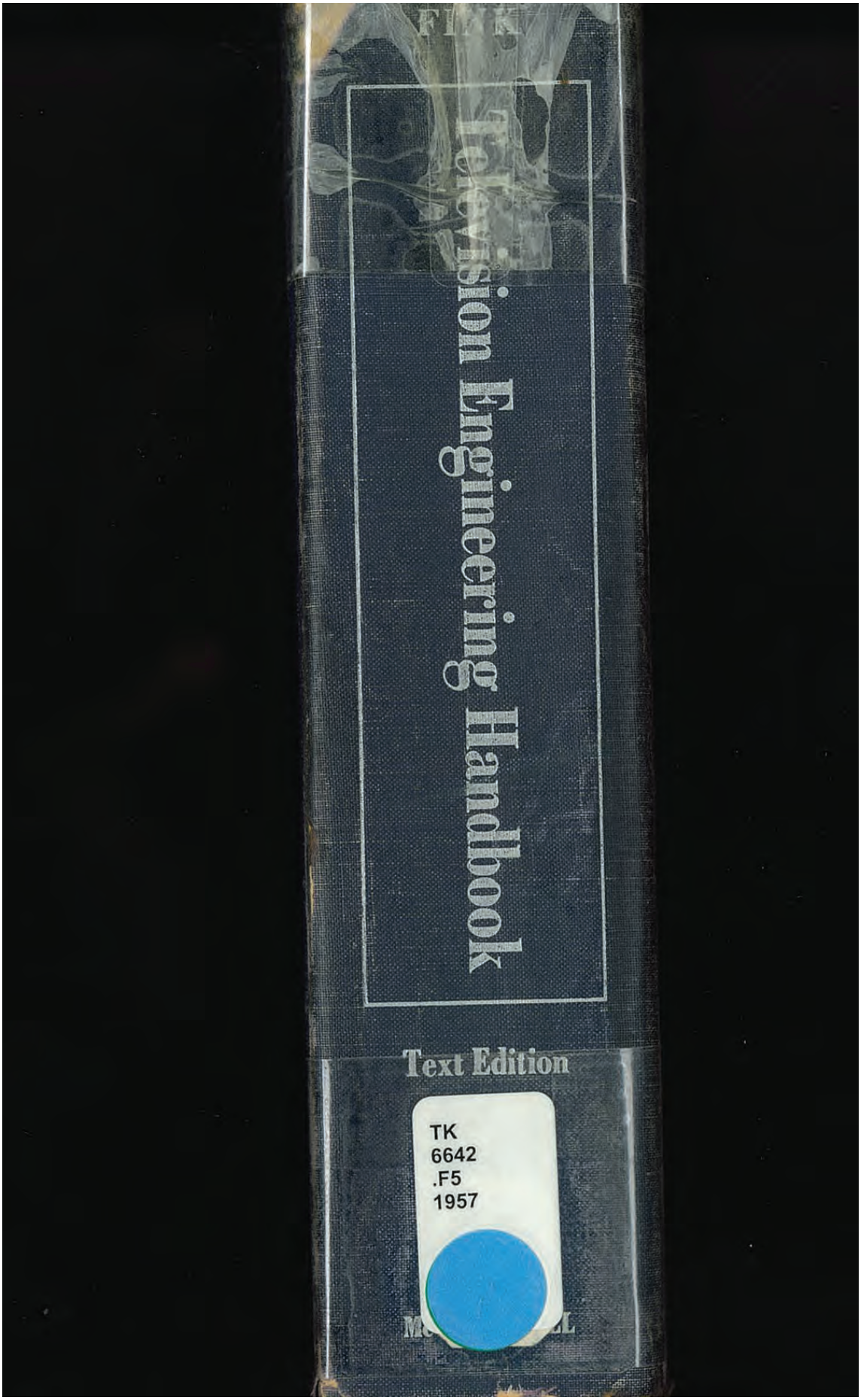
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TELEVISION ENGINEERING HANDBOOK

PREPARED BY A STAFF OF SPECIALISTS

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TELEVISION ENGINEERING HANDBOOK

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To KEITH HENNEY

For a lifetime of inspiration and guidance

92722

PREFACE

The development of the techniques of television engineering, following the establishment of the compatible color system in the United States and the extension of monochrome broadcasting throughout the world in four major systems based on different standards, has reached such a point that no individual engineer can command all of the quantitive data required to design and operate television equipment. This situation has two consequences: there is a need for a unified compilation of these data, and the compilation must be prepared by a team of specialists. The Television Engineering Handbook is intended to fill this need. It has been prepared by thirty-three experts in the twenty special fields denoted by the chapter headings.

To assure uniformity and coherence of coverage, the editor prepared initially a 125-page outline of the book, which was submitted to the contributing authors and from which they in turn have departed as their more comprehensive knowledge of particular subjects has dictated. The plan of the handbook is based on four main aims: to be as detailed and comprehensive as is possible in a single volume of manageable size (1600 pages and 1150 illustrations); to treat monochrome and color systems on a completely equal footing; to cover the systems and standards not only of the United States, but of the British, French, and European (C.C.I.R.) groups as well; and, in the particularly important field of television receivers, to provide detailed design data for every portion of typical receivers, monochrome and color, based on practice as of the time of going to press. The last objective has resulted in Chapter 16, prepared by a team of seven engineers and constituting, in its 258 pages, a textbook in itself.

In a work of this size it is inevitable that errors, omissions, and inconsistencies have occurred, and the editor would appreciate having these brought to his attention for correction in the succeeding edition. No rigorous attempt has been made to exclude duplication among chapters as this would interfere with the full development of individual topics. On this account the reader is advised to consult the index to find all of the references on a given subject.

Since the preparation of this Handbook has involved bringing together information from many scattered sources, the editor and publisher are indebted to many organizations and individuals for permission to reprint

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tabular data and illustrations. These sources are acknowledged on another page. In addition, the editor wishes to acknowledge with deep gratitude the patience and cooperation of the contributing authors and the organizations with which they are associated. Every technical expert owes much to the associates, facilities, and guidance provided by his place of work. On behalf of the authors, therefore, appreciation is hereby extended to their employers: American Broadcasting Company, American Telephone and Telegraph Company, Columbia Broadcasting System, Eastman Kodak Company, Federal Communications Commission, General Electric Company, Hazeltine Corporation, Motorola, Incorporated, Philco Corporation, Radio Corporation of America, and Sylvania Electric Products, Incorporated.

The editor's right-hand man, Mrs. Clare Romano, has been devoted and steadfast during the 40 months spent in preparing this Handbook. For handling voluminous correspondence, for typing manuscript, and for listing and collating the 4100 page references in the index, her boss is eternally grateful.

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* Research Division, Philco Corporation.

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NUMBERS, EQUATIONS, AND DEFINITIONS

1.1 INTRODUCTION

The material in this section consists of numerical constants, standards, and derived quantities, as well as symbolic relationships and definitions, of direct application to the practice of television engineering. No comprehensive compilation of mathematical and physical data has been attempted, beyond those quantities (such as the table of the sine integral) which are of particular interest to the television engineer and not generally available in the standard handbooks of electronics and radio engineering. An annotated bibliography of sources of mathematical and physical data appears in Sec. 1.6.

