 x 7.4	5.6 x 5.6	4.8 x 4.8	9.9 x 9.9	6.5 x 6.25	8.3 x 8.3	4.8 x 4.8
Frame Rate (fps):	90	120	376	100	30	75	240
Monochrome Camera	#87-095 \$675.00	#68-458 \$650.00	#33-982 \$495.00	#87-097 \$795.00	#68-460 \$595.00	#87-099 \$825.00	#33-984 \$525.00
Color Camera	#87-096 \$675.00	#68-459 \$650.00	#33-983 \$495.00	#87-098 \$795.00	#68-461 \$595.00	#87-100 \$825.00	#33-985 \$525.00

BASLER ace GIGABIT ETHERNET CAMERA

Model Number:	acA1280-60g	acA1300-22g	acA1300-30g	acA1300-60g	N acA1300-75g	acA1600-20g	acA1600-60g
Imaging Device:	1/1.8" CMOS	1/3" CCD	1/3" CCD	1/1.8" CCD	1/2" CMOS	1/1.8" CCD	1/1.8" CMOS
Sensor Type:	e2v EV76C560	Sony ICX445	Sony ICX445	e2v EV76C560	ON Semi Python1300	Sony ICX274	e2v EV76C560
Pixels (H x V):	1280 x 1024	1296 x 966	1296 x 966	1280 x 1024	1280 x 1024	1628 x 1236	1600 x 1200
Pixel Size, H x V (µm):	5.3 x 5.3	3.75 x 3.75	3.75 x 3.75	5.3 x 5.3	4.8 x 4.8	4.4 x 4.4	4.5 x 4.5
Frame Rate (fps):	60	22	30	60	88	20	60
Monochrome Camera	#89-974 \$375.00	#88-556 \$495.00	#68-462 \$795.00	#88-327 \$495.00	#33-986 \$535.00	#68-464 \$1,195.00	#88-330 \$725.00
Color Camera	#89-975 \$375.00	#88-557 \$495.00	#68-463 \$795.00	#88-328 \$495.00	#33-987 \$535.00	#68-465 \$1,195.00	#88-331 \$725.00
NIR Camera	N/A —	N/A —	N/A —	#88-329 \$775.00	N/A —	N/A —	N/A —

BASLER ace GIGABIT ETHERNET CAMERA

Model Number:	acA1920-25g	N acA1920-40g	acA1920-50g	acA2000-50g	acA2040-25g	acA2500-14g	acA3800-10g	acA4600-7g
Imaging Device:	1/3.7" CCD	1/1.2" CMOS	1/1.2" CMOS	2/3" CMOS	1" CMOS	1/2.5" CMOS	1/2.3" CMOS	1/2.3" CMOS
Sensor Type:	ON Semi MT9P031	Sony IMX249	Sony IMX174	CMOSIS CMV2000	CMOSIS CMV4000	ON Semi MT9P031	ON Semi MT9J003	ON Semi MT9J002
Pixels (H x V):	1920 x 1080	1920 x 1200	1920 x 1200	2048 x 1088	2048 x 2048	2592 x 1944	3856 x 2764	4608 x 3288
Pixel Size, H x V (µm):	2.2 x 2.2	5.86 x 5.86	5.86 x 5.86	5.5 x 5.5	5.5 x 5.5	2.2 x 2.2	1.67 x 1.67	1.4 x 1.4
Frame Rate (fps):	25	42	50	50	25	14	10	7
Monochrome Camera	#88-558 \$375.00	#33-988 \$550.00	#89-976 \$1,225.00	#87-101 \$1,595.00	#87-104 \$2,295.00	#85-165 \$695.00	#89-978 \$625.00	N/A —
Color Camera	#88-559 \$375.00	#33-989 \$550.00	#89-977 \$1,225.00	#87-102 \$1,599.00	#87-105 \$2,295.00	#85-166 \$695.00	#89-979 \$625.00	#89-980 \$695.00
NIR Camera	N/A —	N/A —	N/A —	#87-103 \$1,850.00	#87-106 \$2,450.00	N/A —	N/A —	N/A —

ACCESSORIES

Description	Stock No.	Price
1/4-20 Mounting Adapter for Basler ace	#88-517	\$45.00
Power Supply for Basler ace 12V, 6 Pin	#68-466	\$75.00
Power over Ethernet Injector*	#68-469*	\$75.00
PLC I/O Cable, 6-Pin, 10m	#68-467	\$170.00
Digital I/O Cable, 6-Pin, 10m	#88-516	\$65.00
Cat 6 GigE Cable, 5m	#68-470	\$55.00
Cat 6 GigE Cable, 10m	#68-471	\$65.00

*PoE Injector requires use of 2 GigE cables

PixeLINK® USB 3.0 AUTOFOCUS LIQUID LENS CAMERAS



Type of Sensor:	CMOS
Video Output:	USB 3.0
Lens Mount:	C-Mount
Input/Output Options:	1 Trigger Input, 2 GPO
#34-779:	2 GPO
Dimensions:	32 x 48 x 11mm
#34-786:	38.5 x 55 x 30mm
Weight:	35.8g
#34-786:	59.87g

- **Seamless Integration of Liquid Lenses**
- **One-Push Autofocus, High Speed Focus Movement**
- **Easy to Use USB 3.0 Interface**

PixeLINK® USB 3.0 Autofocus Liquid Lens Cameras provide the ability to seamlessly integrate and control liquid lenses. By enabling the liquid lens to be directly connected to the camera, it allows for fast, continuous focus control. This simple autofocus system makes these cameras ideal for high speed applications such as bar code reading, inspection, and biomedical applications. PixeLINK® USB 3.0 Autofocus Liquid Lens Cameras are compatible with our TECHSPEC® Cx Series Fixed Focal Length Lenses, which combine high resolution image performance with built-in liquid lens integration. **Note:** Liquid lens is not included.



NEW



See pages 56-57 for compatible Cx Series Lenses and visit our website for Variable Focus Liquid Lenses.

PixeLINK® USB 3.0 AUTOFOCUS LIQUID LENS CAMERAS

Model Number:	PL-D721	PL-D722	PL-D729	PL-D732	PL-D755	PL-D7715	PL-D775
Camera Sensor Format:	1/2"	2/3"	2/3"	2/3"	2/3"	1/2.2"	1/2.5"
Resolution (MegaPixels):	1.3	2.3	9.5	2.2	5	15	5
Imaging Device:	ON Semi Vita 1300	ON Semi Vita 2000	ON Semi Mono 9600	CMOSIS CMV2000	Sony IMX250	ON Semi MTFF002	ON Semi MT9P031
Pixels (H x V):	1280 x 1024	1920 x 1200	3840 x 2484	2048 x 1088	2448 x 2048	4608 x 3288	2592 x 1944
Pixel Size, H x V (µm):	4.8 x 4.8	4.8 x 4.8	2.4 x 2.4	5.5 x 5.5	3.45 x 3.45	1.4 x 1.4	2.2 x 2.2
Frame Rate (fps):	150	92	22	170	75	12	15
Shutter:	Global	Global	Rolling	Global	Global	Rolling	Rolling
Bit Depth:	8 or 10 Bit	8 or 10 Bit	8 or 10 Bit	8 or 10 Bit	8 or 12 Bit	8 or 12 Bit	8 or 12 Bit
Monochrome Camera	#34-775 \$1,375.00	#34-777 \$1,575.00	#34-779 \$1,995.00	#34-781 \$1,825.00	#34-783 \$1,875.00	N/A —	#34-787 \$1,325.00
Color Camera	#34-776 \$1,375.00	#34-778 \$1,575.00	N/A —	#34-782 \$1,825.00	#34-784 \$1,875.00	#34-786 \$1,125.00	#34-788 \$1,325.00

ACCESSORIES

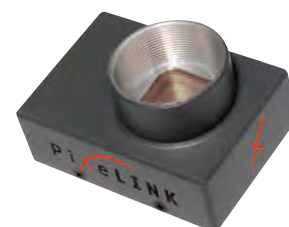
Description	Stock No.	Price
3m USB 3.0 Locking Cable	#34-947	\$75.00
2m USB 3.0 Locking Cable	#34-948	\$65.00
1/4-20 Mounting Adapter	#34-949	\$55.00

PixeLINK® USB 3.0 MICROSCOPY CAMERAS



Type of Sensor:	CMOS Sensor
Video Output:	USB 3.0
Exposure Control:	Freely Programmable
Power Requirement:	Via USB 3.0 interface
Lens Mount:	C-Mount
Operating System:	Software Driver: Windows 64 bit
Operating Temperature:	0° to +50°C
Dimensions:	38.50 x 55 x 30.6mm

- **Easy-to-Setup USB 3.0 Technology (Cable Included)**
 - **Up to 15 MegaPixel Resolution**
 - **Include Extensive µScope Standard Microscopy Software**
- PixeLINK® USB 3.0 Microscopy Cameras are designed to capture high resolution images at up to 15 MegaPixels and with excellent color reproduction. These easy-to-setup cameras feature selectable regions of interest and are powered over USB to ease system integration. PixeLINK® USB 3.0 Microscopy Cameras are ideal for use in brightfield or darkfield microscopy applications in fields such as histology, pathology, or hematology. **Note:** µScope standard microscopy software and USB 3.0 cable are included.



PixeLINK® USB 3.0 MICROSCOPY CAMERAS

Model Number:	PL-D681M/CU-KIT	PL-D625CU-KIT	PL-D685M/CU-KIT	PL-D6215CU-KIT
Camera Sensor Format:	1/2"	1/2.5"	1"	1/2.3"
Resolution (Megapixels):	1.3	5	5.3	14
Imaging Device:	ON Semi VITA 1300	ON Semi MT9P006	ON Semi VITA 5000	ON Semi MT9F002
Pixels (H x V):	1280 x 1024	2592 x 1944	2592 x 2048	4384 x 3288
Pixel Size, H x V (µm):	4.8 x 4.8	2.2 x 2.2	4.8 x 4.8	1.4 x 1.4
Frame Rate (fps):	150	15	75	14
Monochrome Camera	#89-852 \$2,395.00	N/A —	#89-856 \$2,795.00	N/A —
Color Camera	#89-853 \$2,395.00	#89-858 \$2,495.00	#89-857 \$2,795.00	#89-859 \$3,195.00

ACCESSORIES

Description	Stock No.	Price
2m USB 3.0 Cable, A to Micro-B	#89-403	\$35.00
3m USB 3.0 Locking Cable, A to Micro-B	#89-404	\$45.00
Trigger Cable w/ 8-pin Hirose, Push Button	#89-405	\$225.00
Trigger Cable w/ 8-pin Hirose, Bare Leads	#89-406	\$225.00
PL-D Straight 1/4-20 Mount	#89-407	\$45.00
PL-D Right-Angled 1/4-20 Mount	#89-408	\$45.00



How Important Is Illumination?

Customers often struggle with contrast and resolution problems in an imaging system, while underestimating the power of proper illumination. In fact, desired image quality can typically be met by improving a system's illumination rather than by investing in higher resolution detectors, imaging lenses, and software.

Correct illumination is critical to an imaging system and improper illumination can cause a variety of image problems. Blooming or hot spots, for example, can hide important image information, as can shadowing. In addition, shadowing can also cause false edge calculations when measuring, resulting in inaccurate measurements. Poor illumination can also result in a low signal-to-noise ratio. Non-uniform lighting, in particular, can harm signal-to-noise ratios and make tasks such as thresholding more

difficult. These are only a few of the reasons why correct illumination for your application is so important.

To ensure optimal illumination when integrating a system, it is important to recognize the role that the right components play. Every component affects the amount of light incident on the sensor and, therefore, the system's image quality. The imaging lens' aperture ($f/\#$) impacts the amount of light incident on the camera. Illumination should be increased as the lens aperture is closed (i.e., higher $f/\#$). High power lenses usually require more illumination, as smaller areas viewed reflect less light back into the lens. The camera's minimum sensitivity is also important in determining the minimum amount of light required in the system. In addition, camera settings such as gain, shutter speed, etc., affect the sensor's sensitivity.

About Our Target

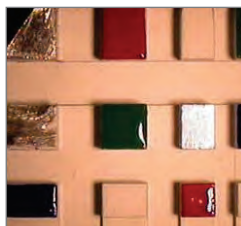
The various examples below illustrate the different types of illumination that are common in machine vision applications. Because the samples that are imaged can vary in shape, material, and reflectivity, the target used throughout this section was developed to demonstrate the strengths

and weaknesses of these various lighting schemes for a variety of object features. The grooves, colors, surface deformations, and specular areas on the target represent some of the common trouble areas that may demand special attention in actual applications.

Common Illumination Types for Opaque Objects (like our Target)

LIGHTING GEOMETRY SELECTION GUIDE:

Application Requirement	Object Under Inspection	Suggested Type of Illumination
Reduction of Specularity	Shiny Object	Diffuse Front, Diffuse Axial, Polarizing
Even Illumination of Object	Any Type of Object	Diffuse Front, Diffuse Axial, Ring Light
Highlight Surface Defects or Topology	Nearly Flat (2-D) Object	Single Directional, Structured Light
Highlight Texture of Object With Shadows	Any Type of Object	Directional, Structured Light
Reduce Shadows	Object With Protrusions, 3-D Object	Diffuse Front, Diffuse Axial, Ring Light
Highlight Defects Within Object	Transparent Object	Darkfield
Silhouetting Object	Any Type of Object	Backlighting
3-D Shape Profiling of Object	Object With Protrusions, 3-D Object	Structured Light



DIRECTIONAL ILLUMINATION

Point source illumination from single or multiple sources. Lenses can be used to focus or spread out illumination. Left image also uses a polarizing filter to reduce glare.

PROS

- Bright
- Flexible
- Adaptable
- Uniform

CONS

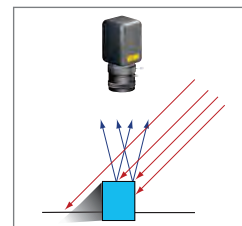
- Shadowing
- Glare

PRODUCTS USED

- Fiber Optic Light Guides
- Focusing Assemblies
- LED Spot Lights

APPLICATION

Inspection and measurement of matte and flat objects.



GLANCING ILLUMINATION

Point source illumination similar to directional illumination, except at a sharp angle of incidence.

PROS

- Show Surface Structure
- Enhances Object Topography

CONS

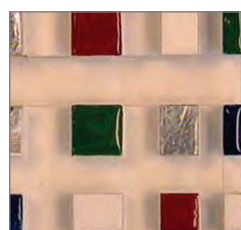
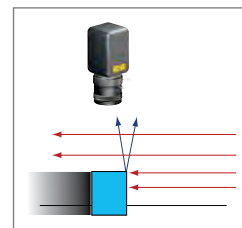
- Hot Spots
- Extreme Shadowing

PRODUCTS USED

- Fiber Optic Light Guides
- Focusing Assemblies
- LED Spot Lights

APPLICATION

Identifying defects in an object with depth and examining finish of opaque objects.



DIFFUSE ILLUMINATION

Diffuse even light from an extended source.

PROS

- Reduces Glare
- Provides Even Illumination

CONS

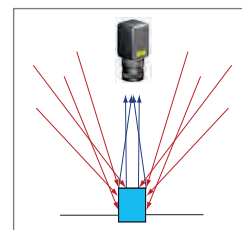
- Large
- Difficult to Fit in Confined Spaces
- Surface Features Less Distinct

PRODUCTS USED

- Diffuselite LED Illuminator
- LED Linear Lights

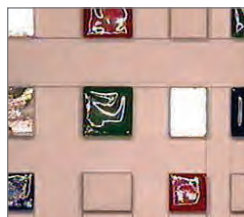
APPLICATION

Best for imaging large, shiny objects with large working distances.





Illumination types (continued)



RING LIGHT

Directional illumination in-line with the optics. Lens looks through circular aperture in center of illuminator or light guide.

PROS

- Reduces Shadows
- Relatively Even Illumination

CONS

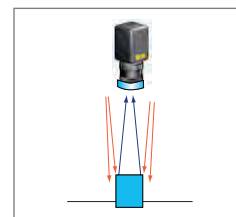
- Circular Glare Pattern from Highly Reflective Surface
- Difficult to Mount

PRODUCTS USED

- Fiber Optic Ring Light Guides
- LED Ring Lights

APPLICATION

Wide variety of inspection and measurement systems with matte objects.



DIFFUSE AXIAL

Diffuse light in-line with the optics. Lens looks through a beamsplitter that is reflecting light onto the object. Illumination is coaxial to imaging system.

PROS

- Shadow-Free
- Even Illumination
- Little Glare

CONS

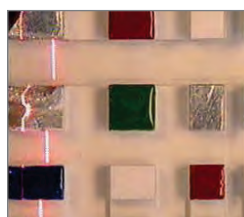
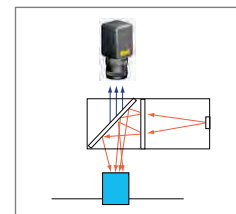
- Lower Intensity Through the Internal Beamsplitter

PRODUCTS USED

- LED Axial Illuminators
- Fiber Optic Diffuse Axial Adapters

APPLICATION

Highly reflective objects



STRUCTURED LIGHT

Patterns that are projected onto the object. Typically, laser projected lines, spots, grids or circles.

PROS

- Brings Out Surface Features

CONS

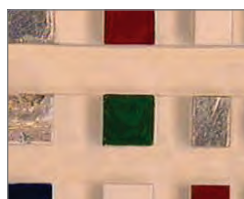
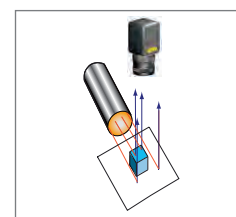
- Extremely Intense Source
- Absorbed by Some Colors

PRODUCTS USED

- Line Generating Laser Diodes
- Fiber Optic Line Light Guides
- LED Projectors

APPLICATION

Inspection of three-dimensional objects for missing features. Topography measurements.



POLARIZED LIGHT

A type of directional illumination that makes use of polarized light to remove specularities and hot spots.

PROS

- Even Illumination
- Minimal Glare

CONS

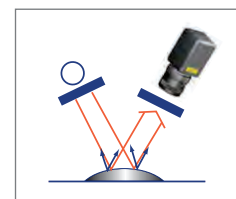
- Lower Intensity Through the Polarizer

PRODUCTS USED

- Attachable Polarization Filters
- Polarizer/Analyzers

APPLICATION

Measurements and inspection of shiny objects.



These types of illumination will work with opaque objects, but what about translucent?



DARKFIELD

Light enters a transparent or translucent object through the edge perpendicular to the lens.

PROS

- High Contrast of Internal & Surface Details
- Enhances Scratches, Cracks and Bubbles

CONS

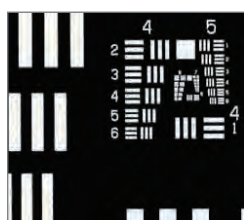
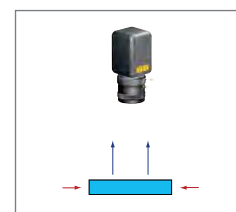
- Poor Edge Contrast
- Not Useful for Opaque Objects

PRODUCTS USED

- Fiber Optic Darkfield Attachment
- Line Light Guides
- Laser Line Generators
- LED Darkfield Ring Lights

APPLICATION

Glass and plastic inspection.



BACKLIGHT

Object is lit from behind. Used to silhouette opaque objects or for imaging through transparent objects

PROS

- High Contrast for Edge Detection

CONS

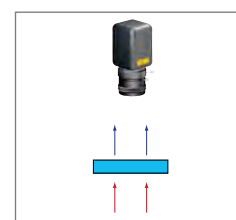
- Eliminates Surface Detail

PRODUCTS USED

- Fiber Optic Backlights
- LED Backlights

APPLICATION

Targets and test patterns, edge detection, measurement of opaque objects and sorting of translucent colored objects.



Illumination

In-line Illumination

In-line illumination is a unique style of lighting that incorporates the illumination into the optical train of the machine vision lens, usually by means of a fiber optic light guide or LED light source and a beam splitting optic. Although in-line illumination is not as bulky as diffuse axial illumination, and may be easier to integrate into a system that has tight space constraints, there are important optical differences a system designer must consider. In-line illumination is much more directional when compared to diffuse axial lighting, which, due to the chief rays being nearly parallel to the optical axis in object space, is one of the reasons that in-line illumination is widely incorporated with telecentric lenses (*Figure 1*). In comparison, diffuse axial lighting will project the illumination at a multitude of different angles, displaying different properties on the object and image planes.

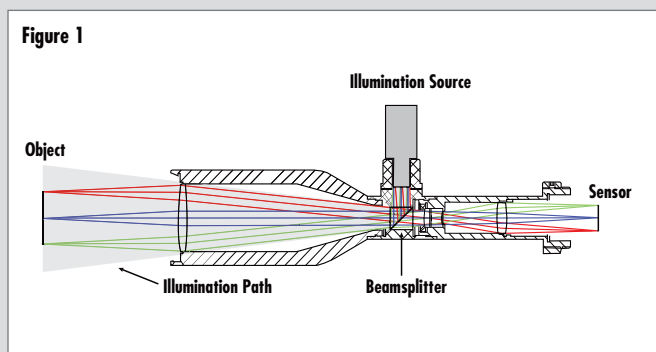


Figure 1: Diagram of in-line illumination within a telecentric lens.

Vastly different results will also come from comparing in-line illumination to brightfield illumination. *Figure 2* shows a chrome on glass, positive USAF 1951 contrast target illuminated both with brightfield illumination and with in-line illumination.

The most immediate difference between the two types of illumination is the complete contrast reversal between the two images. Additionally, the defects in the target are more readily apparent in the brightfield image, which, depending upon the application, can be either a positive or a negative effect. Interestingly, the highly reflective nature of the target yields about 10% better contrast for the in-line image when compared to the brightfield image – the reason for this is explained below.

Figure 2a

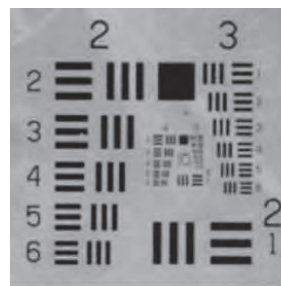


Figure 2b

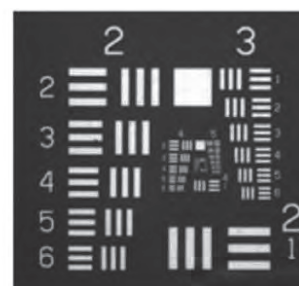


Figure 2: Chrome on glass USAF 1951 resolution target with brightfield illumination (*Figure 2a*), and in-line illumination (*Figure 2b*).

When to Use In-Line Illumination

When considering using in-line illumination, it is important to understand exactly where it is applicable and where it is not. In-line illumination is ideal for the inspection of specular or semi-specular objects, such as semiconductor wafers or CCDs, due to the nature of the rays on the illumination path. Using two different telecentric lenses, one with in-line illumination and one without, images of the same CCD demonstrate the differences between brightfield illumination (using a ring light) and in-line illumination. The images are shown in *Figure 3*.

In-line illumination would be a better choice to inspect the wires along the edge of the CCD due to the higher, more even contrast between the wires and the rest of the CCD. As shown in *Figure 4*, the reason that the wires in *Figure 3* appear bright using brightfield illumination and dark using in-line illumination is due to the ray paths of the lighting. With brightfield illumination, the rays are scattered into the lens, and with in-line illumination, the rays are scattered away from the lens.

With brightfield illumination, the rays originating from the ring light are reflected by the object into the lens. The reflections will vary based on the angle of the individual sources in the ring light as well as the angle of the wires themselves with respect to the CCD surface and the solder material at the tips, which is why the reflections have non-uniform pixel values along the length of the wire. Using in-line illumination, all of the rays are reflected by the object and scattered away from the lens such that none of the light that hits the wires is reflected back into the lens and onto the sensor. The more even contrast of the background, along with the stronger contrast of the wires, makes in-line illumination a better choice for the inspection of the wires than brightfield illumination.

Figure 3

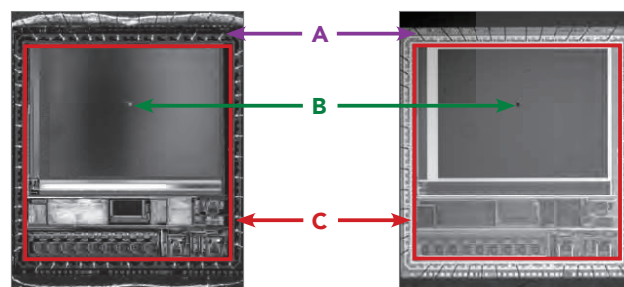


Figure 3: Comparison of brightfield illumination (left) with in-line illumination (right).

Brightfield Illumination	In-line Illumination
Low Contrast Wires	High Contrast Wires
Bright Chip on Faceplate	Dark Chip on Faceplate
High Contrast Image	Even Illumination with Consistent Contrast between Features (red square)

Table 1: Comparison of Brightfield and In-Line Illumination.

(Continued from page 154)

If the CCD cover glass were to be inspected for digs or chips, in-line illumination would also be the more advantageous choice since the overall image has a much more even contrast. The dark chips shown using in-line illumination (a result of the light being scattered as shown in Figure 4) would appear at a much higher contrast to the busy CCD background than the chips shown in the high contrast image formed using a brightfield system, as demonstrated in Figure 3.

Go to WWW.EDMUNDOPTICS.COM/IMAGING-LAB
to learn more about **Illumination**.

When Not to Use In-Line Illumination

Due to its multiple advantages, it is often believed that in-line illumination is always the superior choice for space-constrained systems. Unfortunately, it is not the best solution for objects that are optically diffuse or for objects requiring a large field of view. When used with diffuse objects, in-line illumination produces a hotspot on the image caused by the Lambertian (a nearly constant bidirectional reflectance distribution function) tendencies of the object, which is detrimental to any inspection system. Figure 5 shows an image of a diffuse object of wooden material both with (right image) and without (left image) in-line illumination.

When the primarily Lambertian object is in-line illuminated, the image has a well-defined hotspot in the center of the field of view. This hotspot effectively washes out the desired contrast, yielding a contrast of about 70% for the brightfield image, and about 8% for the in-line illuminated image, with both contrast values taken at the center of the image.

There are, of course, other situations where in-line illumination is not the ideal option. When a large field of view is required, the étendue of the illumination system becomes a problem, in that spreading out the flux of the light over a large field inherently leads to a much less dense bundle of photons, and therefore has a negative impact on the throughput of the system as a whole. Imperfect light sources also significantly and

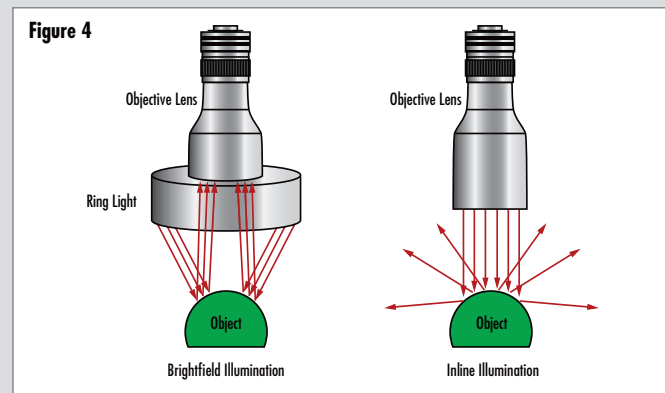


Figure 4: Comparison of ray paths using brightfield illumination (left) and in-line illumination (right).

negatively impact the performance of in-line illumination systems with large fields of view, as the small imperfections are bolstered over the large projection in the object plane.

Figure 5

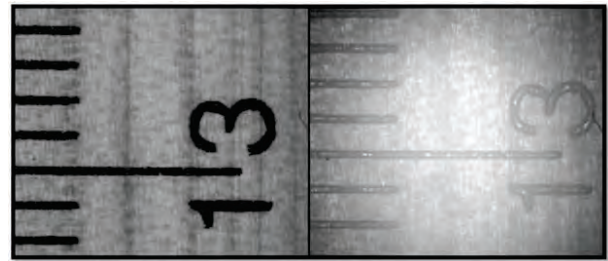


Figure 5: Comparison of wooden object with brightfield illumination (left) and in-line illumination (right).

Using Structured Illumination

Illumination is a critical component of any machine vision system, and can often be the difference between a good imaging system and a great one. Not only does the illumination position and wavelength need to be uniquely considered for each application, but certain systems require structured illumination to maximize system performance.

Structured illumination utilizes specific patterns of light to determine the geometric shape and depth of objects. An effective 3D system can be constructed by illuminating objects with different patterns, such as grids, dots, or lines, while minimizing cost, components, and complexity.

Since a well-calibrated system increases measurement accuracy, it is important to understand that structured illumination is not universal, and certain structures should be used to obtain certain measurements. For example, a dot grid pattern may suffice to inspect a few points on an object, but a line or multiple line pattern is required to measure an object's three dimensional profile.

Table 2 demonstrates common structured illumination patterns and their ideal applications.

Structured Illumination	Method of Determination	Purpose
	Triangulation Based	Determining the dimensions of most objects while the object is scanned
	Shadow and Triangulation Based	Determining the dimensions of refractive objects while the object is scanned
	Distortion Based	Determining the depth information at multiple discrete points in a single exposure

Table 2: Common Structured Illumination Patterns.

Telecentric Illumination

Conventional diffuse backlights are often used in manufacturing environments, where applications demand that objects be inspected and measured. Often, the profile of an opaque object can be checked for size, irregularities, or defects simply by passing it in front of a backlight and processing the image with a vision system. However, as the required measurement accuracies become more demanding, care must be taken in selecting the appropriate illumination.

Standard backlights have several limitations: They must be larger than the object under inspection to cover the entire object's surface and create a profile. They must also be diffuse so as to avoid hot spots, intensity roll-off off near the edges, and other illumination errors. These properties force the backlight to emit light at angles from 0 to nearly 180 degrees. When the very high angle rays are emitted from the outer edges of the backlight,

light glances off the edge of the object under inspection and reflects into the camera lens. This causes the object to be illuminated, rather than silhouetted, which reduces contrast in the image (*Figure 1*).

A Telecentric backlight directs light emitted from a source onto the object with very small deviations in ray angles. Since there is no angle between these rays, light enters the camera lens directly, rather than by stray reflections, creating high contrast images (*Figure 2*). What's more, the volume of light available with a telecentric backlighting configuration increases dramatically. A conventional backlight is diffuse and much of the light never reaches the object. The telecentric backlight is directional, ensuring much more light reaches its target. Typical applications will see a 3 - 5 times decrease in shutter speed at the same aperture with this backlight over a standard diffuse backlight.

Figure 1

Standard Diffuse Backlight

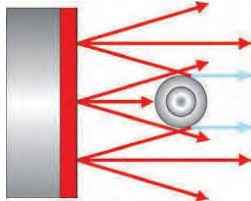
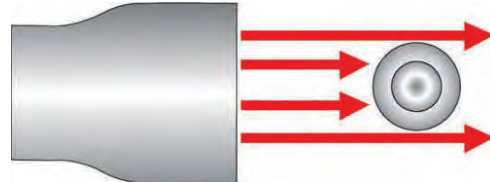


Figure 2

Telecentric Backlight



TECHSPEC® TELECENTRIC BACKLIGHT ILLUMINATOR

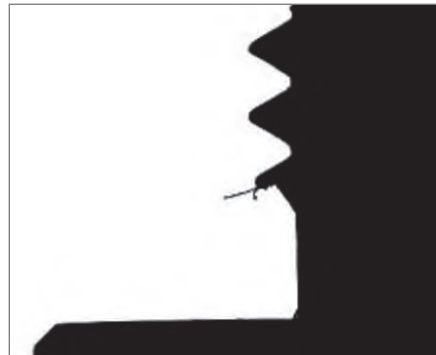


- Adjustable Aperture Allows Variable Output Without Varying Color Temperature
- Accepts 1/4" Fiber Optic or LED Input
- Increases Contrast on Product Edges for Inspection Systems

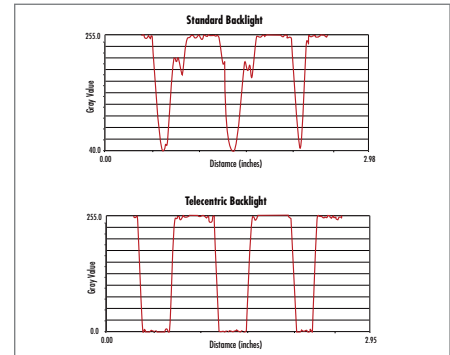
The Telecentric Backlight Illuminator uses optics to direct light from a fiber optic light guide or LED onto an object, producing high contrast silhouette. The illuminator increases edge contrast and measurement accuracy in gauging applications by decreasing diffuse reflections that increase edge softening. The telecentric backlight illuminators, based on design principles from our telecentric measuring lenses, substantially increase illumination, compared to a standard backlight, at nominal working distances. Compatible with 1/4" fiber optic light guides or 0.312" LEDs. **Note:** Power Supply required for LED operation.



Mounting Post using TECHSPEC® 1X SilverTL™ Telecentric Lens and Standard Diffuse Backlight.



Mounting Post using TECHSPEC® 1X SilverTL™ Telecentric Lens and Telecentric Backlight Illuminator.



Telecentric vs. Standard Diffuse Illumination: Line Profile of Mounting Post Threads.

TELECENTRIC BACKLIGHT ILLUMINATOR

Description	Stock No.	Price
Telecentric Backlight Illuminator	#62-760	\$750.00
0.312" LED Spotlight - White	#87-541	\$195.00
0.312" LED Spotlight - Blue	#87-542	\$195.00
0.312" LED Spotlight - Green	#87-543	\$195.00
0.312" LED Spotlight - Red	#87-544	\$195.00
24V Power Supply	#66-855	\$95.00

LED Projectors

ADVANCED ILLUMINATION LED PATTERN PROJECTORS

- Multiple Wavelength Options Available
- Equip C-Mount Imaging Lenses to Control Illumination Geometry
- Ideal for 3D Reconstruction and Mapping

Advanced Illumination LED Pattern Projectors are compact illuminators designed for applications requiring structured illumination. Advanced Illumination LED Pattern Projectors can be used with any C-mount compatible imaging lens and negatively patterned 21mm reticle to achieve specific structured illumination geometries. When used without a reticle, Advanced Illumination LED Pattern Projectors can be adjustable spot lights.

Note: Required power supply and C-mount imaging lens are sold separately.