1.2 RADIO-FREQUENCY DATA

1.201 Designation of R-f Bands. See Table 1.1.

Table 1.1 Designation of R-f Bands

Frequency limits	Wavelength limits	FCC designation	Exponential designation*	Uses in television
Below 30 kc per sec	Above 10^4 meters	Very low frequency (vlf)	Up to band 4	Video and scanning frequencies
30–300 kc per sec	10^3–10^4 meters	Low frequency (lf)	Band 5	Video and scanning frequencies
300–3,000 kc per sec	100–1,000 meters	Medium frequency (mf)	Band 6	Video frequencies
3,000–30,000 kc per sec	10–100 meters	High frequency (hf)	Band 7	Video and intermediate frequencies
30–300 mc per sec	1–10 meters	Very high frequency (vhf)	Band 8	Intermediate frequencies and broadcast channels
300–3,000 mc per sec	10–100 cm	Ultrahigh frequency (uhf)	Band 9	Broadcast, radio relay
3,000–30,000 mc per sec	1–10 cm	Superhigh frequency (shf)	Band 10	Radio relay
30,000–300,000 mc per sec	1–10 mm	Extremely high frequency (ehf)	Band 11	Experimental

* This designation is the exponent which, when applied to the base 10, gives a frequency in cps which is approximately the geometric mean frequency of the band. *Example:* The frequency in band 6 is 10^6 = 1,000,000 cps, which is the geometric mean frequency of the band 300 to 3,000 kc per sec. Stated otherwise, band N extends from 0.3×10^N to 3×10^N cps.

1.202 Velocity of Propagation of Radio Waves in Free Space

$$
\begin{aligned}
c &= 299.76 \text{ meters per microsecond} \\
&= 983.6 \text{ ft per microsecond} \\
&= 327.9 \text{ yd per microsecond} \\
&= 0.1863 \text{ statute mile per microsecond} \\
&= 0.1618 \text{ nautical mile per microsecond}
\end{aligned}
$$

1.203 Reciprocal Velocity of Propagation.

$$
\begin{aligned}
1/c &= 0.003336 \text{ microsecond per meter} \\
&= 0.001017 \text{ microsecond per ft} \\
&= 0.003050 \text{ microsecond per yd} \\
&= 5.368 \text{ microseconds per statute mile} \\
&= 6.180 \text{ microseconds per nautical mile}
\end{aligned}
$$

1.204 Distance versus Time in Multipath Propagation. When the difference in length between one path of propagation and another is d units, the corresponding difference in propagation time is $d(1/c)$ μsec where $1/c$ is expressed in the same units of length. Values of $1/c$ are given in Sec. 1.203.

When the difference in propagation time between one propagation path and another is t μsec, the corresponding difference in length of the propagation paths is ct. Values of c for various units of length are given in Sec. 1.202.

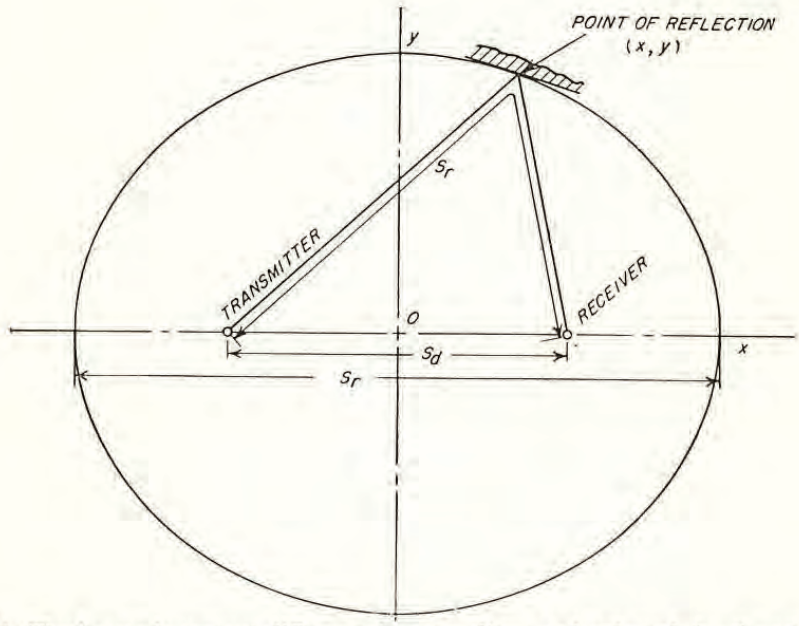


FIG. 1-1. The locus of constant difference between direct and reflected signal paths is an ellipse with foci at transmitter and receiver and major axis equal to the distance traversed by the reflected signal.

1.205 Multipath Locus. The locus of constant path difference (constant difference in distance or constant difference in propagation time) between direct and reflected signals is an ellipse, with transmitter and receiver at its foci. The expression for the ellipse is

$$\frac{4x^2}{s_r^2} + \frac{4y^2}{s_r^2 - s_d^2} = 1 \tag{1.1}$$

where x and y are the coordinates of a point on the ellipse (Fig. 1-1), s_r is the length of the reflected path, and s_d is the length of the direct path. To locate the source of a reflected signal, the ellipse may be constructed from s_d, the distance between the transmitter and receiver, and $s_r - s_d$, the difference in path length. The path difference may be determined from measurement of the displacement of the ghost image (Sec. 1.206). Computations, based on a plane earth, are of sufficient accuracy for locating reflection points when the distances are less than 100 miles.

1.206 Image Displacement Due to Multipath. The ghost image produced by a reflected signal is displaced horizontally from the primary image by

$$d = \frac{s_r - s_d}{522} \quad \text{per cent of the picture width} \tag{1.2}$$

where $s_r - s_d$ is the path-length difference (Sec. 1.205) in feet. The divisor 522 applies to the 525-line 30-frame standard, with 17.5 per cent horizontal blanking. *Example:* For a path-length difference of 1 statute mile, the displacement of the ghost image from the primary image is 5,280/522 = 10.3 per cent of the picture width.

For other scanning standards, the displacement is

$$d = \frac{s_r - s_d}{K} \quad \text{per cent of the picture width} \tag{1.3}$$

where the values of K are given in Table 1.2.

Table 1.2 Reflected Image Displacement Divisor K

Scanning standard	*Value of K*
British: 405-line 25-frame	806
European: 625-line 25-frame	525
French: 819-line 25-frame	398

1.207 United States Carrier Frequencies and Tolerances. (See also Secs. 2.501, 2.502, and 2.603.)

Standard i-f, sound: 41.25 mc per sec. Tolerance: none.

Standard i-f, picture: 45.75 mc per sec. Tolerance: none.

Standard chrominance-subcarrier frequency: 3.579545 mc per sec. Tolerance: ±0.000010 mc per sec.

Standard picture carrier frequency: The location of the picture carrier, with respect to the lower edge of the channel, for United States assignments (see Table 2.10) is

+1.25 mc per sec, for nonoffset stations. Tolerance: ±1,000 cps
+1.26 mc per sec, for plus offset stations. Tolerance: ±1,000 cps
+1.24 mc per sec, for minus offset stations. Tolerance: ±1,000 cps

Standard sound carrier frequency: The standard location of the sound carrier, with respect to the lower edge of the channel, for United States assignments (see Table 2.10) is

+5.75 mc per sec, for nonoffset stations. Tolerance: ±4,000 cps (monochrome), ±1,000 cps (color)
+5.76 mc per sec, for plus offset stations. Tolerance: ±4,000 cps (monochrome), ±1,000 cps (color)
+5.74 mc per sec, for minus offset stations. Tolerance: ±4,000 cps (monochrome), ±1,000 cps (color)

Standard intercarrier frequency: The separation between picture and sound carriers in all classes of United States stations is 4.500 mc per sec. Tolerance: ±5,000 cps (monochrome), ±1,000 cps (color).