LED Life:	50,000 hours	Reticle Edge Sharpness:	<1µm
Reticle Substrate:	Float Glass	Reticles:	20.8mm Dia.
Reticle Coating:	Chrome	Reticle Accuracy:	2µm

ADVANCED ILLUMINATION LED PATTERN PROJECTORS

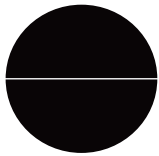
Description	Stock No.	Price
Blue 455nm	#87-447	\$695.00
Green 530nm	#87-448	\$695.00
Red 625nm	#87-449	\$695.00
White	#87-451	\$695.00

ACCESSORIES

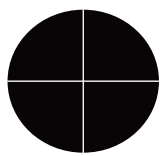
Description	Stock No.	Price
24V Power Supply	#66-855	\$95.00
Manual Intensity Adjustment	#86-887	\$40.00
Industrial DIN Mountable Intensity Adjustment	#89-555	\$125.00
Single Line Reticle	#88-518	\$150.00
Crosshair Reticle	#88-519	\$150.00
8 Line Reticle	#88-520	\$150.00
7 x 7 Grid Reticle	#88-521	\$150.00
Edge Reticle	#88-522	\$150.00
16mm Fixed Focal Length Lens	#59-870	\$295.00
25mm Fixed Focal Length Lens	#59-871	\$295.00
35mm Fixed Focal Length Lens	#59-872	\$295.00
50mm Fixed Focal Length Lens	#59-873	\$395.00



Single Line Reticle (#88-518)



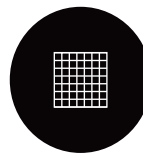
Crosshair Reticle (#88-519)



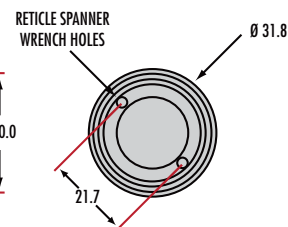
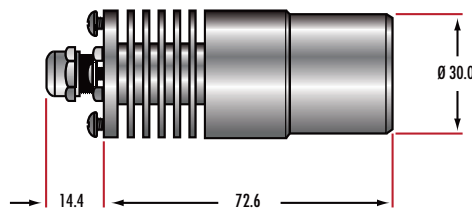
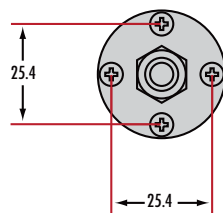
8 Line Reticle (#88-520)



7 x 7 Grid Reticle (#88-521)



Edge Reticle (#88-522)



Units: mm

Laser Diode Modules

COHERENT® HIGH PERFORMANCE STINGRAY™ LASER DIODE MODULES



- **External Focus with up to 90mW Output Power**
 - **Auto Scaling Input Power 5 - 24V DC with Reverse Polarity Protection**
 - **Built-In Microcontroller for Fault Monitor**
- Coherent® High Performance StingRay™ Laser Diode Modules are ideal for a variety of alignment or machine vision applications. Coherent® High Performance StingRay™ Laser Diode Modules are available in a range of wavelengths from the visible to NIR. Due to the human eye being highly sensitive to green light, the green laser diode module provides sharp contrast, especially on red objects. **Note:** For CDRH certified systems, class IIIb lasers require #86-878. Power supply is available with #86-878 or sold separately.

Beam Quality (M²):	<1.5
Spatial Mode:	TEM ₀₀
Pointing Stability (μrad/°C):	<10
Max. Analog Modulation (kHz):	500
Input Voltage (VDC):	5VDC - 24VDC
Electrical Connection:	Hirose HR-10P-12S
Operating Temperature (°C):	-10 to 50
Storage Temperature (°C):	-20 to 60
Dimensions (Dia. x L, mm):	
Standard:	19.1 x 95.1
Line Generator:	19.1 x 97.8



StingRay™ Developers Kit available online

COHERENT® STINGRAY™ LASER DIODE MODULES

Wavelength (nm)	5mW			10mW			35mW		
	CDRH Class	Stock No.	Price	CDRH Class	Stock No.	Price	CDRH Class	Stock No.	Price
514 ±5	IIIb	#86-848	\$745.00	IIIb	#87-522	\$845.00	—	N/A	—
640 +4 / -9	IIIb	#86-849	\$335.00	IIIb	#87-523	\$475.00	IIIb	#87-524	\$625.00
655 ±5	IIIb	#86-850	\$335.00	IIIb	#87-525	\$475.00	—	N/A	—
785 ±10	—	N/A	—	IIIb	#87-527	\$625.00	IIIb	#87-528	\$735.00

COHERENT® STINGRAY™ PROJECTION HEADS

Fan Angle (°)	Number of Lines	514nm	640nm / Max 5mW	640nm / Max 35mW	655nm / Max 5mW	785nm	Price
30	1	#89-574	#89-575	#89-576	#89-577	#89-578	\$160.00
60	1	#89-579	#89-580	N/A	#89-581	N/A	\$160.00
30	3	#89-582	#89-583	N/A	#89-584	#89-585	\$355.00
30	1, Extended Focus	#89-586	#89-587	N/A	#89-588	#89-589	\$160.00

COHERENT® STINGRAY™ PRE-MOUNTED LINE GENERATOR MODULES

Fan Angle (°)	Wavelength (nm)	Wavelength Tolerance (nm)	Output Power (mW)	CDRH Class	Stock No.	Price
30	514	±5	5	II	#86-851	\$970.00
30	514	±5	35	IIIb	#86-854	\$1,220.00
30	640	+4 / -9	5	II	#86-857	\$580.00
30	640	±2	35	IIIb	#86-860	\$655.00
30	655	±5	5	II	#86-863	\$580.00
30	660	±6	50	IIIb	#86-869	\$740.00
45	640	±2	35	IIIa	#86-861	\$655.00
45	660	±6	50	IIIb	#86-870	\$740.00
60	640	+4 / -9	5	II	#86-859	\$580.00
60	660	+7 / -10	35	IIIa	#86-868	\$655.00
60	660	±6	50	IIIb	#86-871	\$740.00

ACCESSORIES

Description	Stock No.	Price
Laser Controller With CDRH Key Lock and Power Supply	#86-878	\$280.00
5V Power Supply	#59-099	\$65.00
Mounting Bracket	#86-879	\$110.00

VLM™ HIGH QUALITY LASER DIODE MODULES



- **Standard and Micro Models Available**
- **Fixed Focus, 635nm or 670nm**
- **Circular, Elliptical or Linear Beams**
- **0.3mW to 4.2mW Outputs**

Applications include measurement, positioning, robot vision, bar code scanning, alignment, guidelines, pointing, switching, timing, and leveling. Useful in a variety of medical, industrial, and scientific instrumentation, as well as general R&D work.

See website for complete specifications.

Beam Diameter:	
Circular:	3.0mm
Elliptical:	4.0 x 1.0mm
Beam Divergence:	
Circular:	0.35mrad
Elliptical:	0.3 x 1.2mrad
Pointing Accuracy:	15 arcmin
Electrical Leads:	36" long, red (+), black (-), case (+)
Power Requirement:	5-10V DC, 3-6V DC (Micro Series)



VLM™ SERIES

	Circular	
	II	IIIa
CDRH Class:	II	IIIa
Maximum Output:	0.6mW	2.3mW
Wavelength:	635nm	670nm
Dimensions (D x L):	0.581" x 1.776"	0.581" x 1.776"
Weight (oz.):	0.72	0.72
Stock No./Price	#54-032 \$240.00	#53-761 \$295.00
Mount for VLM™ Modules	#53-263 \$75.00	

MICRO VLM™ SERIES

	Elliptical			30° Line	60° Line	85° Line
	II	IIIa	IIIa	II	II	II
CDRH Class:	II	IIIa	IIIa	II	II	II
Maximum Output:	0.95mW	2.5mW	4.2mW	1.6mW	2.5mW	4.0mW
Wavelength:	670nm	670nm	670nm	670nm	670nm	670nm
Dimensions (D x L):	0.375" x 0.73"			0.375" x 0.89"		
Weight (oz.):	0.17	0.17	0.17	0.23	0.23	0.23
Stock No.	#52-263	#52-264	#52-265	#52-268	#52-267	#52-266
Price	\$155.00	\$165.00	\$175.00	\$199.00	\$199.00	\$199.00
Mount for Micro VLM™ Modules				#53-261 \$75.00		

METAPHASE TECHNOLOGIES LED BACKLIGHTS



- **2X Brighter than Cold Cathode Fluorescent Backlights**
- **No Warm-Up Time**
- **Flicker-Free LED Illumination**

LED backlights are perfect for machine vision and applications with limited workspace. LED illuminators feature a long lifespan and provide flicker and shadow-free diffuse illumination absent of hotspots ($\pm 5\%$ uniformity). With low power consumption and no warm-up time, LED illuminators are ideal for a wide variety of applications. With twice the brightness, Metaphase Technologies LED Backlights (Patent Pending) offer a great alternative to Cold Cathode Fluorescent illumination. **Note:** A power supply is required for operation.



Metaphase
Technologies, Inc.

METAPHASE TECHNOLOGIES LED BACKLIGHTS

Active Area	Dimensions (W x L x H)	Stock No.		Price	Power Supply	
		White	Red 630nm		Stock No.	Price
3.5" x 6"	5" x 8.5" x 0.75"	#83-873	#85-257	\$295.00	#87-354	\$35.00
5.75" x 10"	7.5" x 12" x 0.75"	#83-874	#85-258	\$550.00	#87-355	\$70.00
9" x 16"	13.5" x 19.5" x 0.75"	#83-875	#85-259	\$725.00	#87-355	\$70.00
21" x 21"	26" x 26.38" x 0.75"	#85-255	—	\$1,595.00	#87-356	\$80.00
21" x 44"	26" x 50" x 0.75"	#85-256	—	\$2,295.00	#87-357	\$80.00

METAPHASE TECHNOLOGIES WIDE BEAM LED SPOT LIGHT



- **6X Brighter than a 60W Incandescent Floodlight**
- **Low Power Consumption**
- **Washdown - IP65 Rating**

LED illuminators feature a long lifespan and provide flicker and shadow free diffuse illumination absent of hotspots. With low power consumption and no warm-up time, LED illuminators are ideal for a wide variety of applications. Metaphase Technologies Wide Beam LED Spot Light is an ideal replacement for a 60W incandescent floodlight. The included mounting bracket increases versatility and allows for precise positioning. The spot light features a full heat sink to ensure long life and output stability. A mounting bracket is included with each spot light. **Note:** Power supply #87-355 is required for operation.



Metaphase
Technologies, Inc.

METAPHASE TECHNOLOGIES WIDE BEAM LED SPOT LIGHT

Wavelength	Dimensions (Ø x L)	Stock No.	Price
White	3.15" x 3.1"	#83-876	\$295.00
Green	3.15" x 3.1"	#86-426	\$295.00
Red	3.15" x 3.1"	#86-427	\$295.00
IR	3.15" x 3.1"	#86-428	\$295.00

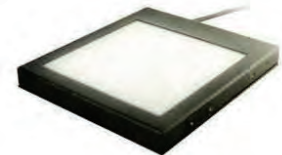
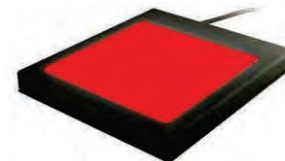
Power Supply #87-355 \$70.00

METAPHASE TECHNOLOGIES LED RGB BACKLIGHTS



- **Individually Controlled Red, Green, and Blue Color Channels**
- **High Intensity and Uniformity**
- **Allows Color Mixing to Tune Your Lighting Profile**

Metaphase Technologies LED RGB Backlights are ideal for machine vision applications where high uniformity is required, such as factory automation or inspection. These LED backlights feature red, green, and blue color channels that can be individually controlled using a manual dimmer to match the application's light intensity and color content requirements. Metaphase Technologies LED RGB Backlights are available in multiple sizes to ease system integration. **Note:** A power supply (sold separately) is required for operation.



METAPHASE TECHNOLOGIES LED RGB BACKLIGHTS

Active Area Size (mm)	Overall Dimensions W x L x D (mm)	Intensity (mW/cm ²)	Uniformity ($\pm\%$)	Stock No.	Price	Power Supply	Price
50 x 50	76 x 95 x 20	1.0	5.0	#89-962	\$895.00	#87-354	\$35.00
100 x 100	156 x 176 x 21	1.0	5.0	#89-963	\$1,295.00	#87-354	\$35.00
150 x 150	188 x 219 x 36	1.0	5.0	#89-964	\$1,495.00	#87-355	\$70.00

METAPHASE TECHNOLOGIES LED LINEAR LIGHTS



- **Perfect Replacement for Linear Fluorescent Lamps**
- **Very Diffuse, Isotropic Output**
- **3X the Brightness of Typical Fluorescent Illumination**

LED linear lights are the ideal high performance replacement for fluorescent tube lighting. LED illuminators feature a long lifespan and provide flicker and shadow free diffuse illumination absent of hotspots. With low power consumption and no warm-up time, LED illuminators are ideal for a wide variety of applications. Equipped with an adjustable bracket, Metaphase Technologies LED Linear Lights (Patent Pending) are capable of 0 - 180° positioning. Models are available with or without an in-line dimmer for intensity control that is easily adjusted by a tunable dial. A tilt bracket is included with each linear light. **Note:** 8" and 14" illuminators require power supply #87-354. 23" and 48" illuminators require power supply #87-355.



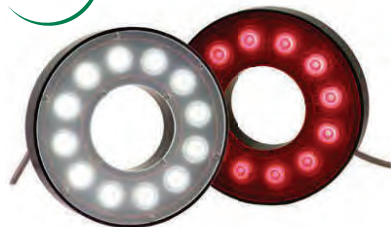
Metaphase
Technologies, Inc.

METAPHASE TECHNOLOGIES LED LINEAR LIGHTS

Wavelength	Intensity Control	8" Length		14" Length		23" Length		48" Length	
		Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price
White	No	#83-857	\$475.00	#83-858	\$575.00	#83-859	\$775.00	#83-860	\$1,575.00
Red 630nm	No	#83-861	\$475.00	#83-862	\$575.00	#83-863	\$775.00	#83-864	\$1,575.00
White	Yes	#83-865	\$550.00	#83-866	\$650.00	#83-867	\$850.00	#83-868	\$1,650.00
Red 630nm	Yes	#83-869	\$550.00	#83-870	\$650.00	#83-871	\$850.00	#83-872	\$1,650.00
Power Supply	—	#87-354	\$35.00	#87-354	\$35.00	#87-355	\$70.00	#87-355	\$70.00

LED Lights

ADVANCED ILLUMINATION HIGH INTENSITY LED RING LIGHTS



- Slim Profile to Ease System Integration
- High Brightness LEDs
- Multiple Size, Wavelength, and Working Distance Options

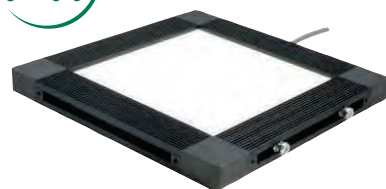
Advanced Illumination High Intensity LED Ring Lights utilize an arrangement of high brightness LEDs to precisely illuminate a wide variety of imaging applications. Advanced Illumination High Intensity LED Ring Lights feature a slim profile to ease system integration, and are available in a variety of sizes, wavelengths, and working distance options. A manual intensity adjustment option is also available for added flexibility. 4.6" and 6" models are IP67 complaint. An adapter is also available for mounting the 2.95" ring light to M25 x 0.5 lenses. **Note:** 24V power supply (sold separately) is required for operation.

	2.95"	4.6"	6"	6" Ultrabright
Dimensions (mm):	74.9 Dia. x 14.2 L	116.8 Dia x 19.1 L	152.4 Dia x 26.7 L	152.4 Dia x 26.7 L
Working Distance:	75 - 150mm	100 - 300mm	225 - 600mm	225 - 600mm
Mounting Threads:	M35.5 x 0.5	M67 x 0.75	None, ID 66mm	None, ID 66mm
Number of Channels:	1	1	1	1
Weight:	164g	304g	681g	681g
Operating Temperature:	0 to 60°C	0 to 60°C	0 to 60°C	0 to 60°C
Lifetime:	50,000 hrs	50,000 hrs	50,000 hrs	50,000 hrs

ADVANCED ILLUMINATION HIGH INTENSITY LED RING LIGHTS

Wavelength	2.95"	4.6"	6"	6" Ultrabright
White	Stock No. #88-484 Price \$425.00	Stock No. #88-487 Price \$795.00	Stock No. #88-490 Price \$1,225.00	Stock No. #88-493 Price \$1,455.00
Blue 470nm	Stock No. #88-485 Price \$425.00	Stock No. #88-488 Price \$795.00	Stock No. #88-491 Price \$1,275.00	Stock No. #88-494 Price N/A
Red 625nm	Stock No. #88-486 Price \$425.00	Stock No. #88-489 Price \$795.00	Stock No. #88-492 Price \$1,225.00	Stock No. #88-494 Price N/A
24V Power Supply				Stock No. #66-855 Price \$95.00
Manual Intensity Adjustment				Stock No. #86-887 Price \$40.00
Industrial Intensity Adjustment, DIN Rail Mount				Stock No. #89-555 Price \$125.00
M35.5 x 0.5 to M25.5 x 0.5 Adapter				Stock No. #88-494 Price \$95.00

ADVANCED ILLUMINATION SIDE-FIRED LED BACKLIGHTS



- 30% Brighter than Comparable Surface Mount Light
- Uniform, Low Heat Illumination
- Optional Manual Intensity Adjustment Available

Advanced Illumination Side-Fired LED Backlights are high performance alternatives to surface mount lights. Advanced Illumination Side-Fired LED Backlights provide uniform, low heat illumination that is 30% brighter than surface mount lights of equal size. To simplify system integration, these backlights include mounting brackets and mounting channels for M6 nuts. A manual intensity adjustment option is also available for added flexibility. **Note:** 24V power supply is required for operation.