1.208 Beat Frequencies. *Intrachannel Beat Frequencies.* The nominal values of beat frequencies within each television channel are:

Picture-sound beat frequency: 4.500000 mc per sec ±5,000 cps (monochrome), ±1,000 cps (color)
Picture-chrominance beat frequency: 3.579545 mc per sec ±10 cps
Sound-chrominance beat frequency: 0.920455 mc per sec ±1,010 cps

Interchannel Beat Frequencies. The nominal values of beat frequencies between carrier in the desired channel and those in the upper and lower adjacent channels are

given in Table 1.3. The tolerances given apply when the desired and interfering stations are offset in like fashion (both stations nonoffset, plus offset, or minus offset). If the stations are offset in unlike fashion, the variation in the beats may be as great as ±0.02 mc per sec.

Table 1.3 Beats Between Carriers in Adjacent Channels
(Megacycles per second)

Desired channel	Upper adjacent channel			Lower adjacent channel		
	Picture	Sound	Chrominance	Picture	Sound	Chrominance
Picture.....	6.00 ± 0.002	10.50 ± 0.002	9.58 ± 0.001	6.00 ± 0.002	1.50 ± 0.002	2.42 ± 0.001
Sound.....	1.50 ± 0.002	6.00 ± 0.002	5.08 ± 0.001	10.50 ± 0.002	6.00 ± 0.002	6.92 ± 0.001
Chrominance .	2.42 ± 0.002	6.92 ± 0.002	6.00 ± 0.001	9.58 ± 0.002	5.08 ± 0.002	6.00 ± 0.001

1.209 I-f Rejection Frequencies. The signal frequencies to be attenuated in picture i-f amplifiers using the standard intermediate frequencies (41.25 and 45.75 mc per sec) are:

Associated sound.....41.25 mc per sec
Associated chrominance.....42.17 mc per sec (attenuated in luminance channel only)
Upper adjacent picture.....39.75 mc per sec
Upper adjacent sound.....35.25 mc per sec
Upper adjacent chrominance.....36.17 mc per sec
Lower adjacent picture.....51.75 mc per sec
Lower adjacent sound.....47.25 mc per sec
Lower adjacent chrominance.....48.17 mc per sec

Tuned traps are required for the interfering signals within the desired channel (41.25 and 42.17 mc per sec) and the proximate signals in the adjacent channels (47.25 and 39.75 mc per sec). The remaining signals are, in most cases, so attenuated by the interstage coupling circuits that additional traps are not necessary.

1.210 Local Oscillator Frequencies. The United States standard intermediate frequencies imply a local oscillator frequency located 47 mc per sec above the lower limit of the desired channel, 41 mc per sec above its upper limit.

1.211 Sound Image Frequencies. Interference to the sound system of a television receiver can occur from image responses. The principal responses of a receiver employing the standard intermediate frequencies are:

First-order Sound Image (+). This response is located above the desired sound carrier by 82.5 mc per sec (twice the sound i-f).

Second-order Sound Image (−). This response is located 41.25 mc per sec below twice the local oscillator frequency for the desired channel.

The bandwidth of the image response in each case is equal to the effective bandwidth of the sound i-f system. This is typically ±200 kc per sec.

1.212 Picture Image Frequencies. Interference to the picture system of a television receiver, due to image responses, can occur over a bandwidth equal to the effective bandwidth of the picture i-f amplifier, typically 4.5 mc per sec. When the standard intermediate frequencies are used, the principal picture image responses are:

First-order Picture Image (+). This response is located in the region from 82.75 to 87.25 mc per sec above the upper edge of the desired channel.

Second-order Picture Image (−). This image is located in the region from 41.75 to 46.25 mc per sec below twice the local oscillator frequency for the desired channel.

1.213 Frequencies Associated with United States Television Channels. See Table 1.4.

Table 1.4 Frequencies Associated with Television Channels in the United States
(Megacycles per second)

Channel number	Frequency limits	Picture carrier[a]	Sound carrier[b]	Chrominance subcarrier[c]	Local oscillator[d]	First-order sound image (+)[d,e]	Second-order sound image (−)[f,i]	First-order picture image (+)[d,g]	Second-order picture image (−)[h,i]
2	54–60	55.25	59.75	58.829545	101.00	142.25	160.75	142.75–147.25	155.75–160.25
3	60–66	61.25	65.75	64.829545	107.00	148.25	172.75	148.75–153.25	167.75–172.25
4	66–72	67.25	71.75	70.829545	113.00	154.25	184.75	154.75–159.25	179.75–184.25
5	76–82	77.25	81.75	80.829545	123.00	164.25	204.75	164.75–169.25	199.75–204.25
6	82–88	83.25	87.75	86.829545	129.00	170.25	216.75	170.75–175.25	211.75–216.25
7	174–180	175.25	179.75	178.829545	221.00	262.25	401.75	262.75–267.25	396.75–401.25
8	180–186	181.25	185.75	184.829545	227.00	268.25	413.75	268.75–273.25	408.75–413.25
9	186–192	187.25	191.75	190.829545	233.00	274.25	425.75	274.75–279.25	420.75–425.25
10	192–198	193.25	197.75	196.829545	239.00	280.25	437.75	280.75–285.25	432.75–437.25
11	198–204	199.25	203.75	202.829545	245.00	286.25	449.75	286.75–291.25	444.75–449.25
12	204–210	205.25	209.75	208.829545	251.00	292.52	461.75	292.75–297.25	456.75–461.25
13	210–216	211.25	215.75	214.829545	257.00	298.25	473.75	298.75–303.25	468.75–473.25
14	470–476	471.25	475.75	474.829545	517.00	558.25	992.75	558.75–563.25	987.75–992.25
15	476–482	477.25	481.75	480.829545	523.00	564.25	1,004.75	564.75–569.25	999.75–1,004.25
16	482–488	483.25	487.75	486.829545	529.00	570.25	1,016.75	570.75–575.25	1,011.75–1,016.25
17	488–494	489.25	493.75	492.829545	535.00	576.25	1,028.75	576.75–581.25	1,023.75–1,028.25
18	494–500	495.25	499.75	498.829545	541.00	582.25	1,040.75	582.75–587.25	1,035.75–1,040.25
19	500–506	501.25	505.75	504.829545	547.00	588.25	1,052.75	588.75–593.25	1,047.75–1,052.25
20	506–512	507.25	511.75	510.829545	553.00	594.25	1,064.75	594.75–599.25	1,059.75–1,064.25
21	512–518	513.25	517.75	516.829545	559.00	600.25	1,076.75	600.75–605.25	1,071.75–1,076.25
22	518–524	519.25	523.75	522.829545	565.00	606.25	1,088.75	606.75–611.25	1,083.75–1,088.25
23	524–530	525.25	529.75	528.829545	571.00	612.25	1,100.75	612.75–617.25	1,095.75–1,100.25
24	530–536	531.25	535.75	534.829545	577.00	618.25	1,112.75	618.75–623.25	1,107.75–1,112.25
25	536–542	537.25	541.75	540.829545	583.00	624.25	1,124.75	624.75–629.25	1,119.75–1,124.25
26	542–548	543.25	547.75	546.829545	589.00	630.25	1,136.75	630.75–635.25	1,131.75–1,136.25
27	548–554	549.25	553.75	552.829545	595.00	636.25	1,148.75	636.75–641.25	1,143.75–1,148.25
28	554–560	555.25	559.75	558.829545	601.00	642.25	1,160.75	642.75–647.25	1,115.75–1,160.25
29	560–566	561.25	565.75	564.829545	607.00	648.25	1,172.75	648.75–653.25	1,167.75–1,172.25
30	566–572	567.25	571.75	570.829545	613.00	654.25	1,184.75	654.75–659.25	1,179.75–1,184.25
31	572–578	573.25	577.75	576.829545	619.00	660.25	1,196.75	660.75–665.25	1,191.75–1,196.25
32	578–584	579.25	583.75	582.829545	625.00	666.25	1,208.75	666.75–671.25	1,203.75–1,208.25
33	584–590	585.25	589.75	588.829545	631.00	672.25	1,220.75	672.75–677.25	1,215.75–1,220.25
34	590–596	591.25	595.75	594.829545	637.00	678.25	1,232.75	678.75–683.25	1,227.75–1,232.25
35	596–602	597.25	601.75	600.829545	643.00	684.25	1,244.75	684.75–689.25	1,239.75–1,244.25
36	602–608	603.25	607.75	606.829545	649.00	690.25	1,256.75	690.75–695.25	1,251.75–1,256.25
37	608–614	609.25	613.75	612.829545	655.00	696.25	1,268.75	696.75–701.25	1,263.75–1,268.25
38	614–620	615.25	619.75	618.829545	661.00	702.25	1,280.75	702.75–707.25	1,275.75–1,280.25
39	620–626	621.25	625.75	624.829545	667.00	708.25	1,292.75	708.75–713.25	1,287.75–1,292.25
40	626–632	627.25	631.75	630.829545	673.00	714.25	1,304.75	714.75–719.25	1,299.75–1,304.25
41	632–638	633.25	637.75	636.829545	679.00	720.25	1,316.75	720.75–725.25	1,311.75–1,316.25
42	638–644	639.25	643.75	642.829545	685.00	726.25	1,328.75	726.75–731.25	1,323.75–1,328.25
43	644–650	645.25	649.75	648.829545	691.00	732.25	1,340.75	732.75–737.25	1,335.75–1,340.25
44	650–656	651.25	655.75	654.829545	697.00	738.25	1,352.75	738.75–743.25	1,347.75–1,352.25
45	656–662	657.25	661.75	660.829545	703.00	744.25	1,364.75	744.75–749.25	1,359.75–1,364.25
46	662–668	663.25	667.75	666.829545	709.00	750.25	1,376.75	750.75–755.25	1,371.75–1,376.25
47	668–674	669.25	673.75	672.829545	715.00	756.25	1,388.75	756.75–761.25	1,383.75–1,388.25
48	674–680	675.25	679.75	678.829545	721.00	762.25	1,400.75	762.75–767.25	1,395.75–1,400.25
49	680–686	681.25	685.75	684.829545	727.00	768.25	1,412.75	768.75–773.25	1,407.75–1,412.25
50	686–692	687.25	691.75	690.829545	733.00	774.25	1,424.75	774.75–779.25	1,419.75–1,424.25
51	692–698	693.25	697.75	696.829545	739.00	780.25	1,436.75	780.75–785.25	1,431.75–1,436.25
52	698–704	699.25	703.75	702.829545	745.00	786.25	1,448.75	786.75–791.25	1,443.75–1,448.25
53	704–710	705.25	709.75	708.829545	751.00	792.25	1,460.75	792.75–797.25	1,455.75–1,460.25
54	710–716	711.25	715.75	714.829545	757.00	798.25	1,472.75	798.75–803.25	1,467.75–1,472.25
55	716–722	717.25	721.75	720.829545	763.00	704.25	1,484.75	804.75–809.25	1,479.75–1,484.25

[a] The figures tabulated are for nonoffset assignments. Certain stations are assigned picture carrier frequencies higher or lower than the tabulated figures by 0.01 mc per sec. See Table 2.10, Chap. 2, for the locations of such offset assignments. *Example:* The plus offset picture carrier frequency for channel 2 is 55.26 mc per sec; the minus offset picture carrier frequency for channel 2 is 55.24 mc per sec. The tolerance on the assigned picture carrier frequency is ±1,000 cps.

Table 1.4 Frequencies Associated with Television Channels in the United States (*Continued*)

Channel number	Frequency limits	Picture carrier[a]	Sound carrier[b]	Chrominance subcarrier[c]	Local oscillator[d]	First-order sound image (+)[d,e]	Second-order sound image (−)[f,i]	First-order picture image (+)[d,g]	Second-order picture image (−)[h,i]
56	722–728	723.25	727.75	726.829545	769.00	810.25	1,496.75	810.75–815.25	1,491.75–1,496.25
57	728–734	729.25	733.75	732.829545	775.00	816.25	1,508.75	816.75–821.25	1,503.75–1,508.25
58	734–740	735.25	739.75	738.829545	781.00	822.25	1,520.75	822.75–827.25	1,515.75–1,520.25
59	740–746	741.25	745.75	744.829545	787.00	828.25	1,532.75	828.75–833.25	1,527.75–1,532.25
60	746–752	747.25	751.75	750.829545	793.00	834.25	1,544.75	834.75–839.25	1,539.75–1,544.25
61	752–758	753.25	757.75	756.829545	799.00	840.25	1,556.75	840.75–845.25	1,551.75–1,556.25
62	758–764	759.25	763.75	762.829545	805.00	846.25	1,568.75	846.75–851.25	1,563.75–1,568.25
63	764–770	765.25	769.75	768.829545	811.00	852.25	1,580.75	852.75–857.25	1,575.75–1,580.25
64	770–776	771.25	775.75	774.829545	817.00	858.25	1,592.75	858.75–863.25	1,587.75–1,592.25
65	776–782	775.25	781.75	780.829545	823.00	864.25	1,604.75	864.75–869.25	1,599.75–1,604.25
66	782–788	783.25	787.75	786.829545	829.00	870.25	1,616.75	870.75–875.25	1,611.75–1,616.25
67	788–794	789.25	793.75	792.829545	835.00	876.25	1,628.75	876.75–881.25	1,623.75–1,628.25
68	794–800	795.25	799.75	798.829545	841.00	882.25	1,640.75	882.75–887.25	1,635.75–1,640.25
69	800–806	810.25	805.75	804.829545	847.00	888.25	1,652.75	888.75–893.25	1,647.75–1,652.25
70	806–812	807.25	811.75	810.829545	853.00	894.25	1,664.75	894.75–899.25	1,659.75–1,664.25
71	812–818	813.25	817.75	816.829545	859.00	900.25	1,676.75	900.75–905.25	1,671.75–1,676.25
72	818–824	819.25	823.75	822.829545	865.00	906.25	1,688.75	906.75–911.25	1,683.75–1,688.25
73	824–830	825.25	829.75	828.829545	871.00	912.25	1,700.75	912.75–917.25	1,695.75–1,700.25
74	830–836	831.25	835.75	834.829545	877.00	918.25	1,712.75	918.75–923.25	1,707.75–1,712.25
75	836–842	837.25	841.75	840.829545	883.00	924.25	1,724.75	924.75–929.25	1,719.75–1,724.25
76	842–848	843.25	847.75	846.829545	889.00	930.25	1,736.75	930.75–935.25	1,731.75–1,736.25
77	848–854	849.25	853.75	852.829545	895.00	936.25	1,748.75	936.75–941.25	1,743.75–1,748.25
78	854–860	855.25	859.75	858.829545	901.00	942.25	1,760.75	942.75–947.25	1,755.75–1,760.25
79	860–866	861.25	865.75	864.829545	907.00	948.25	1,772.75	948.75–953.25	1,767.75–1,772.25
80	866–872	867.25	871.75	870.829545	913.00	954.25	1,784.75	954.75–959.25	1,779.75–1,784.25
81	872–878	873.25	877.75	876.829545	919.00	960.25	1,796.75	960.75–965.25	1,791.75–1,796.25
82	878–884	879.25	883.75	882.829545	925.00	966.25	1,808.75	966.75–971.25	1,803.75–1,808.25
83	884–890	885.25	889.75	888.829545	931.00	972.25	1,820.75	972.75–977.25	1,815.75–1,820.25

[b] The figures tabulated are for nonoffset assignments. See Table 2.10, Chap. 2. For plus offset assignments, add 0.01 mc per sec. For minus offset assignments, subtract 0.01 mc per sec. The tolerance on the sound carrier is ±4,000 cps for monochrome transmissions, ±1,000 cps for color transmissions. The tolerance on the sound-picture intercarrier frequency is ±5,000 cps for monochrome transmissions, ±1,000 cps for color transmissions.