	2" x 2"	4" x 4"	8" x 8"
Active Area:	115.1 L x 115.1 W x 20.1 T	165.9 L x 165.9 W x 20.1 T	267.5 L x 267.5 W x 20.1 T
Dimensions (mm):	1	1	2
Number of Channels:	0 to 60°C	0 to 60°C	0 to 60°C
Operating Temperature:	50,000 hrs	50,000 hrs	50,000 hrs
Lifetime:			

ADVANCED ILLUMINATION LED SIDE-FIRED LED BACKLIGHTS

Size Wavelength	2" x 2"	4" x 4"	8" x 8"
White	Stock No. #88-500 Price \$550.00	Stock No. #88-504 Price \$650.00	Stock No. #88-508 Price \$995.00
Blue 455nm	Stock No. #88-501 Price \$550.00	Stock No. #88-505 Price \$650.00	Stock No. #88-509 Price \$995.00
Green 530nm	Stock No. #88-502 Price \$550.00	Stock No. #88-506 Price \$650.00	Stock No. #88-510 Price \$995.00
Red 625nm	Stock No. #88-503 Price \$550.00	Stock No. #88-507 Price \$650.00	Stock No. #88-511 Price \$995.00
24V Power Supply			Stock No. #66-855 Price \$95.00
Manual Intensity Adjustment			Stock No. #86-887 Price \$40.00
Industrial Intensity Adjustment, DIN Rail Mount			Stock No. #89-555 Price \$125.00

ADVANCED ILLUMINATION DIFFUSE AXIAL LED ILLUMINATORS



- Bright, Uniform Illumination over Field of View
- Built-In Dust Cover Protects Internal Beamsplitter
- Ideal for Inspecting Highly Reflective Objects

	1" x 1"	2" x 2"	4" x 4"
Aperture Size:	94 L x 33 W x 33 T	117 L x 58 W x 54 T	178 L x 110 W x 111 T
Dimensions (mm):	1 HB	4 HB	144
Number of LEDs:	1	1	2
Number of Channels:	20 x 20	32 x 32	100 x 100
Diffuse Field Coverage (mm):	±10%	±10%	±10%
Projected Light Distribution:	M6	M6	M6
Mounting Holes:			

ADVANCED ILLUMINATION HIGH INTENSITY LED RING LIGHTS

*LEDs in 4" Version are 880nm

Wavelength	1" Diffuse Axial	2" Diffuse Axial	4" Diffuse Axial*
White	Stock No. #66-798 Price \$725.00	Stock No. #66-800 Price \$950.00	Stock No. #66-803 Price \$1,895.00
Red 625nm	Stock No. #66-799 Price \$725.00	Stock No. #66-801 Price \$950.00	Stock No. #66-804 Price \$1,595.00
IR 850nm*	Stock No. #88-495 Price \$775.00	Stock No. #66-802 Price \$995.00	Stock No. #66-805 Price \$1,595.00
24V Power Supply			Stock No. #66-855 Price \$95.00
Manual Intensity Adjustment			Stock No. #86-887 Price \$40.00
Industrial Intensity Adjustment, DIN Rail Mount			Stock No. #89-555 Price \$125.00

ADVANCED ILLUMINATION LED SPOT LIGHTS



- Ideal for Machine Vision Illumination
- Provides 43mm Coverage at 100mm
- 50,000 Hour Product Lifetime



Model:	0.9" High Bright	1.25" Ultra Bright	1.5"	2.1"
Dimensions (mm):	22.9 Dia. x 54.0 L	31.8 Dia. x 46.7 L	38 Dia. x 54.0 L	54 Dia. x 38.0 L
Number of LEDs:	1 HB	1 UB	20	36
Number of Channels:	1	1	1	1



ADVANCED ILLUMINATION LED SPOT LIGHTS

*LED in 0.9" Version is 530nm and 850nm

Wavelength	0.9" High Bright*		1.25" Ultra Bright		1.5"		2.1"	
	Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price
White	#66-856	\$375.00	#88-512	\$475.00	#66-815	\$450.00	#66-820	\$750.00
Blue 470nm	#66-857	\$375.00	N/A	—	#66-816	\$450.00	#66-821	\$750.00
Green 520nm*	#66-858	\$375.00	N/A	—	#66-817	\$450.00	#66-822	\$750.00
Red 625nm	#66-859	\$375.00	N/A	—	#66-818	\$375.00	#66-823	\$650.00
IR 880nm*	#66-860	\$375.00	N/A	—	#66-819	\$375.00	#66-824	\$650.00
24V Power Supply							#66-855	\$95.00
Manual Intensity Adjustment							#86-887	\$40.00
Industrial Intensity Adjustment, DIN Rail Mount							#89-555	\$125.00

ADVANCED ILLUMINATION HIGH INTENSITY COAXIAL LED SPOT LIGHT ILLUMINATORS



- Compatible with 8mm In-Line Illumination Ports
- Multiple Versions Offered
- Fixed Intensity and Strobed Options

Designed to fit into the common 8mm port found on many in-line illumination lenses, Advanced Illumination High Intensity Coaxial LED Spot Light Illuminators are a simple, compact lighting solution. Featuring state-of-the-art high intensity LEDs, these illuminators are ideal for even the most demanding illumination requirements. **Note:** Required 24V power supply #66-855 and optional Manual Intensity Adjustment #86-887 are sold separately.



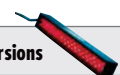
Light Distribution:	±10%	Lifetime:	50,000 hrs	Number of LEDs:	1 HB
Operating Temp.:	0 to 60°C	Weight:	42.5g (1.5oz)	Cable Length:	1.5m



ADVANCED ILLUMINATION HIGH INTENSITY COAXIAL LED SPOT LIGHT ILLUMINATORS

Wavelength	Stock No.	Price
White	#66-861	\$495.00
Blue 470nm	#66-862	\$495.00
Green 530nm	#66-863	\$495.00
Amber 590nm	#66-864	\$495.00
Red 625nm	#66-865	\$495.00
24V Power Supply	#66-855	\$95.00
Manual Intensity Adjustment	#86-887	\$40.00
Industrial Intensity Adjustment, DIN Rail Mount	#89-555	\$125.00

See Website for Strobed Versions

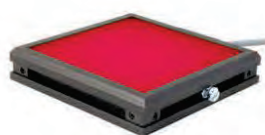


SO MUCH MORE ONLINE . . .

Advanced Illumination High Intensity LED Spot Lights



Advanced Illumination LED Backlights



Advanced Illumination Diffuselite LED Illuminators



Advanced Illumination LED Line Lights



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LED Lights

ADVANCED ILLUMINATION EUROBRITE™ LIGHTS



- Available in White, Red, and Blue
- Variety of Geometry Options Available
- Heat Sink Not Required

Advanced Illumination EuroBrite™ Lights feature on-board smart drivers functional during strobe and continuous operation modes making them ideal for the most demanding performance constraints. Adaptive OverDrive™ allows for power optimization while in strobing mode, and Adaptive Thermal Feedback™ gives operational current control to the user, preventing overheating and eliminating the need for a heat sink. Advanced Illumination EuroBrite™ Ring Lights feature a ruggedized, sealed enclosure, and are available in white, red, or blue versions. Advanced Illumination EuroBrite™ Bar Lights, 100 x 150mm Spot Lights, and 100 x 150mm Back Lights have the ability to operate with four units connected to one another. An analog dimming control operable in both strobe and continuous modes add to illuminator's customizability. **Note:** A 24V power supply is required.

ACCESSORIES		
Description	Stock No.	Price
M12 Female to Male, Spin, 0.2m	#33-462	\$40.00
M12 Female to Bare Leads, 5 pin, 2m	#33-463	\$40.00
24V Power Supply	#66-855	\$95.00

Input Voltage:	24V Nominal (min. 22 / max. 28)	Operating Temperature:	0 - 60°C
Maximum Input Current:	0.42 - 0.49A	Environment:	IP67
Analog Intensity Control:	10% @ 0.7V, 100% @ 10V	Typical Lifetime:	50,000 hrs
Trigger to Pulse Latency:	10µs		

SPOT LIGHTS SPECIFICATIONS			
Typical Intensity			
Working Distance:	100mm	300mm	600mm
Illuminated Area:	79 x 51mm	Ø104mm	Ø196mm
Typ. Irradiance (W/M²):	420.0	128.0	38.4
Typ. Illuminance (kLux):	136.0	41.0	12.2

ADVANCED ILLUMINATION EUROBRITE™ SPOT LIGHTS								
Active Area:	50 x 75mm			100 x 150mm				
Weight:	97g			253g				
Dimensions:	75 L x 89 W x 30mm H			150 L x 139 W x 30mm H				
Wavelength	Stock No.	Price			Stock No.	Price		
		1-10	11-25	26+		1-10	11-25	26+
White	#33-450	\$425.00	\$382.50	Call	#33-453	\$825.00	\$742.50	Call
Blue 470nm	#33-452	\$425.00	\$382.50	Call	#33-455	\$825.00	\$742.50	Call
Red 625nm	#33-451	\$425.00	\$382.50	Call	#33-454	\$825.00	\$742.50	Call

BACKLIGHTS SPECIFICATIONS		
Typical Intensity		
Active Area:	50 x 75mm	100 x 150mm
Working Distance:	At Surface	At Surface
Illuminated Area:	61 x 43mm	135 x 94mm
Typ. Irradiance (W/M²):	285	184
Typ. Illuminance (kLux):	101	65.5

ADVANCED ILLUMINATION EUROBRITE™ BACKLIGHTS								
Active Area:	50 x 75mm			100 x 150mm				
Weight:	93g			253g				
Dimensions:	75 L x 89 W x 30mm H			150 L x 139 W x 30mm H				
Wavelength	Stock No.	Price			Stock No.	Price		
		1-10	11-25	26+		1-10	11-25	26+
White	#33-456	\$425.00	\$382.50	Call	#33-459	\$825.00	\$742.50	Call
Blue 470nm	#33-458	\$425.00	\$382.50	Call	#33-461	\$825.00	\$742.50	Call
Red 625nm	#33-457	\$425.00	\$382.50	Call	#33-460	\$825.00	\$742.50	Call

BAR LIGHTS SPECIFICATIONS			
Typical Intensity			
Working Distance:	200mm	300mm	600mm
Illuminated Area:	292 x 67mm	290 x 102mm	318 x 191mm
Typ. Irradiance (W/M²):	142	93.2	43
Typ. Illuminance (kLux):	45	30	14

ADVANCED ILLUMINATION EUROBRITE™ BAR LIGHTS				
Weight:	241g			
Dimensions:	300 L x 64 W x 30mm H			
Wavelength	Stock No.	Price		
		1-10	11-25	26+
White	#33-444	\$695.00	\$625.50	Call
Blue 470nm	#33-446	\$695.00	\$625.50	Call
Red 625nm	#33-445	\$695.00	\$625.50	Call

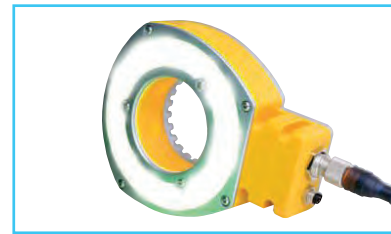
RING LIGHTS SPECIFICATIONS			
Typical Intensity			
Working Distance:	200mm	300mm	600mm
Illuminated Area:	Ø137mm	Ø147mm	Ø213mm
Typ. Irradiance (W/M²):	104	75.6	31.0
Typ. Illuminance (kLux):	33.3	24.5	10.0

ADVANCED ILLUMINATION EUROBRITE™ RING LIGHTS				
Weight:	173g			
Dimensions:	120 L x 120 W x 30mm H			
Inner Diameter:	52mm			
Wavelength	Stock No.	Price		
		1-10	11-25	26+
White	#33-447	\$395.00	\$355.50	Call
Blue 470nm	#33-449	\$395.00	\$355.50	Call
Red 625nm	#33-448	\$395.00	\$355.50	Call

ADJUSTABLE LED RING LIGHTS

- **Easy to Access Lens Array for Quick, Manual Adjustment of Illumination Emission Angles**
- **Included Interchangeable Windows Allows for Easy Adjustment of Light Diffusion**
- **Integrate Polarizer Accessory for Glare Elimination**

Adjustable LED Ring Lights provide high intensity and uniform LED illumination, while also providing the flexibility to customize the angle at which the light is emitted. The easy to access lens array allows for quick, manual adjustment of the illumination emission angles. Simply remove the LED window that's held in place by screws and rotate the lens array to one of the three indicated positions for the various emission angles. Adjustable LED Ring Lights include three interchangeable windows (transparent, semi-diffuse, and opaline) and an optional polarizer accessory is available to be placed beneath the transparent window for glare elimination. The modification flexibility allows these ring lights to be used in a variety applications. **Note:** 24V power supply and M12 female to male cable are required.



NEW

Dimensions:	151 L x 117 W x 40mm H	Connectors:	M12, 5 pins
Inner Diameter:	58mm	Input Voltage:	24V DC
Weight:	400g	Operating Temperature:	-10°C to 50°C
Mounting Holes:	M4 (x4) and 3.5mm Thru (x4)	Environment Rating:	IP65
Illumination Mode:	Continuous or Strobe		

Lens Rotation Position:	Emission Angle
Without Lens:	90°
Position 1:	45°
Position 2:	25°
Position 3:	10°

ADJUSTABLE LED RING LIGHTS

Wavelength	White		Red 625nm		IR 850nm		RGB		White, UV, IR	
Stock No. / Price	#34-861	\$725.00	#34-862	\$725.00	#34-863	\$795.00	#34-864	\$895.00	#34-865	\$1,295.00

ACCESSORIES

Description	Stock No.	Price
Polarizer Accessory	#34-866	\$90.00
Mounting Bracket, Vertical	#34-867	\$185.00
Mounting Bracket, Right Angle	#34-868	\$185.00
M12 Female to Male, 5 pin, 2m	#34-869	\$60.00
M12 Female to Bare Leads, 5 pin, 2m	#34-870	\$35.00
24V Power Supply, 1 Channel	#34-871	\$450.00

ADJUSTABLE LED BAR LIGHTS

- **Direct Access to Optics for Quick, Manual Adjustment of Illumination Cone Angles**
- **Included Interchangeable Windows Allows for Easy Adjustment of Light Diffusion**
- **Easy to Integrate Linescan Accessory for Linear or Darkfield Lighting**

Adjustable LED Bar Lights provide versatility by allowing the emission angle of the light to be modified by the user. Various illumination emission angles can be modified by simply removing the LED window that's held in place by screws to access the lens array and adjust the lens array height to one of the three indicated positions. Adjustable LED Bar Lights include three interchangeable windows: transparent, semi-diffuse, and opaline. By placing the optional polarizer or linescan accessories beneath the transparent window, glare can be eliminated or linear lighting created. The flexibility and ease of user modifications for these bar lights make them ideal for use in many application types. **Note:** 24V power supply and M12 female to male cable are required.



NEW

	1 LED Bar Light	5 LED Bar Light	10 LED Bar Light	15 LED Bar Light
Number of LEDs:	55 L x 51 W x 49mm H	135 L x 51 W x 49mm H	235 L x 51 W x 49mm H	335 L x 51 W x 49mm H
Dimensions:	55 L x 51 W x 49mm H	135 L x 51 W x 49mm H	235 L x 51 W x 49mm H	335 L x 51 W x 49mm H
Number of Connectors:	1	1	1	1
Mounting Holes:	2 Rails (1 for M6 T-Nuts)	2 Rails (1 for M6 T-Nuts)	2 Rails (1 for M6 T-Nuts)	2 Rails (1 for M6 T-Nuts)
Illumination Mode:	Continuous or Strobe	Continuous or Strobe	Continuous or Strobe	Continuous or Strobe
Connectors:	M12, 5 pins	M12, 5 pins	M12, 5 pins	M12, 5 pins
Input Voltage:	24V DC	24V DC	24V DC	24V DC
Operating Temperature:	-10°C to 50°C	-10°C to 50°C	-10°C to 50°C	-10°C to 50°C
Environment Rating:	IP40	IP40	IP40	IP40

Lens Height:	Illumination Emission Angle
Without Lens:	90°
Height 1:	45°
Height 2:	25°
Height 3:	10°

ADJUSTABLE LED BAR LIGHTS

Number of LEDs	1 LED Bar Light		5 LED Bar Light		10 LED Bar Light		15 LED Bar Light	
Wavelength	Stock No.	Price	Stock No.	Price	Stock No.	Price	Stock No.	Price
White	#34-873	\$350.00	#34-875	\$650.00	#34-877	\$795.00	#34-879	\$950.00
Red 625nm	#34-874	\$350.00	#34-876	\$650.00	#34-878	\$795.00	#34-880	\$950.00
Polarizer Accessory	#34-881	\$25.00	#34-882	\$60.00	#34-884	\$70.00	#34-886	\$85.00
Linescan Accessory	N/A	—	#34-883	\$145.00	#34-885	\$170.00	#34-887	\$195.00

ACCESSORIES

Description	Stock No.	Price
M6 T-Nut (includes M6x14 screw)	#34-888	\$15.00
Swivel Mounting Accessory	#34-889	\$60.00
M12 Female to Male, 5 pin, 2m	#34-869	\$60.00
M12 Female to Bare Leads, 5 pin, 2m	#34-870	\$35.00
Power Supply, 1 Channel	#34-871	\$450.00

Testing and Targets

VIEW THIS
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Test targets are designed to help evaluate or calibrate the performance (imaging quality) of an imaging system. This could include troubleshooting a system; benchmarking, certifying, or evaluating measurements; or establishing a foundation to ensure multiple systems work well with one another. Because image quality can be defined by different components, particularly resolution, contrast, Modulation Transfer Function (MTF), Depth of Field (DOF), or distortion, different systems may require different targets, and some systems may require more than one.

It is important to keep in mind that the results of using a test target

are subjective if only viewed visually; using visual observation is dependent on who is looking at the target. For instance, someone with 20/20 vision is typically capable of discerning higher resolution or more detail than someone with 20/25 or 20/30 vision. Additionally, individuals that regularly look at these targets can have their brains trained to see detail that may not actually exist due to viewing the target's repetitive frequencies or patterns. While visual inspection can help compare two different systems, it does not always validate results. If possible, it is important to use software to truly validate measurements.

TARGETS FOR RESOLUTION MEASUREMENTS			
Target	Applications	Pros	Cons
USAF 1951	Test resolution in vision systems, optical test equipment, microscopes, high magnification video lenses, fluorescence and confocal microscopy, photolithography, and nanotechnology	Simultaneously test the vertical and horizontal resolutions at discrete spatial frequencies	Must reposition target to fully evaluate a system's performance
	Testing resolution and contrast		Can be difficult to determine when the entire FOV is in best focus
Ronchi Ruling	Diffraction testing	Can simultaneously determine system's best focus across entire FOV	Different target required for each frequency that needs to be evaluated
	Comparing highly resolved or magnified imaging systems	Potentially most powerful for testing resolution and contrast	Non-symmetrical resolution reductions cannot be analyzed
Star	System alignment	Can evaluate continuous change in resolution across multiple orientations without repositioning target	Difficult to determine exact resolution that the test system is achieving at each element
	Assembly assistance	Eases the comparison of different imaging systems	
			Requires advanced image analysis software

Table 1: Applications, Pros, and Cons of Resolution Targets.