[c] The figures tabulated are for nonoffset assignments. The chrominance-subcarrier frequency is located 3.579545 mc per sec above the picture-carrier frequency actually in use, with a tolerance of ±0.000010 mc per sec. See Table 2.10, Chap. 2, for offset assignments. For plus offset assignments, add 0.010000 mc per sec to the tabulated figures; for minus offset assignments, subtract 0.010000 mc per sec.

[d] The frequencies tabulated are for the standard intermediate frequencies, 41.25 mc per sec for sound and 45.75 mc per sec for picture, with the local oscillator frequency above the desired channel. For plus offset assignments, add 0.01 mc per sec; for minus offset assignments, subtract 0.01 mc per sec.

[e] The frequencies tabulated are those to which the sound system of the receiver is sensitive, due to beats between the fundamental of the local oscillator and interfering signals higher in frequency than the local oscillator frequency. The bandwidth of the image response is about ±200 kc per sec in typical receivers.

[f] The frequencies tabulated are those to which the sound system of the receiver is sensitive, due to beats between the second harmonic of the local oscillator and interfering signals lower in frequency than the second harmonic of the local oscillator. The bandwidth of the image response is typically ±200 kc per sec.

[g] The frequencies tabulated indicate the limits of the image response of the picture system of the receiver, due to beats between the fundamental of the local oscillator and interfering signals higher in frequency than the local oscillator. A picture i-f bandwidth of 4.5 mc per sec (41.75 to 46.25) is assumed.

[h] The frequencies tabulated are the limits of the image response of the picture system of the receiver, due to beats between the second harmonic of the local oscillator and interfering signals lower in frequency than the second harmonic of the local oscillator. A picture bandwidth of 4.5 mc per sec (41.75 to 46.25) is assumed.

[i] For plus offset assignments, add 0.02 mc per sec; for minus offset assignments, subtract 0.02 mc per sec.

1.214 Principal Interfering Services. Major sources of interference to television service in the United States are listed in Table 1.5.

Table 1.5 Principal Services Causing Interference to Television

Interfering service	Interfering frequencies, mc per sec	Type of interference
Amateur	1.8–2.0	Transmitter harmonics
	3.5–4.0	Transmitter harmonics
	7.0–7.3	Transmitter harmonics
	14.00–14.35	Transmitter harmonics
	21.00–21.45	Transmitter harmonics; direct i-f*
	26.96–29.7	Transmitter harmonics
	50.0–54.0	Transmitter harmonics; adjacent to channel 2
	144–148	Transmitter harmonics
	220–225	Transmitter harmonics
	420–450	Transmitter harmonics
	1,215–1,300	Second-order images (−)
Citizen radio	460–470	Adjacent to channel 14
F-m broadcast	88–108 (100–200 kc-per-sec channels)	Adjacent to channel 6; transmitter harmonics; first-order picture images*
Public safety (police, fire, etc.)	33.42–33.98	Transmitter harmonics
	37.02–37.42	Transmitter harmonics
	37.90–37.98	Transmitter harmonics
	39.02–39.98	Transmitter harmonics
	42.02–42.94	Direct i-f pickup; harmonics
	44.62–47.66	Direct i-f pickup; harmonics
	153.77–154.43	First-order images (+)
	154.65–156.21	First-order images (+)
	158.73–159.21	First-order images (+)
Industrial scientific, medical (diathermy, induction heating, etc.)	27.12	Harmonics
	40.66–40.70	Harmonics

* For receivers employing 21 and 26 mc per sec intermediate frequencies only.

1.3 VIDEO-FREQUENCY DATA

1.301 Video Signal Spectrum. (See also Chap. 10.) The spectrum of the video signal, arising from the scanning process in a television camera, extends from a lower-frequency limit determined by the time rate of change of average luminance of the scene to an upper limit determined by the rate at which the scanning spot crosses the sharpest vertical boundary between the dark and light areas present in the scene, as focused within the camera. The distribution of spectrum components within these limits depends on the scanning constants (distribution of energy in the camera scanning spot, number of lines scanned per second, percentage of horizontal blanking, and number of fields scanned per second; see Sec. 1.302) and the rates at which the luminances and chrominances of the scene change in size, position, and boundary sharpness. To the extent that the contents of the scene and the changes therein cannot be predicted, the limits and energy distribution of the video spectrum are indefinite. However, the spectra corresponding to certain static scene configurations are uniquely determined by the scanning constants and these spectra are commonly

used as the basis of television system design. Among the configurations of interest (Fig. 1-2) are a scene of uniform luminance and chrominance ("flat field") and scenes divided into two or more segments of different luminance by sharp vertical, horizontal, or oblique boundaries, including as special cases the horizontal and vertical resolution wedges of test charts. The image reproductions of such scene configurations generally display diffuse boundaries and other degradations which indicate the distortions introduced by the camera scanning spot, the responses of the transmission system, and the

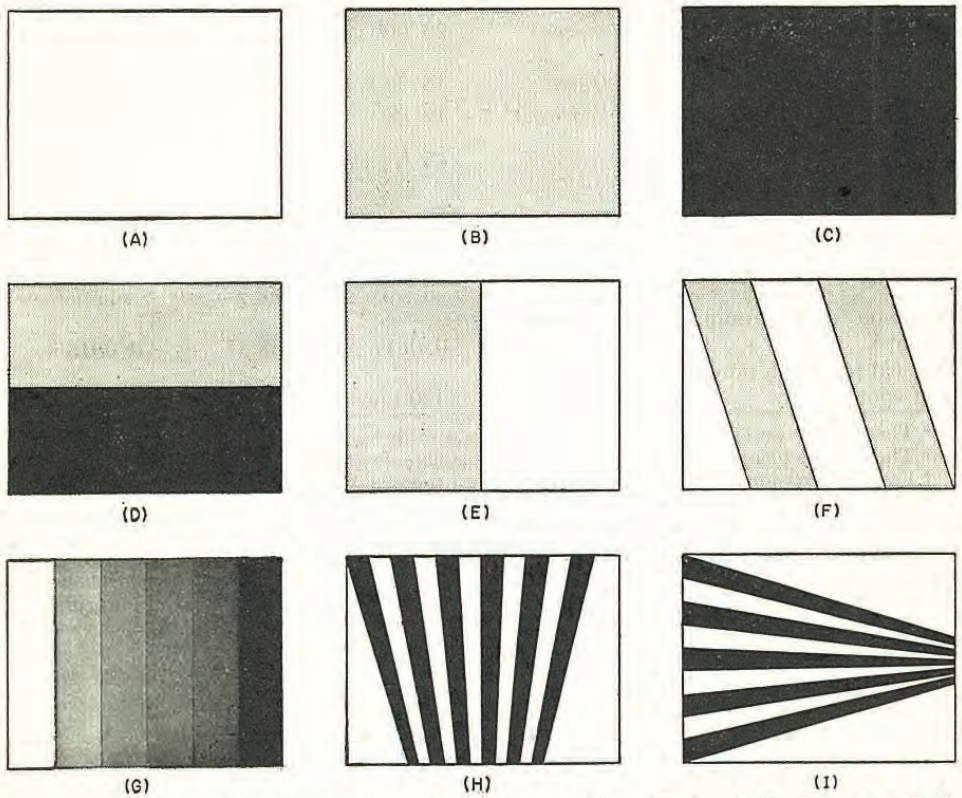


FIG. 1-2. Scanning patterns of interest in analyzing video signals: *A*, *B*, *C* are flat fields used in determining color purity, large area contrast, and transfer gradients; *D* is a horizontal half-field pattern for measuring low-frequency performance; *E* is vertical half field of interest in examining high-frequency transient performance; *F* displays oblique bars (see also patterns in Fig. 1-5); *G* is a tonal step wedge useful in contrast and transfer characteristic measurements; *H* and *I* are resolution wedges.

receiver scanning spot. The upper frequency limit of the video spectrum actually employed in reproducing a particular image is usually determined by the amplitude-versus-frequency and phase-versus-frequency responses of the receiver in use. These responses are selected as an economic compromise between the subjective sharpness demanded by the user of the receiver on the one hand, and the effects of interference and noise on the other. Video spectrum limits and energy distributions of interest in the design of television systems are specified in Secs. 1.303, 1.304, 1.305, and 1.307.

1.302 Scanning Constants. The constants which determine the video spectrum arising from scanning a scene are given in Table 1.6.

1.303 Minimum Video Frequency. To reproduce a uniform value of luminance from top to bottom of an image scanned in the conventional interlaced pattern, the video signal spectrum must extend downward to include the field-scanning frequency (Table 1.6). This frequency represents the lower limit of the spectrum arising from

Table 1.6 Scanning Constants of the Principal Television Systems*

Scanning constant	American system†	European system	British system	French system
Frame frequency	30(29.97) cps	25 cps	25 cps	25 cps
Frame period	33,333 μsec	40,000 μsec	40,000 μsec	40,000 μsec
Active frame period (nominal blanking)	31,000 μsec	37,000 μsec	37,000 μsec	36,000 μsec
Field frequency	60(59.94) cps	50 cps	50 cps	50 cps
Field period	16,667 μsec	20,000 μsec	20,000 μsec	20,000 μsec
Active field period (nominal blanking)	15,500 μsec	18,500 μsec	18,500 μsec	18,000 μsec
Line frequency	15,750 (15,734+) cps	15,625 cps	10,125 cps	20,475 cps
Line period	63.5 μsec	64.0 μsec	98.8 μsec	48.8 μsec
Active line period (nominal blanking)	53.0 μsec	53.4 μsec	82.0 μsec	40.5 μsec
Horizontal resolution factor‡	80 lines per mc per sec	80 lines per mc per sec	123 lines per mc per sec	61 lines per mc per sec
Diameter of scanning spot¶	0.0021	0.0017	0.0027	0.00135
Vertical resolving power of spot§	340 lines	420 lines	270 lines	525 lines

* The system designations refer to those listed in detail in Chap. 2, Table 2.1.

† The figures in parentheses apply to compatible color transmissions.

‡ For a discussion of the horizontal resolution factor, see Sec. 1.306.

¶ The spot diameter is expressed as a fraction of the picture height, and is equal to the reciprocal of the number of active lines per frame (Table 2.1). In a stationary scanning spot having a Gaussian (error-function) distribution of energy, the spot diameter may be taken as the width of a rectangle having the same height and the same area as that under the error curve, neglecting the ordinates smaller than 1 per cent of the maximum ordinate. This rectangle (Fig. 1-3) intersects the error curve at about half (actually 45.6 per cent) of the maximum ordinate.

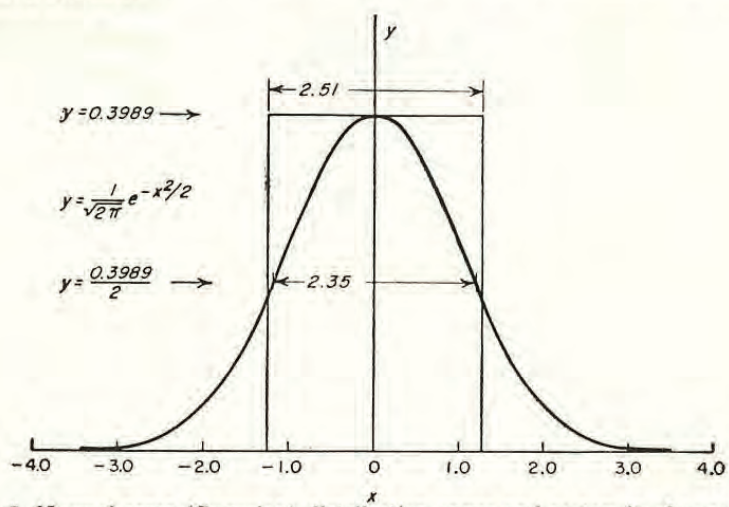


FIG. 1-3. Normal error (Gaussian) distribution curve and rectangle of equal area.

§ The vertical resolving power of the scanning spot is less than the inverse of the spot diameter¶ since the scanning lines have fixed ("quantized") positions with respect to the image detail. The resolving power is commonly taken as 71 per cent of the reciprocal of the spot diameter.

scanning a scene whose average luminance does not change.* Changes in the average luminance are reproduced by extending the video spectrum to a lower frequency equal to the reciprocal of the duration of the luminance change. Since a given average luminance change may persist for many minutes, the spectrum extends sensibly to zero frequency (d-c component, see Sec. 1.304). The technique of preserving or restoring the d-c component is employed to extend the spectrum from the field frequency downward to zero frequency.

1.304 D-c Component. It is customary, in radiating the picture signal, to maintain constant the carrier envelope level corresponding to black (zero luminance), irrespective of the average luminance of the scene. The corresponding level in the video signal, as applied to the control electrode of the picture tube, can be held constant by conductive coupling of the amplifiers following the second detector, or, more commonly, by restoring the constancy of this level through peak detection at the control electrode. In images so reproduced the average illumination of the image bears a direct correspondence to the average illumination of the televised scene. The time constant of the d-c restoring system may be designed to be either long or short compared with the line-scanning period (Table 1.6). When peak detection of the sync pulses is used to establish the black level, the time constant is long (see Chap. 16); when a clamp circuit is used (Chap. 19), it rapidly brings the black level of each line to the desired constant value, irrespective of prior disturbances to the black level. Since each line scan is thereby reproduced with correct average brightness, it follows that any number of successive line scans, no matter how great, has the correct average value and the video spectrum is thus effectively extended to zero frequency. The peak detector system is subject to overload, from which it recovers slowly, when subjected to strong impulse noise; the clamp circuit is free of this difficulty but is generally considered too elaborate for use in domestic receivers. Direct-current restoration is, in fact, often omitted in receivers to save cost and to obviate errors in the d-c component present at the studio or introduced by the effects of impulse noise on the restorer circuit. In such receivers, the image maintains a fixed average illumination determined only by the setting of the brightness control. The minimum video frequency then utilized is the field frequency (60 cps in the United States).

1.305 Maximum Video Frequency Three values of maximum video frequency should be distinguished: (1) the *maximum camera frequency* generated by the camera, (2) the *maximum modulating frequency* corresponding to the fully transmitted radiated sideband, and (3) the *maximum receiver video frequency* present at the picture-tube control electrode.