The USAF 1951 Target

One of the most commonly used test targets is the USAF 1951 target, which is comprised of sets of horizontal and vertical lines, called elements, of varying sizes (*Figure 1*). The horizontal and vertical elements are used by a system to simultaneously test the vertical and horizontal resolutions at discrete spatial frequencies (line pairs per millimeter, or lp/mm) in the object plane. Each element has a unique set of widths and spacings and is identified with a number from 1 to 6. Together, six sequentially numbered elements are considered a group, and each group has an identifying number that can be positive, negative, or zero. Typically, this number ranges from -2 to 7. The group number and element number are then used together to determine spatial frequency. The resolution is based on bar width and space, where the length of the bars is equal to five times the width of a bar (*Figure 2*). One line pair (lp) is equivalent to one black bar and one white bar. Vertical bars are used to calculate horizontal resolution, and horizontal bars are used to calculate vertical resolution.

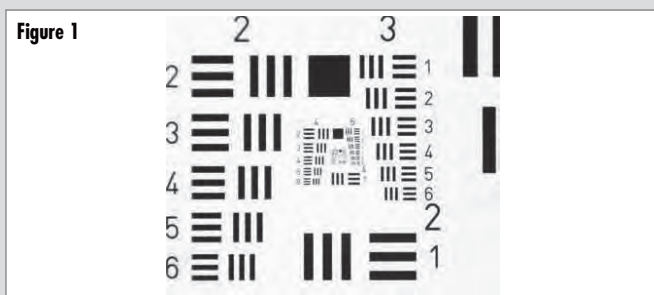


Figure 1: Example of a USAF 1951 Target.

Figure 2

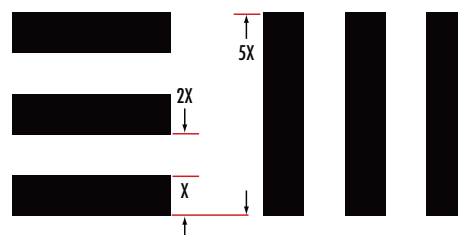


Figure 2: USAF 1951 Target Specifications.

Qualitatively, the resolution of an imaging system is defined as the group and element combination that is located directly before the black and white bars begin to blur together. Quantitatively, resolution (in terms of lp/mm) can be calculated by *Equation 1*.

$$\text{Resolution} = 2^{\left(\text{GroupNumber} + \frac{\text{ElementNumber}-1}{6}\right)} \quad 1$$

A chart showing how groups and elements match to their associated lp/mm frequencies can be found on *page 168*.

USAF 1951 targets are designed so that the elements increase in frequency along a spiral towards the target's center; higher-resolution elements are placed in the middle of the target. This arrangement is beneficial when testing zoom lenses because it avoids the need to reposition the target by allowing the higher resolution elements to remain in the FOV as the lens magnification causes the FOV to decrease.

Limitations of USAF 1951 Targets

USAF 1951 targets do have some drawbacks by having the higher-resolution elements placed in the center. For instance, lenses produce different levels of resolution from the center as they do the corners of the FOV. In most cases, moving away from the center of the field causes the resolution to drop, making it important to check resolution and contrast levels at a variety of positions. This requires repositioning the target around the field of view and taking additional images to fully evaluate a system's performance, increasing testing time. This also can cause issues depending on whether the system is only focused in the center of the FOV or across the entire FOV; because of the resolution varying based on location, it can be difficult to determine when the entire FOV is in best focus. Some lenses obtain very high resolution in the center of the FOV, but very low resolution in the corners when the lens and camera system is focused on the center of the image. A slight defocusing of the lens can balance the resolution across the field, although usually to the detriment of the center resolution. This loss of center resolution is not necessarily bad, however, because the lens could very well still meet the demands of the application even when achieving balanced focus (Figure 3).

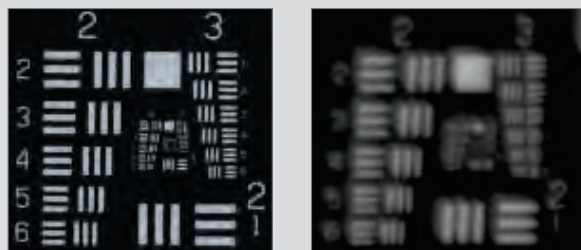


Figure 3a: USAF 1951 Example: The center and corner of an image that has been repositioned so that the best focus is only in the middle of the target.



Figure 3b: The center and corner of an image that features balanced focus across the entire field.

The potential for variability in resolution across the field of view reinforces the need to analyze all field positions before drawing conclusions on a system's performance. The lens that performs optimally with the target at the center may not perform the best overall. However, it is critical to perform all of the analysis at a single focus setting. Although it may seem intuitive to determine the system's best performance through the middle of the lens and then refocus to see the best performance in the corner, this will not show how the system will perform once deployed since refocusing during operation is often not possible.

There are variations of this target that allow for analysis across the entire FOV by repeating the patterns in numerous locations on the target (Figure 4).

Figure 4a

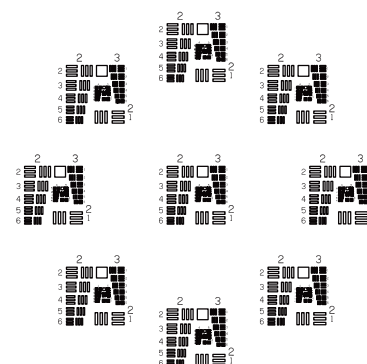


Figure 4a: USAF 1951 Pattern Wheel Target.

Figure 4b

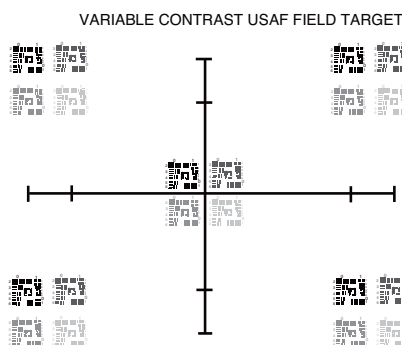


Figure 4b: USAF 1951 Variable Contrast and Field Target.

Ronchi Rulings

Some of the issues associated with the USAF 1951 target can be overcome using a different target known as the Ronchi ruling. This target consists of repeating lines at one spatial frequency, running in one orientation that covers the target's entire surface (Figure 5). Because there is detail across the entire target, the system's best focus across the entire field can be determined simultaneously. For applications that need only one frequency to be analyzed, this can be an easy to use, straightforward tool. (Continued on page 166)

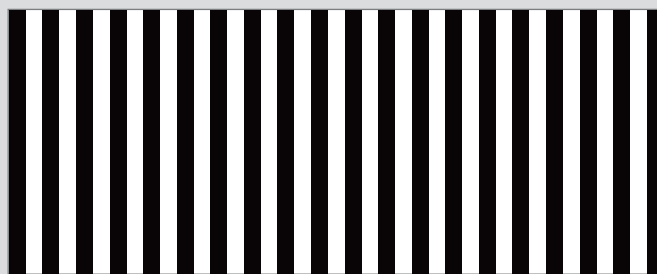


Figure 5: Ronchi Ruling.



Limitations of Ronchi Rulings

There are two drawbacks to using the Ronchi ruling. First, since a given target provides only one frequency, a different target is required for each frequency that needs to be evaluated. Second, non-symmetrical resolution reductions across the field that are the result of factors such as astigmatism cannot be analyzed because the lines

only propagate in one direction. To overcome this, the target needs to be rotated by 90° and a second image must be used to analyze the resolution. Additionally, while a lens' focus can be balanced for best focus, even for cases of astigmatism, it can be difficult to find this balance when flipping a target back and forth.

The Star Target

The multi-element star target, possibly the most powerful for testing the resolution and contrast of a system, combines many of the strengths of both the USAF and Ronchi targets. Each element of the star target consists of a circle formed of alternating positive and negative pie-shaped wedges that are tapered towards the center at a known angle (*Figure 6*). The element's tapered wedges provide a continuous change in resolution that can be evaluated in both vertical and horizontal directions, along with a variety of other orientations, without repositioning the target.

Having many stars across the field of view eases the comparison of different imaging solutions by providing the ability to determine the best focus across the FOV while simultaneously analyzing horizontal and vertical information at a variety of resolutions. *Figure 7* shows the complete star target; the highlighted areas located in the center, bottom middle, and the corner of the target are compared between two different lenses in the additional example images. For these examples, a Sony ICX625 monochrome sensor with 3.45µm pixels and a total resolution of 5 megapixels and a white light back light illuminator are used.

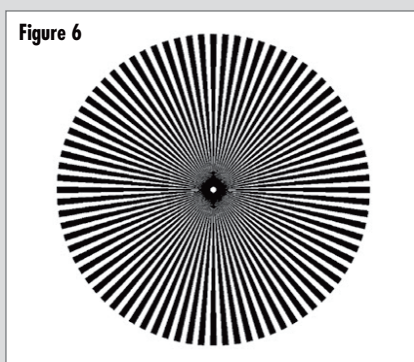


Figure 6: Star Target.

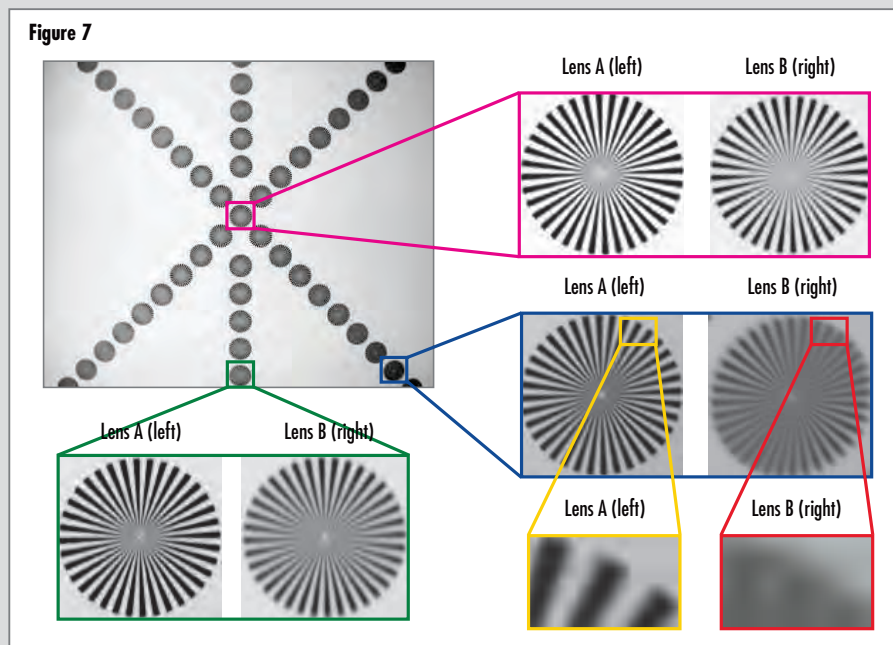


Figure 7: A star target is imaged with two lenses (A and B) with the same focal length, f#, field of view, and sensor. The superiority of lens A becomes apparent along the edge and in the corner of the image.

Limitations of a Star Target

As with other targets, the star target has its drawbacks. Because the wedges provide continuous changes in resolution, it is more difficult to determine the exact resolution that the test system is achieving at each element. While this can be done mathematically, it is not easily done visually. Additionally, the combination

of the star elements' circular nature with the potential for non-symmetrical blurring make it more difficult to use simple software tools, such as line profilers, to extract information from the image. More advanced image analysis software is required in order to make full use of the star target.



Depth of Field (DOF) Targets

DOF targets enable the visualization and quantification of how well focus is maintained as details move away from the plane that the lens is focused in. DOF targets are fairly straightforward: lines of known frequencies (resolutions) are tipped at a known angle, and are used to determine how well focus is maintained. As the lines proceed closer to and farther away from the lens, the blurrier they become until they are no longer able to be distinguished from one another. Contrast measurement can be made at different distances in order to determine when the desired level of resolution is lost; this determines the DOF limit for a lens at a particular setting. *Figures 8 and 9* demonstrate how to use a depth of field target.



Figure 8: A depth of field target should be at 45° from the lens.

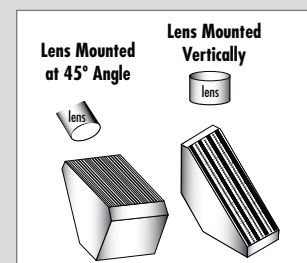


Figure 9: Sample configurations using a depth of field target.

▶ Example: Using a DOF Target

50mm Double Gauss lens

Figure 10 Shows a vertically mounted camera looking down at a DOF target that has been set at a 45° angle to the imaging path. Since the lens is focused at the middle of the target vertically, the image goes out of focus at the top and bottom of the target. The images show three different $f/\#$ settings and how adjustments to the iris change the ability to obtain depth of field. Note: Ronchi rulings can also be used to perform this type of testing, as they have fixed frequencies and can be tilted to create this effect; the greater the tip, the more of the DOF that can be measured.

Go to WWW.EDMUNDOPTICS.COM/IMAGING-LAB to view **EO Imaging Lab Module 1.8** on **Depth of Field**

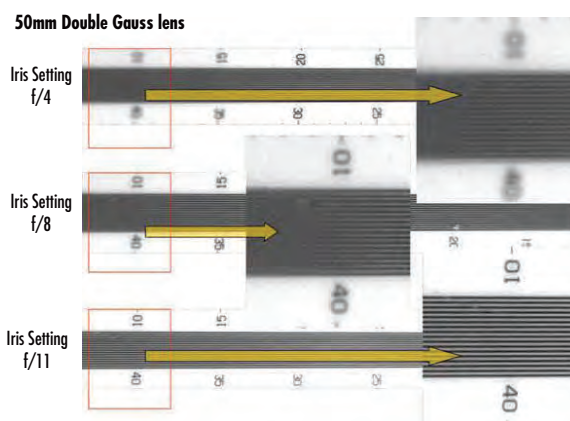


Figure 10: Images of a depth of field target taken with a 50mm lens at $f/4$, $f/8$, and $f/11$.

Distortion Targets

Distortion targets are used to calibrate systems in order to correctly measure the optical misplacement of imaging information. These targets generally consist of dot, grid, or square patterns, are compatible with the calibration routines of most imaging software, and can either remap or adjust measurements

across the FOV *Figure 11*. *Figure 12* shows the types of distortion that can be adjusted.

Once the pattern is imaged, the known size and spacing of the pattern allow adjustments to be made (*Figure 13*).

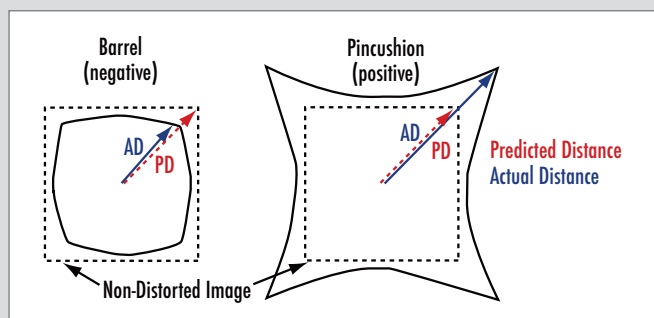


Figure 12: Types of Distortion.

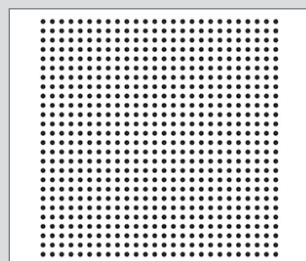


Figure 11: A dot grid distortion target.

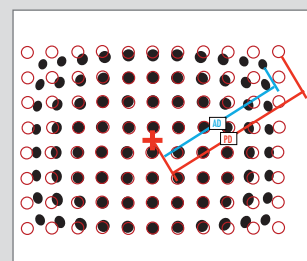


Figure 13: Positional difference can be measured and corrected with software.

Using 1951 USAF Resolution Targets

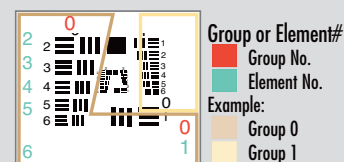
1951 USAF Resolution Targets are a well-established standard for testing the resolution of an imaging system. They consist of horizontal and vertical bars organized in groups and elements. Each group is composed of six elements, and each element is composed of three horizontal and three vertical bars equally spaced with one another. There can be a total of twelve groups, with larger numbers used for higher resolution. Vertical bars are used to calculate horizontal resolution and horizontal bars are used to calculate vertical resolution.

Qualitatively, the resolution of an imaging system is defined as the group and element combination directly before the black and white bars begin to blur together. Quantitatively, resolution (in terms of line pairs per millimeter, or lp/mm) can be calculated by:

$$\text{Resolution} = 2^{\left(\text{Group Number} + \frac{\text{Element Number} - 1}{6}\right)}$$

Resolution for each group and element pair is calculated in the table below.

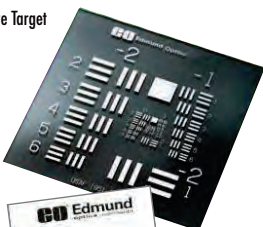
NUMBER OF LINE PAIRS / mm IN USAF RESOLVING POWER TEST TARGET 1951											
Element	Group Number										For High Res Only
	-2	-1	0	1	2	3	4	5	6	7	
1	0.250	0.500	1.00	2.00	4.00	8.00	16.00	32.0	64.0	128.0	256.0
2	0.280	0.561	1.12	2.24	4.49	8.98	17.95	36.0	71.8	144.0	287.0
3	0.315	0.630	1.26	2.52	5.04	10.10	20.16	40.3	80.6	161.0	323.0
4	0.353	0.707	1.41	2.83	5.66	11.30	22.62	45.3	90.5	181.0	362.0
5	0.397	0.793	1.59	3.17	6.35	12.70	25.39	50.8	102.0	203.0	406.0
6	0.445	0.891	1.78	3.56	7.13	14.30	28.50	57.0	114.0	228.0	456.0



Resolution Targets

1951 USAF RESOLUTION TARGETS

Negative Target



Positive Target



- **Negative & Positive Patterns on Glass**
- **Each is Boxed and Includes Resolution Value Chart**
- **High Resolution Targets Available (up to 645 lp/mm)**

Resolution test slides with the USAF 1951 test pattern are available in either positive (chrome pattern, clear background) or negative (clear pattern, chrome background) patterns. The positive pattern is recommended for quality control of vision systems and testing equipment. The negative pattern is most often backlit and is ideal for use with microscopes and high magnification video lenses. Each is boxed and includes resolution value chart. Targets conform to MIL-S-150A specifications.

Substrate:	1.5mm (0.06") float glass with beveled edges
Flatness:	0.0001" or better
Surface Quality:	20-10
Coating:	Vacuum-deposited durable chromium, density 3.0 or greater

1951 USAF RESOLUTION TARGETS				
USAF Targets	Standard Resolution		High Resolution	
	Stock No.	Price	Stock No.	Price
2" x 2" Positive	#38-257	\$165.00	#58-198	\$625.00
2" x 2" Negative	#38-256	\$165.00	#55-622	\$625.00
3" x 3" Positive	#36-275	\$200.00	#64-862	\$1,450.00
3" x 3" Negative	#36-408	\$200.00	#64-863	\$1,450.00

UV FUSED SILICA & FLUORESCENT USAF 1951 RESOLUTION TARGETS



- **Designed for Calibration of UV or Fluorescence Microscopes**
- **Fluorescent Targets have 365nm Excitation Wavelength, 550nm Emission Wavelength**
- **Negative, Positive, & High Resolution Targets Available**

Made with UV Fused Silica, these targets are ideal for calibration of imaging systems using UV illumination. The Fused Silica Positive Target (chrome pattern, clear background) has the chrome pattern deposited on the top surface of the target, as does the Fused Silica Negative Target (clear pattern, chrome background). The Fluorescent Fused Silica Targets are ideal for applications involving fluorescence and confocal microscopy, nanotechnology, photolithography, and other UV-based imaging systems. The Fluorescent Fused Silica Positive Target (chrome pattern, clear background) has a fluorescent material on the top surface of the target. The Fluorescent Fused Silica Negative Target (clear pattern, chrome background) has a fluorescent material on the bottom surface. **Note:** Chrome coated top surface will reflect UV radiation.

Substrate:	UV Fused Silica	Thickness (mm):	1.0 ± 0.1*	Pattern Coating:	Chromium, OD>3.0
Surface Accuracy:	2λ	Surface Quality:	20-10		

UV FUSED SILICA & FLUORESCENT USAF 1951 RESOLUTION TARGETS						* Fluorescent coating adds 0.1 to 0.2mm to the thickness	
Pattern Size (mm):	2" x 2" Std. Resolution	3" x 3" Std. Resolution	2" x 2" High Resolution	2" x 2" Fluorescent Std. Resolution	3" x 3" Fluorescent Std. Resolution		
Min Frequency:	15.0 x 14.0	60.7 x 56.6	15.0 x 14.0	15.0 x 14.0	62.0 x 58.0		
Max Frequency:	Group 0, Element 1	Group -2, Element 1	Group 0, Element 1	Group 0, Element 1	Group -2, Element 1		
Transmissive Coating:	Group 7, Element 6	Group 7, Element 6	Group 9, Element 3	Group 7, Element 6	Group 7, Element 6		
	N/A	N/A	N/A	365nm Excitation, 550nm Emission*	365nm Excitation, 550nm Emission*		
Positive	#57-896 \$230.00	#57-898 \$365.00	#59-152 \$1,010.00	#57-855 \$285.00	#57-894 \$400.00		
Negative	#57-895 \$230.00	#57-897 \$365.00	#59-153 \$1,010.00	#57-792 \$285.00	#57-893 \$400.00		

Resolution Targets

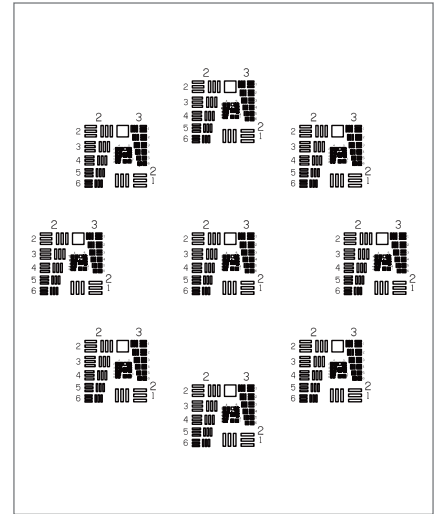
USAF PATTERN WHEEL TARGET

- Tests Resolutions from 4 - 228 lp/mm
- Reduces Testing Time
- Tests Multiple Field Points

The USAF pattern wheel is an ideal target to measure resolution at different field points within an imaging system's field of view. The pattern is available on three different substrate sizes: 1" square, 1.5" diameter, or a 1" x 3" slide. Each size includes 8 USAF patterns in a circular pattern plus one pattern in the center. Each size is offered as positive (opaque pattern on clear background) or negative (clear pattern on opaque background).

No. of USAF Patterns:	9	Surface Quality:	20-10
Line Width Tolerance:	±0.0005mm	Maximum Resolution:	Group: 7 Element: 6 (228 lp/mm)
Substrate:	Float Glass 1.5mm thick	Parallelism:	<0.0005"/inch
Flatness:	2 λ /inch	Coating:	First Surface Reflective Chromium
Minimum Resolution:	Group: 2 Element: 1 (4 lp/mm)		

USAF PATTERN WHEEL TARGET		
USAF Wheel Target Negative, 1" x 3"	#59-204	\$285.00
USAF Wheel Target Positive, 1" x 3"	#59-203	\$285.00
USAF Wheel Target Negative, 1" x 1"	#59-206	\$285.00
USAF Wheel Target Positive, 1" x 1"	#59-205	\$285.00
USAF Wheel Target Negative, 1.5" Diameter	#59-207	\$285.00
USAF Wheel Target Positive, 1.5" Diameter	#59-208	\$285.00



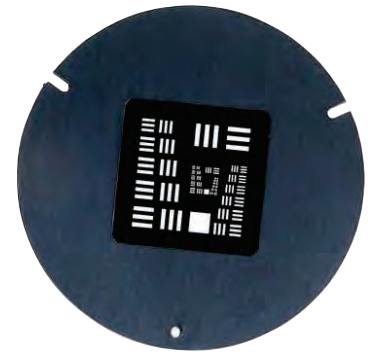
CLEAR OPTICAL PATH USAF TARGET

- Determine Resolution for X-Ray, UV, Thermal, and Far-IR Imaging Systems
- Easy Mounting
- Ideal for Transmittance Applications

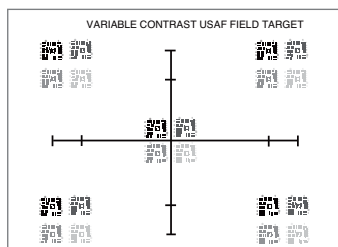
Our Clear Optical Path USAF targets are manufactured from an extremely thin electroformed nickel substrate. Since there is no glass in the pattern area, light travels only through air, eliminating chromatic and absorption issues. The target pattern covers from Group 0, Element 1 to Group 3, Element 6. Our UV Fused Silica & Fluorescent USAF targets (at left) are available for most NUV applications, but the Clear Optical Path Target can be used for very deep UV and far-IR applications.

Minimum Resolution:	Group 0, Element 1 (1 lp/mm)	Mount Material:	Anodized Aluminum
Maximum Resolution:	Group 3, Element 6 (14.30 lp/mm)	Electroform Thickness:	0.0005" Nominal
Mount Thickness:	0.0405"		

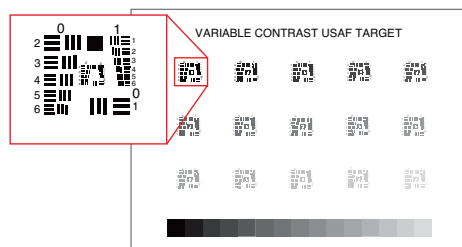
Clear Optical Path USAF Target - 38mm Dia.	#58-402	\$790.00
Metric Optical Mount for 38.1mm Dia. Optics	#64-565	\$42.50



1951 USAF FIELD RESOLUTION TARGET



1951 USAF CONTRAST RESOLUTION TARGET



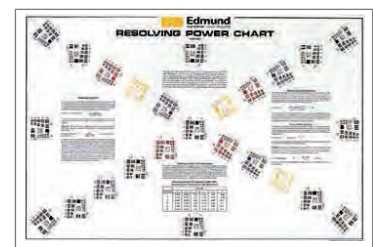
- Arranged on a 4:3 Aspect Ratio to Measure Resolution as a Function of Field
- Each Section Contains Four USAF Targets of Varying Density Levels

1951 USAF PHOTOGRAPHIC TARGET		
Substrate:	8.5" x 11" Photo Paper	
Thickness:	0.2mm	
Density Values:	0.07, 0.55, 1.03, 1.5	
Min. Resolution:	Group 0 Element 1	
Max. Resolution:	Group 4 Element 3	
Stock No./Price	#53-715	\$120.00

- 15 USAF Targets Which Vary in Density
- Allows Resolution Measurements at Different Contrast Levels

1951 USAF CONTRAST TARGET		
Substrate:	8.5" x 11" Photo Paper	
Thickness:	0.2mm	
Density Values:	Varies linearly 1.5 - 0.09	
Min. Resolution:	Group 0 Element 1	
Max. Resolution:	Group 4 Element 3	
Stock No./Price	#53-714	\$120.00

RESOLVING POWER REFERENCE CHART



1951 USAF COLOR TARGET

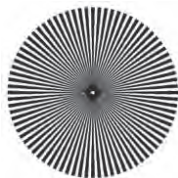
Substrate:	White Poster Paper	
Size:	36" L x 24" W	
Min. Resolution:	Group -2 Element 1	
Max. Est. Resolution:	Group 2 Element 1	
Stock No./Price	#83-001	\$40.00

For complete specifications on our Pocket USAF Target, see our website.
#38-710 \$6.00



Resolution Targets

STAR TARGETS



- Ideal for Detection of Focus Errors and Astigmatism
- 0.6 to 14 lp/mm Wedge Spacing
- Available on White Photographic Paper or Chrome on Glass

Star targets are ideal for identifying focus errors, astigmatism, and other aberrations existing in an imaging system. We have several targets to choose from. Our 60mm diameter (#58-832 and #58-833) targets feature an unresolved core of 100µm, and are ideal for high-resolution or high magnification imaging systems. Both targets are chrome on glass. Our 4" x 4" targets, available as chrome on glass (#46-247) or photo paper (#46-246), feature an unresolved core of 2.7mm, and are designed for mid- to low-range spatial frequencies common in macro imaging systems.

STAR TARGETS

*Sector = 1 transparent/1 opaque pair

Pattern Diameter	Target Dimensions	Thickness	Wedge Angle*	Number of Sectors*	Unresolved Core	Substrate	Target Edge		Target Center		Stock No.	Price
							Frequency	Line Width	Frequency	Line Width		
50mm	60mm Dia.	1.5mm	10°	36	0.1mm	Float Glass	0.229 lp/mm	2.2mm	114.5 lp/mm	0.009mm	#58-832	\$310.00
50mm	60mm Dia.	1.5mm	5°	72	0.1mm	Float Glass	0.459 lp/mm	1.1mm	229 lp/mm	0.009mm	#58-833	\$340.00
62.5mm	4" x 4"	1.5mm	6°	60	2.7mm	Float Glass	0.31 lp/mm	1.6mm	7.14 lp/mm	0.070mm	#46-247	\$290.00
62.5mm	4" x 4"	0.2mm	3°	120	2.5mm	Photo Paper	0.6112 lp/mm	0.8181mm	15.28 lp/mm	0.0327mm	#46-246	\$110.00

STAR TARGET ARRAYS



- Detect Aberrations at Various Field Points

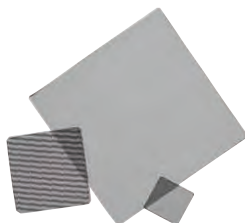
Our star target arrays are designed to identify focus errors and astigmatism along field points in the image of a vision system. With star targets located at the center, corner, and along the diagonals of the sensor, determining precision location and amplitude of the problem areas couldn't be easier. The small array features unresolved centers of 0.1mm, whereas the large array features unresolved centers of 0.15mm.

STAR TARGET ARRAYS

*Sector = 1 transparent/1 opaque pair

Description	Target Dimensions	Pattern Area	Number of Stars	Individual Star Diameter	Number of Sectors*	Frequency Range	Stock No.	Price
Small Star Target Array	50 x 50 x 1.5mm	29.2 x 21mm	33	2.0mm	36	2.86 - 57.5 lp/mm	#58-834	\$245.00
Large Star Target Array	101 x 101 x 2.0mm	90 x 90mm	59	4.5mm	36	1.27 - 38.5 lp/mm	#58-835	\$470.00

HIGH PRECISION RONCHI RULINGS



- Chrome on Glass
- Superior to Etched and Filled Rulings
- English & Metric Versions
- High Tolerance
- Lines Parallel to Edge

HIGH PRECISION RONCHI RULINGS - METRIC

lp/mm	0.5" x 0.5" Target		1" x 1" Target		2" x 2" Target	
5	*	—	#58-775	\$100.00	#58-782	\$160.00
10	*	—	#58-776	\$120.00	#58-783	\$175.00
20	*	—	#58-777	\$150.00	#58-784	\$225.00
30	*	—	#66-347	\$165.00	#66-352	\$315.00
40	*	—	#58-778	\$175.00	#58-785	\$400.00
50	*	—	#58-779	\$225.00	#58-786	\$425.00
60	*	—	#66-348	\$235.00	#66-353	\$475.00
72	#66-339	\$145.00	#66-349	\$250.00	#66-354	\$495.00
80	#66-340	\$155.00	#62-199	\$255.00	#62-200	\$545.00
100	#66-341	\$170.00	#58-780	\$285.00	#58-787	\$630.00
120	#66-342	\$200.00	#62-201	\$315.00	#62-202	\$655.00
145	#66-343	\$225.00	#66-350	\$340.00	#66-355	\$675.00
165	#66-344	\$240.00	#66-351	\$375.00	#66-356	\$710.00
200	#66-345	\$260.00	#58-781	\$450.00	#58-788	\$740.00
240	#66-346	\$285.00	#62-203	\$495.00	#62-204	\$895.00

HIGH PRECISION RONCHI RULINGS - ENGLISH

lp/inch	1" x 1" Target		2" x 2" Target		4" x 4" Target	
25	#58-529	\$55.00	#58-530	\$105.00	#58-531	\$260.00
50	#56-592	\$60.00	#56-605	\$120.00	#56-618	\$280.00
100	#56-593	\$75.00	#56-606	\$135.00	#56-619	\$300.00
150	#56-594	\$90.00	#56-607	\$150.00	#56-620	\$340.00
200	#56-595	\$95.00	#56-608	\$155.00	#56-621	\$400.00
250	#56-596	\$105.00	#56-609	\$165.00	#56-622	\$440.00
300	#56-597	\$115.00	#56-610	\$175.00	#56-623	\$520.00
500	#56-598	\$130.00	#56-611	\$225.00	#56-624	\$675.00
750	#56-599	\$150.00	#56-612	\$285.00	#58-459	\$770.00
1000	#56-600	\$190.00	#56-613	\$400.00	#58-460	\$875.00
2000	#56-601	\$215.00	#56-614	\$515.00	#58-461	\$1,010.00
2500	#56-602	\$225.00	#56-615	\$565.00	#58-462	\$1,075.00
3000	#56-603	\$285.00	#56-616	\$630.00	#58-463	\$1,125.00
5000	#56-604	\$355.00	#56-617	\$790.00	#58-464	\$1,350.00

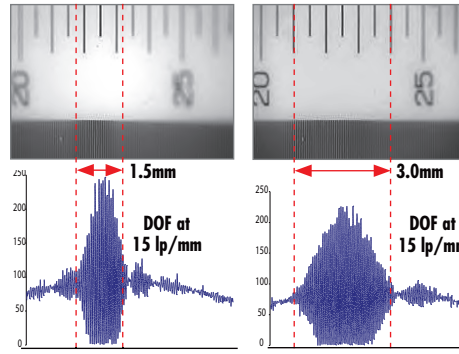
Speciality Targets

DOF 5-15 DEPTH OF FIELD TARGET

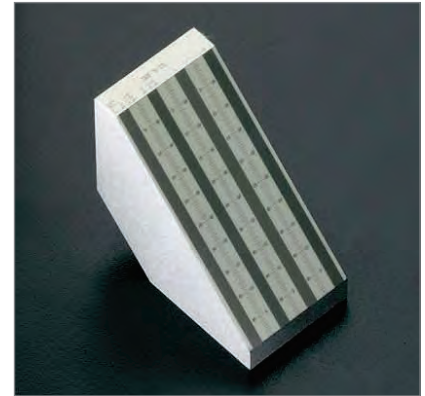
- **Test Depth of Field in Imaging Systems**
- **Eliminates Need for Calculations**

This target measures an area of optical tolerancing often determined theoretically. Depth of field calculations are often misleading, a problem this target solves by accurately determining the amount of object shift possible before affecting image quality. The degree of image quality needed is determined by user and application.

The DOF 5-15 consists of two sets of scales. Each, when viewed at 45°, consists of horizontal and vertical lines at a frequency of 5 and 15 line pairs per mm. Instructions included.

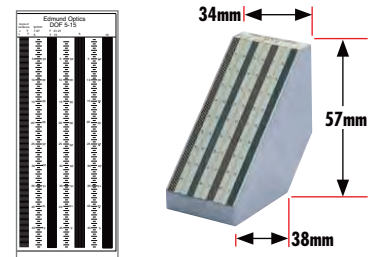
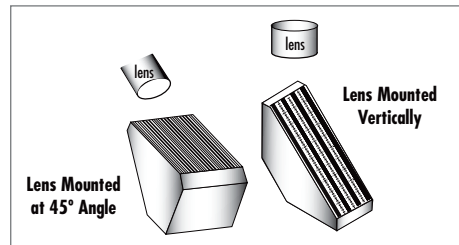


Line spread functions of ruling. Taken with VZM™ 200i at 1X PMAG.
Left: Iris Open. Right: Iris Half Open.