The *maximum camera frequency* is determined by the size and current distribution of the camera scanning spot (Table 1.6), and the time the spot takes to move over the sharpest vertical boundary in the scene as focused on the scanned surface of the camera. The resulting transient video signal current is represented by the convolution integral of the spot distribution and the brightness distribution of the boundary, both measured along the scanning line (Fig. 1-4). The spectrum of the video signal transient includes significant amplitudes up to the frequency equal to the inverse of the time of rise of the resultant transient. Higher frequencies are also present but have a small effect on the shape of the reproduced transient, after transmission of the video signal. Television cameras and scanners are usually designed to generate maximum camera frequencies approximately twice as great as the maximum modulating frequency (see below), typically 6 to 8 mc per sec.

The *maximum modulating frequency* is determined by the extent of the television channel reserved for the fully transmitted picture sideband (see Chap. 2, Modulation

* An exception occurs when the luminance of the scanning lines oscillates between two values on successive scannings of each line. The average luminance then does not change when averaged over many fields, but it does change between successive pairs of field scans; that is, there is a 30-cps component present in the video signal. This type of scanning was employed in the *color-phase-alternation* (c-p-a) technique tested during the development of the NTSC compatible color system, but was later abandoned because of the 30-cps flicker it introduced at vertical boundaries between areas of unlike chrominance (see Chap. 9).

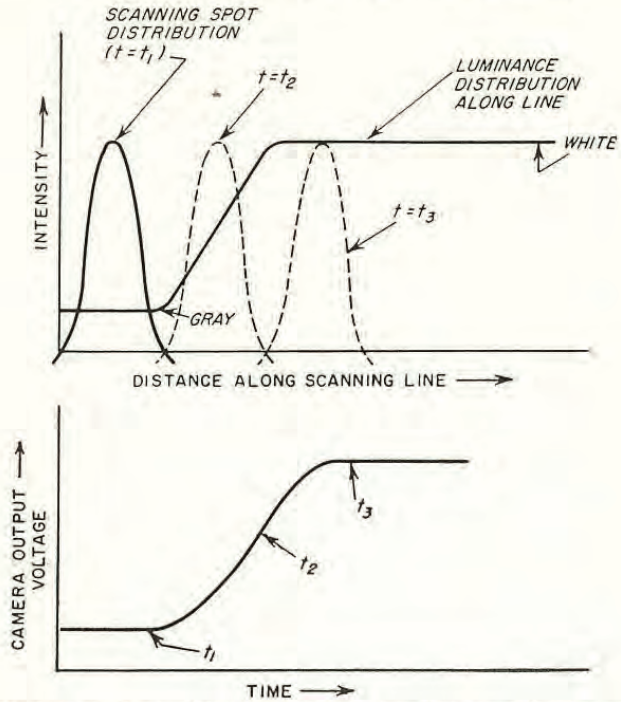


FIG. 1-4. Scanning spot (Gaussian distribution) passing over luminance boundary on scanning line. Convolution of spot and luminance distributions produces camera voltage shown below.

Standards and Channel Standards, Tables 2.3 and 2.7). The channel width in turn is chosen to provide a value of horizontal resolution (see Horizontal Resolution Factor, Sec. 1.306) approximately equal to the vertical resolution implicit in the scanning pattern (Table 1.6). The maximum modulation frequencies of the principal systems are given in Table 1.7.

Table 1.7 Maximum Modulating Video Frequencies

	American system	European system	British system	French system
Standard maximum modulating frequency	4 mc per sec	5 mc per sec	3 mc per sec	10.4 mc per sec
Maximum horizontal resolution	320 lines	400 lines	370 lines	635 lines
Ratio of horizontal resolution to vertical resolution	0.94	0.95	1.70	1.21
Modulating frequency for unity resolution ratio	4.25 mc per sec	5.28 mc per sec	1.77 mc per sec	8.6 mc per sec

The *maximum receiver video frequency* (as applied to the picture tube) depends on the bandwidth of the picture i-f amplifier, picture second detector, and video amplifier. The value selected as an economic compromise in American design practice is approxi-

mately 1 mc per sec less than the transmitter maximum modulating frequency (Table 1.7), that is, about 3 mc per sec. The attainable horizontal resolution is reduced proportionately below the value given in Table 1.7.

1.306 Horizontal Resolution Factor. The horizontal resolution factor (Table 1.6) is the proportionality factor between horizontal resolution and video frequency. When expressed in lines per megacycle per second, this factor is numerically equal to three-halves the active line period in microseconds (e.g., $\frac{3}{2} \times 53 = 80$ lines per mc per sec for the American standard; see Table 1.6). The three-halves factor represents the number of lines of horizontal resolution per cycle of the video waveform (2), divided by the aspect ratio ($\frac{4}{3}$). See also Sec. 2.303.

1.307 Resolution of Chrominance Information. The FCC standards specifying the chrominance signal in compatible color transmissions (for definition of chrominance signal, see Sec. 2.305) state that the Q signal shall be attenuated, prior to modulation, less than 6 db at 500 kc per sec, and the I signal less than 2 db at 1.3 mc per sec. Since the chrominance signals arise from the same scanning process as the luminance (monochrome) signal, the scanning constants of Table 1.6 apply to these signals. Table 1.8 gives the maximum horizontal resolution attainable in the three types of color reproduction of the compatible system, in terms of the corresponding maximum video frequencies. The vertical resolution applicable to the three types of reproduction is that implied by the scanning pattern.

Table 1.8. Resolution of Components in Color Reproduction
(NTSC compatible system)

Type of color reproduction	Maximum video frequency, mc per sec	Maximum horizontal resolution, lines	Maximum vertical resolution, lines
Monochrome (Y signal only)	4	320	340
Orange-cyan (Y signal plus I signal)	1.5*	120	340
Red-green-blue (Y signal plus I signal plus Q signal)	0.5	40	340

* The standard specifies attenuation of the I signal less than 2 db at 1.3 mc per sec; the 6-db attenuation point, to match the standard of the Q signal, is taken as 1.5 mc per sec.

1.308 Video Frequencies Arising from Scanning. The signal spectrum arising from scanning (Mertz and Gray,[1,2,*]) comprises a number of discrete components at multiples of the scanning frequencies (Table 1.6). Each spectrum component is identified by two numbers m and n, which describe the pattern that would be produced if that component alone were present in the signal. The value of m represents the number of sinusoidal cycles of brightness measured horizontally (in the width of the picture) and n the number of cycles measured vertically (in the picture height). The 0,0 pattern is the d-c component of the signal, the 0,1 pattern is produced by the field-scanning frequency, and the 1,0 pattern by the line-scanning frequency. Typical patterns for various values of m and n are shown in Fig. 1-5. By combining a number of such patterns (including m and n values up to several hundred) in the appropriate amplitudes and phases, any image capable of being represented by the scanning pattern may be built up. This is a two-dimensional form of the Fourier series.

The amplitudes of the spectrum components decrease as the values of m and n increase. Since m represents the order of the harmonic of the line-scanning frequency, the corresponding amplitudes are those in the spectrum of the left-to-right variation in brightness in the image. The spectra of various brightness distributions are given in Sec. 1.310. A typical spectrum resulting from scanning a static scene is shown in

* Superscript numbers refer to References at end of chapter.

Fig. 1-6. The components of major amplitude are the d-c component, the field-frequency component, and the components at the line frequency and its harmonics. Surrounding each line-frequency harmonic is a cluster of components, separated at intervals equal to the field-scanning frequency.