Target: Black on white-backed film
Substrate: Aluminum
Maximum Depth: 50mm
Dimensions: 57 H x 34 W x 57mm D
Scale: 5 and 15 lp/mm (both horizontal and vertical)

Depth of Field Target #54-440 \$650.00



EO TELECENTRICITY TARGET

- **Critical Tool for Any Vision System Making Size or Distance Measurements**
- **Calibrates Any Type of Lens**
- **Covers Large Range of Magnifications**

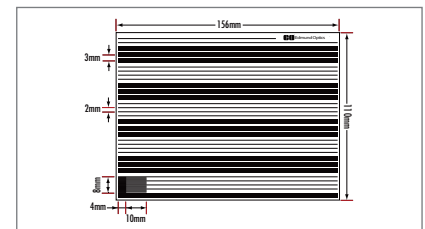
Telecentricity is an extremely useful metric for measuring the amount of perspective error inherent in an imaging system. Determining the degree of telecentricity allows the user to calculate an imaging system's maximum measurement accuracy. The target can be used to calibrate the degree of telecentricity in both telecentric and non-telecentric lenses. Keystoning becomes visual with the target and can be measured with software.



Dimensions: 110 W x 110 H x 110mm L
Pattern Size: 110 H x 156mm V
Pattern: Black Print on White Mylar® with Protective Lamination
Low Mag Pattern: 1) 3 lines, 2mm thick on 3mm centers
2) 4 lines, 0.1mm thick on 2mm centers

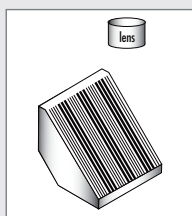
Mid Mag Pattern: 20 lines, 0.1mm thick on 0.5mm centers
High Mag Pattern: 40 lines, 0.1mm thick on 0.25mm centers
Base: Aluminum
Magnification Range: 0.08X to 5X

EO Telecentricity Target #58-404 \$955.00



TECHNICAL NOTE

Our telecentric target allows keystone in an image to be visualized and accurately measured. The amount of keystone is related to the telecentricity of the lens that is imaging the target. The target is placed at a 45° angle to the optical axis so that the bottom of the target is further away from the lens than the top of the target. When imaging the target through a non-telecentric lens, the distance between the vertical lines will appear to decrease at the bottom of the image; this effect is known as keystone. A perfectly telecentric lens will have no keystone and the telecentricity will be 0°.



It is apparent that the blur in this image (taken with a telecentric lens) is symmetric. If you take a horizontal line profile across the image and find the horizontal component of the center of each black line, the location will be equal in the blurred part of the image and the focused part of the image.



This image (taken with an 8mm focal length lens) demonstrates keystone. Clearly, the lines converge at the bottom of the image. The center location of a line at the bottom of the image does not have the same center location at the top of the image.

This difference in position can be converted to a degree of telecentricity with the following steps:

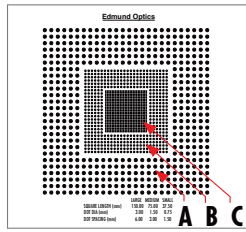
- 1) Find the distance between your top line profile and your bottom line profile, Y_1 & Y_2 $Y = (Y_1 - Y_2)$
- 2) Find the horizontal displacement ("X") of a target line: $X = |X_1 - X_2|$
- 3) Calculate the telecentric angle: $\epsilon = \tan^{-1}(X/Y)$

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Distortion Targets

MULTI-FREQUENCY GRID DISTORTION TARGETS



Multi-Frequency Target

- For Calibration of Imaging Systems
- Fixed and Multi Frequency Targets Available
- N.I.S.T. Certificate of Accuracy Included

Although distortion can often be troublesome in measurement applications, it is important to note that no information about the object is actually lost, but merely misplaced in the image. Using these targets, one can easily determine the precise amount of distortion present and back it out of measurements. The dot center can be located using blob (or centroid) analysis in measurement software. To accommodate the expanding variety of image analysis software and applications, we offer fixed frequency and variable fre-

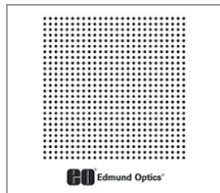
quency targets. The fixed frequency targets are available in a variety of dot size/spacing combinations to complement our full line of imaging lenses. Select a target to cover your entire field of view while maintaining an adequate number of dots across the field, and an adequate number of pixels per dot. The 3 or 5 grids on the multi frequency target scale down so that one target can be used for a variety of lenses and fields of view. Both types of targets are available in a chrome on glass or chrome on opal target to accommodate transmission or reflection based on applications respectively. Included in the packaging is a serialized N.I.S.T. Traceable Certificate of Accuracy per MIL-STD-45662A.

MULTI-FREQUENCY GRID DISTORTION TARGETS

*Opal Glass is 3.2mm Thick

	3 Freq. Glass Target			5 Freq. Glass Target				
	Float Glass or White Opal Glass			Float Glass or White Opal Glass				
Substrate:	76.2 x 76.2 x 1.5"			76.2 x 76.2 x 1.5"				
Overall Dimensions (L x W x T) (mm):	76.2 x 76.2 x 1.5"			76.2 x 76.2 x 1.5"				
Tolerances: Placement of Squares (A, B, C, D, E) (mm):	±0.004			±0.004				
Dot Diameter (mm):	±0.0025			±0.0025				
Dot Center to Center Spacing (mm):	±0.0025			±0.0025				
Grid Corner to Corner Accuracy (mm):	±0.004			±0.004				
Surface Flatness:	4-6 μ /25.4mm area			1 μ /25.4mm area				
Surface Quality:	40-10 (within 51mm sq. area)			20-10 (within 51mm sq. area)				
Coating:	Vacuum Deposited Chromium Oxide (specular reflectivity <5% @ 550nm)			Vacuum Deposited Chromium Oxide (specular reflectivity <5% @ 550nm)				
Square:	A	B	C	A	B	C	D	E
Square Size (center to center of dots) (mm):	50.00	25.00	12.50	50.00	34.00	20.00	10.00	5.00
Dot Diameter (mm):	1.00	0.50	0.25	1.00	0.50	0.25	0.125	0.0625
Dot Center Spacing (mm):	2.00	1.00	0.50	2.00	1.00	0.50	0.25	0.125
Chrome on Float Glass Stock No. / Price	#46-250 \$520.00			#64-864 \$630.00				
Chrome on Opal Glass Stock No. / Price	#58-774 \$630.00			#64-865 \$675.00				

FIXED FREQUENCY GRID DISTORTION TARGETS



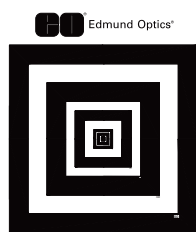
Fixed Frequency Target

	Chrome on Glass Target	Chrome on Opal Target
Substrate:	Clear Float Glass	White Opal Glass
Substrate Thickness:	1.5mm	3.2mm
Tolerances:		
Dot Diameter:	±0.002mm	±0.002mm
Dot Center to Center Accuracy:	±0.001mm	±0.001mm
Surface Flatness:	4-6 μ /25.4mm area	4-6 μ /25.4mm area
Surface Quality:	40-20	40-20
Coating:	Reflective First Surface Chromium OD > 3.0, R _{abs} = 50% ±5% @ 550nm	Reflective First Surface Chromium OD > 3.0, R _{abs} = 50% ±5% @ 550nm

FIXED FREQUENCY GRID DISTORTION TARGETS

Target Dimensions	Pattern Size (mm)	Dot Dia. (mm)	Dot Spacing (mm)	Chrome on Glass			Chrome on Opal		
				Overall Accuracy (mm)	Stock No.	Price	Overall Accuracy (mm)	Stock No.	Price
2" x 2"	25 x 25	0.0625	0.125	±0.001	#58-509	\$540.00	±0.001	#59-209	\$635.00
2" x 2"	25 x 25	0.125	0.250	±0.001	#58-527	\$480.00	±0.001	#63-983	\$565.00
2" x 2"	25 x 25	0.250	0.500	±0.001	#57-981	\$440.00	±0.001	#59-210	\$525.00
2" x 2"	25 x 25	0.250	1.000	±0.001	#62-209	\$400.00	±0.001	#63-984	\$495.00
3" x 3"	50 x 50	0.125	0.250	±0.001	#59-213	\$565.00	±0.001	#63-985	\$750.00
3" x 3"	50 x 50	0.250	0.500	±0.001	#58-536	\$520.00	±0.001	#63-986	\$675.00
3" x 3"	50 x 50	0.250	1.000	±0.001	#62-211	\$505.00	±0.001	#63-987	\$655.00
3" x 3"	50 x 50	0.500	1.000	±0.001	#57-983	\$450.00	±0.001	#59-211	\$635.00
5" x 5"	100 x 100	0.250	0.500	±0.0015	#59-215	\$1,010.00	±0.0015	#63-988	\$1,350.00
5" x 5"	100 x 100	0.250	1.000	±0.0015	#62-213	\$975.00	±0.0015	#63-989	\$1,325.00
5" x 5"	100 x 100	0.500	1.000	±0.0015	#59-217	\$985.00	±0.0015	#63-990	\$1,295.00
5" x 5"	100 x 100	1.000	2.000	±0.002	#57-985	\$955.00	±0.002	#59-212	\$1,295.00
7" x 7"	150 x 150	0.500	1.000	±0.002	#62-207	\$1,550.00	±0.002	#63-991	\$2,125.00
7" x 7"	150 x 150	1.000	2.000	±0.002	#58-507	\$1,550.00	±0.002	#63-992	\$2,125.00

CONCENTRIC SQUARE TARGET



- For Calibration of Measurement Software
- N.I.S.T. Traceable Certificate of Accuracy Included
- 1 - 50mm Squares

These targets provide an accurate means of calibrating measurement software for image processing. The squares vary in dimensions to accommodate different fields of view. Included in the packaging is a serialized N.I.S.T. Traceable Certificate of Accuracy per MIL-STD-45662A.

Concentric Square Target	#46-248	\$450.00
Concentric Square Target on Opal Glass	#58-773	\$565.00

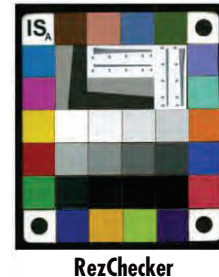
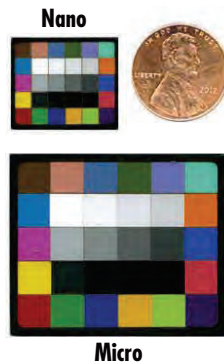
Dimensions:	76.2 x 76.2 x 1.5mm (3.2mm Thick for Opal)
Square Sizes:	1, 2, 3, 4, 5, 10, 15, 20, 30, 40, 50mm
Line Width Tolerance:	±0.0025mm
Diagonally Opposite Corner Spacing (50mm square):	70.7107mm ±0.004mm
Centering Tolerance:	±0.004mm
Surface Flatness:	4 to 6 μ /25.4mm area
Surface Quality:	40-10 (within 50mm sq. area)
Coating:	Vacuum-deposited chromium oxide (specular reflectivity < 5% @ 550nm)

Color Targets

X-RITE COLORCHECKER®

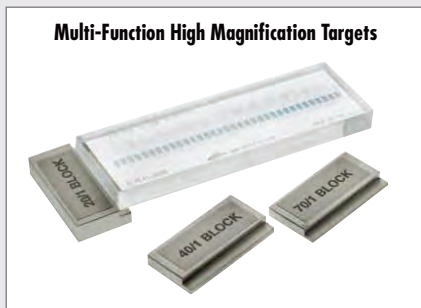
- Test True Color Balance
- Include Natural, Chromatic, Primary, and Grayscale Colors
- 24, 30, 50, or 140 Scientifically Designed Patches

The X-Rite ColorChecker® is a unique test pattern scientifically designed to help determine the true color balance or optical density of any color rendition system. It is an industry standard that provides a non-subjective comparison with a "test pattern" of 24 scientifically prepared colored squares. Each color square represents a natural object—human skin, foliage, blue sky, etc, providing a qualitative reference to quantifiable values. Each color will reflect light in the same way in all parts of the visible spectrum, thus maintaining color consistency over different illumination options. Some applications include spectroscopy, machine vision, photography, graphic arts, electronic publishing, and television.



X-RITE COLORCHECKER®							
	Color Patch Size	Total # of Patches	Overall Size (L x W)	Notes	Stock No.		Price
					Gloss	Matte	
ColorChecker® SG Chart	5/8"	140	8" x 11.5"	All Patches Semi-Gloss	#58-288	N/A	\$410.00
Large Mactheth® ColorChecker®	1 5/8"	24	8" x 11.5"	—	N/A	#37-756	\$200.00
ColorGauge Micro	1/4"	30	1 3/8" x 1 5/8"	All 18 Color Patches Matte	#68-767	#87-420	\$235.00
ColorGauge Nano	1/8"	30	1 1/16" x 1 3/16"	All 18 Color Patches Matte	#68-768	#87-421	\$235.00
ColorGauge Pico	1/16"	30	3/8" x 7/16"	All 18 Color Patches Matte	#87-413	#87-414	\$235.00
RezChecker	1/4"	30	1 5/8" x 1 7/8"	All 18 Color Patches Matte	#87-422	#87-423	\$235.00
Mactheth® White Balance Checker®	—	1	8" x 11.5"	—	N/A	#58-604	\$95.00
ColorChecker® Passport	Varies	50	4.92" x 3.54"	Includes Standard, Grayscale, and Balance Targets	N/A	#33-270	\$195.00

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WWW.EDMUNDOPTICS.COM/TARGETS

Glossary

A

Aberations

Deviation from perfection in an optical system that result as a product of imperfect ray bending to form an image. Aberrations are inherent in all optical systems. Chromatic aberration, spherical aberration, coma, astigmatism, field curvature, and distortion are the most commonly referred to aberrations.

Achromatic

Correction for primary chromatic aberration at two wavelengths. The simplest form is an achromatic doublet, consisting of two optical elements, a positive crown glass element and a negative flint glass element, cemented together.

Airy Disk

The resultant diffraction pattern created after a point source of light is imaged perfectly through an aperture, consisting of a bright central core surrounded by diffraction rings.

Analog-to-Digital Conversion (A/D)

The process of discretizing an analog signal for processing, interpretation or transmission via a digital interface or computer.

Analyzer

Polarizing filter placed over the objective lens in an imaging system, used in conjunction with polarized illumination, allowing only light of a particular polarization to be imaged.

Angular Field of View (AFOV)

The angle of a lens's view cone, typically specified as the full angle (in degrees) with respect to the horizontal sensor dimension. Used to determine FOV at a given working distance.

Anti-Reflection Coating (AR)

A type of coating applied to optics designed to minimize reflections within an optical system and maximize throughput.

Aperture Stop

The limiting aperture that defines how much light is allowed through an optical system. It can be an optical lens surface or an iris, but it is always a physical surface.

Apochromatic

Correction for primary chromatic aberration at three wavelengths.

Automatic Gain Control

Used in cameras to maintain a constant average grayscale value despite changes in light levels by automatically adjusting the signal gain value.

Axial Illumination

Refers to light that strikes an object along the optical axis, typically introduced by a beamsplitter in front of the lens.

B

Back Focal Length

A mechanical measurement given as the distance from the last optical surface of a lens to its image plane.

Bayer Filter

Color filter array on an imaging sensor that allows for production of color images when deciphered by an algorithm.

BBAR Coating

Broad Band Anti-Reflection coating. Optical coating that reduces reflections over a wide range of wavelengths.

Binning

The physical summing of signals from adjacent pixels on an image sensor into one larger effective pixel, resulting in increased sensitivity but lower resolution.

Blocking Range

Also referred to as stopband, a wavelength interval used to denote a spectral region of energy that is not transmitted by a filter.

Blooming

Spill-over of charge from an over-saturated pixel to adjacent pixel sites in a CCD, causing large bright spots and/or streaks to be visible in the image. Reducing exposure time and/or illumination levels prevents blooming.

Board Level Camera

A type of camera consisting of a sensor mounted on a PC board, not connected to particular terminations. Intended for integration by the user.

Borescope

A optical device, typically a long, narrow tube, allowing for the internal inspection of voids or hard-to-reach mechanical parts.

Brightfield Illumination

An illumination technique which has most of the light bouncing off the object and collected by the lens. Surface defects then appear as high-contrast dark spots.

C

CCD (Charge Coupled Device)

Silicon chip containing an array of photosensitive sites. The imaging area consists of rows and columns of photosensitive pixels that accumulate and store electric charge. The term CCD refers to the way the photoelectron packets are moved around on the chip, the shift registers. Each column is separated by a shift register, to which pixel charge is transferred. Charge is read out from each pixel of the device through the shift register sequentially to an amplifier. The raw analog signal is either used directly, or quantized by an A/D converter.

Chief Ray

In geometric optics, the chief ray defines the size of the paraxial object, location of pupils, and size of the paraxial image. It begins at the edge of the object and goes through the center of the entrance pupil, exit pupil, and the aperture stop.

Chromatic Focal Shift

A measure of axial chromatic aberration, quantifying the change in position along the optical axis where different wavelengths will focus.

Clear Aperture (CA)

The unobscured portion of an optic or mechanical

component which has a limited area through which light can pass. CA takes into account mounting rings, etc. on optics which reduce the usable area.

CMOS Sensor

Complementary metal-oxide semiconductor sensor. A type of imaging sensor in which the charge-to-voltage conversion is done at each individual pixel and the signal is read out by a multiplexing to an A/D converter. Can yield a less uniform output and very low power dissipation compared to CCD, but at much higher speeds due to lack of shift registers.

C-Mount

A camera and lens standard with a 17.526mm flange distance and mounting threads of 1" x 32 TPI.

Cold Mirror

A mirror-like filter which transmits infrared light while reflecting visible light. See also Hot Mirror.

Collimated Light

A ray bundle, or beam of light, in which every ray is parallel to every other ray of light, which effectively originates from an infinitely small point source located at infinity. Note that light is never perfectly collimated.

Color Sensor

A camera sensor that uses a mosaic filter to separate incoming light into a series of colors. Each color is then by a different set of pixels. In the filtering process some spatial resolution is lost because the sensor is not using every pixel for every color. See also Bayer Filter.

Color Temperature

Colorimetric parameter associated with light sources (compared with blackbodies) that relates to apparent visual color. Expressed in degrees Kelvin.

Coma

An optical aberration that yields a variation in magnification (and therefore image size) across the FOV, causing an asymmetric blur for features in the image.

Confocal Microscopy

Microscopy technique using spatial filtering to eliminate out-of-focus light in specimens that are thicker than the plane of focus. Allows for controllable depth of field and built-up 3D representations by z-sectioning of an object.

Conjugate Distance

The distance along the optical axis of a lens from the principle plane of that lens to either the image plane (for an image conjugate) or the object plane (for an object conjugate).

Contrast, Optical

The quantified difference between adjacent features of a specific size for an object, as imaged through a lens.

CS-Mount

A camera and lens standard with a 12.526mm flange distance and mounting threads of 1" x 32 TPI. CS-mount lenses will not work with C-mount cameras.

D

Darkfield Illumination

In microscopy, refers to light that enters a translucent object through an edge perpendicular to the lens. In machine vision, an illumination geometry which has most of the light bounce off of the object; light from edges and surface defects is scattered to the detector yielding a high contrast bright spot.

Depth of Field (DOF)

The distance through which an object being imaged may move in or out of the plane of best focus while maintaining an acceptable level of contrast at a particular spatial frequency or resolution.

Depth of Focus

The image-space equivalent of depth of field. For a fixed object distance, the maximum displacement from the plane of best focus through which the image maintains a particular contrast at a specific spatial frequency.

Dichroic Coating

A filter or mirror coating that transmits or reflects light depending on wavelength. The color varies with angle of incidence and thickness of deposition material.

Diffraction

The change in intensity distribution of waves caused by constructive and destructive interference as they contact an obstruction, yielding a distribution that differs from the incident wavefront's.

Diffraction Limit

A theoretical limiting factor governing the maximum obtainable resolution of an optical or imaging system, defined by the inverse of the wavelength of light being used multiplied by the f/# of the lens.

Diffuse

Light coming from (or reflected in) all directions, not collimated or structured in anyway.

Diffuse Illumination

Diffuse, spatially uniform light from an extended source. Used for even illumination of an object.

DIN (Deutsche Industrie Norm)

An industry standard for the design of microscope objectives and eyepieces. DIN standard microscopes have a 160mm tube length.

Directional Illumination

Point source illumination from single or multiple sources.

Distortion

A geometrical aberration in which magnification changes with field height. If imaging a square grid, positive distortion gives a pincushion effect while negative distortion yields a barrel effect.

Distortion, Non-Monotonic

Distortion which changes sign, as well as magnitude, across the image. Also called wave or mustache distortion.

Divergence, Beam

The increase in cross-sectional area of a propagating beam of light that is not perfectly collimated.

Double Gauss (Design Form)

An optical lens design consisting of two Gauss lenses (a singlet followed by a cemented doublet) arranged symmetrically about the system's aperture stop.

Dynamic Range

The difference between the lowest detectable light level and the highest detectable light level. Physically, this is determined by the saturation capacity of each pixel, the dark current or dark noise, the ADC circuits, and gain settings.

E-F

Electronic Shutter

Controls the amount of time a camera collects light or charge during each frame, also known as the exposure time.

Entrance Pupil

The image of the aperture stop through the lens elements preceding it into object space.

Exit Pupil

The image of the aperture stop through the lens elements following it into image space.

Extinction Ratio

The relationship between the intensity of incident light to intensity of transmitted light passing through an optic. It is used to categorize a polarizer or laser's ability to pass a given polarization state relative to another.

f/#

Also denoted by f-number or f-stop, refers to the ratio of the focal length to diameter of the entrance pupil. A low f/# (fast lens) has high light collecting ability while a high f/# (slow lens) has low light collecting ability.

Fan Angle

The divergence angle of a laser or LED line generator. Used to calculate the length of the illumination line as a function of working distance.

Field Curvature

An optical aberration where focal position changes with field height in a spherical fashion, resulting in flat objects being imaged onto a curved surface, as the product of imaging through spherical lens elements. Results in increasing defocus when moving away from imaging axis.

Field Height

Half the image circle.

Field of View (FOV)

The imaged area of an object under inspection. This is the portion of the object that fills the camera's sensor.

Filter

An optical component that allows certain wavelengths or frequencies of light to pass through while reflecting or absorbing all others. Types of filters include bandpass, longpass, shortpass, interference notch and rugate notch, color, dichroic, and neutral density.

Filter, Colored Glass

An absorptive filter created by doping glass ma-

terials with elements that selectively change their absorption and transmission spectra.

Filter, Interference

A type of filter made up of several metallic or dielectric layers of material, typically composing a three-cavity design. The correct combination yields high spectral transmittance over very narrow wavelength ranges due to interference effects between layers.

Filter, Longpass

A type of filter in which the transmission band is a higher wavelength region as compared to the region blocked.

Filter, Neutral Density (ND)

A type of filter that yields a constant attenuation, or optical density, value over a range of wavelengths (e.g. spectrally flat). It is useful for attenuating, or reducing, the amount of light in a system.

Filter, Notch

A type of filter designed to block a pre-selected bandwidth while transmitting all other wavelengths within the design range of the filter. Manufactured using the dielectric stack method which involves using a series of thin layers of dielectric materials, of alternating refractive index.

Filter, Shortpass

A type of filter where the transmission band is a low wavelength range, typically lower than the region blocked.

Finite Conjugate

A conjugate distance relationship in which light is focused from a source located a finite distance away.

First Surface Mirror

A type of mirror featuring a high reflectivity coating, deposited on the front surface of the glass substrate. Light does not pass through any glass before it is reflected, but the coating is not protected and is more prone to scratching and oxidation.

Fixed Focal Length Lens

A lens with a fixed Angular Field of View (AFOV), also known as a conventional or entocentric lens.

Fixed Focus Lens

A lens which is used at a single, specific working distance and cannot be refocused for different distances.

Flange Distance, Back

The distance from the front of a camera's lens mounting flange to the sensor plane (image distance).

Fluorescence Microscopy

An optical microscopy technique that utilizes fluorescence, which is induced using fluorophores, as opposed to absorption, scatter, or refraction.

F-Mount

Also known as a Nikon-style F-mount bayonet, it is a camera and lens standard with a 46.5mm flange distance.

Focal Length Extender

A negative group of lenses that effectively changes the focal length (and therefore the

field of view) of the lens being used, at a loss of brightness and image quality.

Focal Length, Effective (EFL)

An optical measurement given as the distance from the rear principle plane of an optical system to its imaging plane, with an object located at infinity. Determines angular field of view of a lens.

Frame

A single full image in a sequence of video.

Frame Rate

The number of full frames (which may consist of two fields) composed in a second. In high-speed applications, it may be beneficial to choose a faster frame rate to acquire more "images" of the object as it moves.

G

Gain

The amount a signal increases while going through an amplifier. Most cameras have optional automatic gain (autogain or AGC). When possible, increased exposure or light levels should be used in lieu of gain, as gain reduces image quality by amplifying noise as well as signal.

Gamma

The exponent of the function relating output signal to input signal in video cameras and monitors. Industrial cameras naturally have a gamma of 1, that is, they are linear in response. Displays, however, can have a nonlinear response corresponding to gamma values between 2 and 3. When used together the camera may incorporate gamma correction to linearize the resulting system.

Ghost Image

In optics, a faint second image caused by reflections within an optical component. In paranormal investigation, a picture of a ghost, spectre, or phantom.

Glancing Illumination

Point source illumination similar to directional illumination, except at a sharp angle of incidence.

H-I

Hot Mirror

A mirror-like filter which reflects infrared light while transmitting visible light. See also Cold Mirror.

Hyperfocal Distance

The (usually long) working distance beyond which all objects are at an acceptable focus. See also Depth of Field.

Image Capture Board (Frame Grabber)

A computer card that samples and digitizes analog video signals so that the information may be processed, stored, or operated on by the computer. Ideal for analog cameras because they have no computational software or digital cameras to maximize bandwidth by transmitting data from large sensors at high frame rates.

Image Circle

The diameter of the maximum usable image produced by an imaging lens.

Infinite Conjugate

A conjugate distance relationship in which light is focused from a source located optically at infinity.

Integration Time

In an imaging device, the length of time during which the sensing elements are collecting charge between transfers to the transport registers. Also known as exposure time.

Interlaced Scan

Interlaced imaging devices produce images by scanning and reading out odd-numbered lines in the first pass, then even-numbered lines in the second pass, and so on. Two fields are assembled into one full frame.

Interline Transfer

Also referred to as 2:1 interlaced video, it combines two fields to make up each video. If each field is scanned at 60Hz, the frame rate is necessarily 30Hz.

Iris Diaphragm

A mechanical aperture designed to smoothly change the aperture size. It can be used to control the amount of light entering an optical system if used as the aperture stop.

Irradiance

Denoted by E, it is the incident power per unit area, measured in W/m². Also known as radiant flux density.

L

Lambertian

A perfectly diffuse reflecting surface, where light is scattered equally in all directions. See also Specular.

Lateral Color

The difference in image height as a function of wavelength.

Line Pair (lp)

A pair of alternating black and white bars at a specific frequency.

Linear Polarizer

A type of filter used to limit the polarization of light to a specific plane by absorbing components oscillating in planes other than the specified polarization transmission axis.

Lux

Unit of measure of luminous flux incident per unit area. One lux (lx) equals one lumen per square meter.

M

Magnification

See Primary Magnification.

Marginal Ray

In geometric optics, the marginal ray of an optical system determines the paraxial image location, and hits the edge of all pupils in the optical system. Along with the chief ray, it describes the entire paraxial image.

MgF₂ Coating

BBAR coating with reflection minimized at one specified wavelength, typically 550nm. Retains good transmission throughout visible into the NIR.

Glossary

Minimum Sensitivity

The minimum level of illumination required to produce a full video signal from a camera, expressed as luminous flux per unit area (lux or footcandles) through a specified imaging lens.

Modulation Transfer Function (MTF)

A measure of contrast as a function of spatial frequency. Defined as 100% at zero-frequency, MTF continuously declines with increasing spatial frequency to zero contrast at a theoretical maximum resolution frequency defined by the diffraction limit of the optical system.

Monochromatic

Refers to one specific wavelength or color.

Monochrome Sensor

A camera sensor that outputs grayscale images. It is ideal for machine vision applications due to the absence of Bayer pattern color filters which reduce sensitivity and spatial resolution.

N-O-P

NIR (Near Infrared)

The portion of the electromagnetic spectrum from 700 to 1100nm. Definition may differ by application.

Numerical Aperture (NA)

The sine of the vertex angle of the largest cone of marginal rays that can enter or exit an optical system. In other words, it governs the amount of light entering or exiting a system. It is inversely related to the $f/\#$.

Nyquist Limit

The theoretical limit of a camera's resolution or sampling ability, defined as the inverse of twice the pixel size.

Optical Density (OD)

Describes the amount of energy that can pass through an optical material. It is directly related to the transmittance of the material, which is the ability of light to propagate through a given medium. A large OD means more blocking.

Parallax

Perspective distortion caused by the change in magnification of an object with distance from a lens, making objects farther away seem smaller than those close up.

Paraxial

In geometric optics, the design paradigm in which small-angle approximations (e.g. $\sin \epsilon \approx \epsilon$) remain accurate.

Pixel

Photosite, or potential wells, on a camera sensor. In a CCD, each pixel's charge is converted to voltage, buffered, and transferred through a single node as an analog signal. In a CMOS sensor, the charge-to-voltage conversion is done at the pixel level.

Pixel Clock

In a CCD camera sensor, it describes the speed of the complementary signals which are used to move the charge packets through the shift registers towards the read out amplifiers. This determines how long it takes to read out the entire sensor, but

it is also limited by noise and spillover issues which occur when the packets are transferred too quickly.

Plate Beamsplitter

A type of beamsplitter fabricated from glass plates with a partially reflective metallic or dichroic coating. The thin glass substrate means small beam deviation and a very low absorption.

Polarization

A property arising from the wave nature of light. Polarized light consists of waves which oscillate in a defined and predictable manner. The direction in which the electric field vector points as it propagates through space defines the polarization state. If it oscillates in a single plane, the polarization state is linear. If it rotates about the axis of propagation, the polarization state is elliptical or circular.

Polarization Efficiency

A common measure of the polarizing characteristics of a polarizer. 100% efficiency is ideal though not feasible due to manufacturing limitations. 95 - 99% polarizing efficiency is typical.

Polarizer

Polarizing filter placed over the light source in an imaging system to polarize light, used in conjunction with an analyzing filter.

Polychromatic

Refers to multiple wavelengths as opposed to monochromatic which refers to only one specific wavelength.

Primary Magnification (PMAG)

Ratio of the sensor size on the camera being used to the field of view that the system produces.

Progressive Scan

A scanning method in which the sensor scans each line of the field sequentially (rows 1, 2, 3, 4..., etc.). All image data is recorded in a single exposure making this ideal for high speed applications.

R-S

Refraction

The term given for the bending of light rays that occurs at the interface between two materials with different indices of refraction. A higher index of refraction results in a lower refracted angle.

Relative Illumination (RI)

A measure of a lens's uniformity of sensor illumination across the lens's full image circle for a uniform object illumination, defined radially.

Resolution

The ability to distinguish object detail. It is often expressed in terms of line pairs per millimeter (lp/mm), or microns (μm).

Sagittal Plane

The radial component of the spot (or ray bundle) in the z-plane (perpendicular to image axis) at a given image height.

Scheimpflug Condition

Condition wherein both image and object planes are tilted with respect to the optical axis, in order to focus over a depth despite the camera being oblique to the object.

Sensor Active Area

The size of a camera sensor's active area, specified as the horizontal dimension by the vertical dimension (H x V). It is important in determining the proper lens magnification required to obtain a desired field of view.

Sensor Format

Refers to the historical nominal inch-based dimension naming scheme for image sensors, not the physical sensor dimensions above $\frac{1}{3}$ ".

Signal Format

The standardization of transmission and reception of analog signals, typically determined by geographical region. Signal parameters include synchronization, number of scanlines, bandwidth, black and blanking levels, frame rate, aspect ratio, etc. Video components of one signal format are not compatible with those of another.

S-Mount

A mounting thread denoted by M12 x 0.5, with no specified flange distance.

Snell's Law

Physical law governing the refraction (bending) of light rays at an interface between two regions of different index of refraction.

Spatial Frequency

Method of quantifying object size by a density (e.g. linepairs per millimeter) rather than a size. Allows for more precise way of describing resolution as it considers the necessary space between defects that allows for their detection, as well as describing lens performance by way of a transfer function.

Spectral Response

Measure of a detector's signal during exposure to radiation of a constant power level and varying wavelength.

Specular

A reflection which comes from a surface at an angle equal to the angle of incidence. An example is a high quality mirror.

Spherical Aberration

A type of optical aberration in which light rays from the outer portion of a lens focus either in front of (undercorrected) or behind (overcorrected) the focus point of the rays from the center portion of the lens. Unlike most other monochromatic aberrations, spherical aberration appears on-axis as well as off-axis.

Stray Light

Energy outside of the field of view of an optical system that scatters off of the edges of an optical or mechanical component and reaches the sensor in the form of background noise. This can decrease an image's contrast by lightening the background.

SWIR (Short Wave Infrared)

The portion of the electromagnetic spectrum from 900 to 1800nm. Definition may differ by application.

T

Tangential Plane

The component of the spot (or ray bundle) that

lies parallel to the tangent line of a circle in the z-plane with diameter of the image height at that field point. See also Sagittal Plane.

Telecentricity

The ability of a lens to maintain a constant magnification under changes in working distance. Quantified by the maximum angular deviation of a chief ray from parallel to the optical axis.

Throughput

Determines the light collecting efficiency of a lens or optical system. High throughput means high transmitted intensity while low throughput means low transmitted intensity.

Tube Lens

A lens used to focus an infinity corrected objective to a sensor. Typically this is an achromatic lens with a 200mm focal length.

V-W-Z

Varifocal

Low magnification lens which has a variable focal length, but which requires refocus with adjustment.

Vignetting

A fall-off in illumination of the image. This can occur when the sensor is larger than the specified maximum sensor size of the lens is used or can naturally occur due to limitations of the geometry of the system.

VIS Coating

BBAR coating optimized for use in the visible spectrum between 425nm and 675nm. Does not transmit NIR efficiently.

VIS/NIR Coating

BBAR coating optimized for use from 425nm to 900nm with good transmission out to 1000nm.

Visible Spectrum

The part of the electromagnetic spectrum from approximately 400 to 700nm.

Wavelength (λ)

The peak to peak distance covered by one cycle of an electromagnetic wave. It is inversely related to frequency. The longer the wavelength, the lower the frequency; conversely, the shorter the wavelength, the higher the frequency.

Working Distance (WD)

The distance from the front end of a lens system to the object under inspection.

Working $f/\#$

The effective $f/\#$ of a lens, taking into consideration the magnification at finite working distances. Calculated by $(1+|m|) \times \text{Infinite } f/\#$, where m is lens magnification.

Zoom

Ability to change the magnification of a lens at a specific working distance, with no refocus in the case of parfocal.

Z-Sectioning

Building up a 3D representation of an object by taking multiple images with incremental change in working distance.

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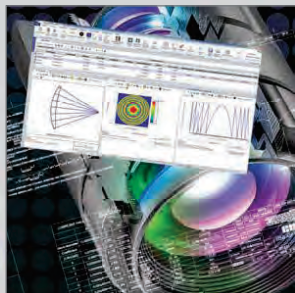
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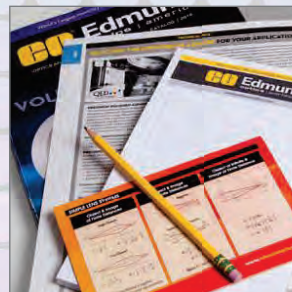
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