It is possible for the clusters surrounding adjacent line-frequency harmonics to overlap each other; this corresponds to two patterns in Fig. 1-5 situated on adjacent vertical columns, which produce the same value of video frequency when scanned. Such "intercomponent" confusion of spectral energy is a fundamental defect of the scanning process. Its effects are visible when a heavily striated object (such as a fabric having a heavily accented weave) is scanned with the striations nearly parallel to the scanning lines.

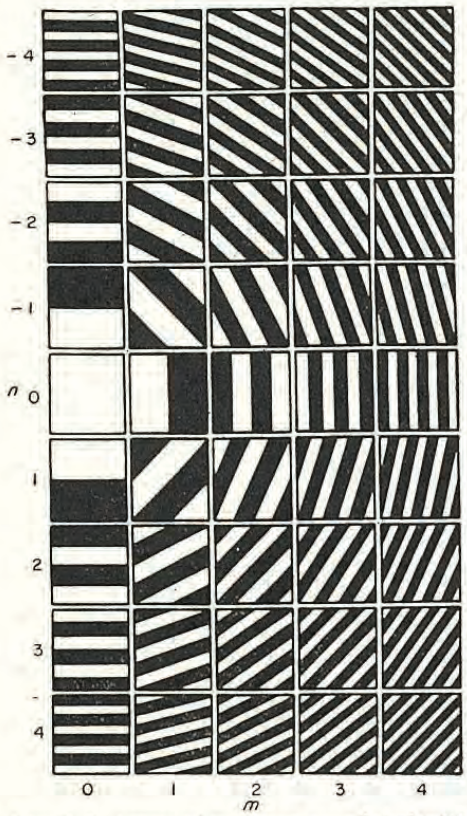


Fig. 1-5. Array of patterns associated with indicated values of m and n. (*After Mertz.*)

In static or slowly moving subjects, the clusters surrounding each line-frequency harmonic are compact, seldom extending further than $\pm 1{,}200$ cps (= 20th harmonic of the field frequency) from the line-frequency harmonic. The remaining space in the spectrum is unoccupied, and may be used by other signals having a spectrum distribution appropriate to fill in the gaps (see Sec. 1.309). When the scene contains rapid motion the spectrum becomes more diffuse, since the successive scanning patterns, and their spectra, are unlike. Stated otherwise, the signal components of the spectrum are then modulated and develop sidebands. For these sidebands to overlap (and the spectrum thereby to become completely diffused) the motion must be so rapid that the change in brightness of a given portion of the image, due to motion, occurs in $\frac{1}{30}$ sec or less. Fortunately, the eye loses its acuity for the details of an object in rapid motion. It is feasible, therefore, to design television systems on the assumption that less than half of the space between line harmonics is occupied by energy of significant amplitude.

1.309 Interleaving of Spectrum Components. The unoccupied portions of the video signal spectrum, between harmonics of the line frequency, may be filled in by the harmonic clusters of another signal and both signals transmitted simultaneously without significant interference. This technique is known as *frequency interleaving* (or *frequency interlace*). It is employed (1) to transmit the luminance and chrominance signals simultaneously in the compatible color system, (2) to transmit pilot signals in the operation of coaxial-cable facilities, (3) to minimize co-channel interference between stations, and (4) to minimize interference between chrominance and sound signals.

The signals to be interleaved must arise from integrally related frequencies to preserve the interleaved relationship throughout the spectrum. When both signals arise from the same scanning process (as do the luminance and chrominance signals in color transmissions), the interleaved frequency relationship can be very precisely maintained by deriving the chrominance-subcarrier frequency and the scanning frequencies from the same source. Frequency-division circuits are then arranged to produce a line-scanning frequency equal to twice some odd subharmonic of the

chrominance frequency (chrominance frequency equal to an odd multiple of half the line-scanning frequency). *Example:* In the United States compatible color system, the line-scanning frequency is 15,734.26 cps and the chrominance-subcarrier frequency is 3.579545 mc per sec, the 455th multiple of 15,734.26/2 cps. Similarly the spacing between chrominance and sound signals (see Sec. 1.208) is 0.920455 mc per sec, the 117th multiple of 15,734.26/2 cps.

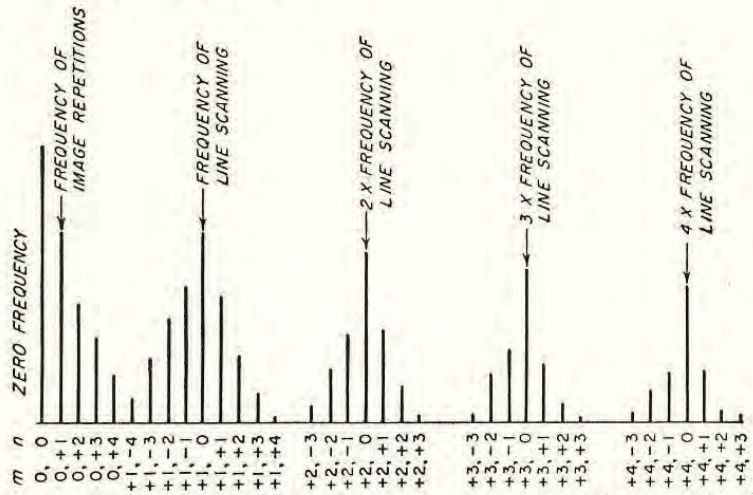


FIG. 1-6. Typical spectrum of video signal, showing harmonics of line-scanning frequency surrounded by clusters of components separated by intervals equal to the field-scanning frequency. (*After Mertz.*)

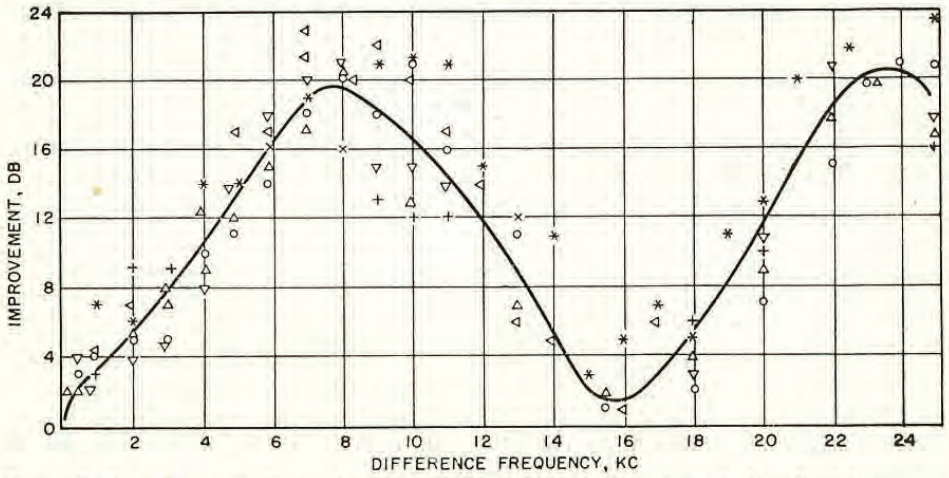
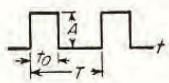
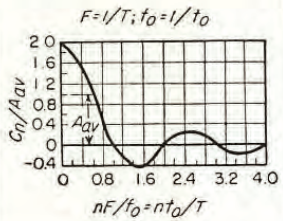
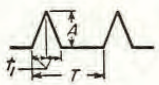
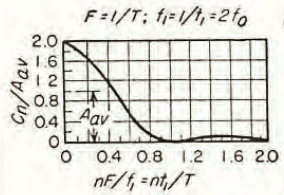
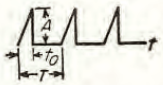
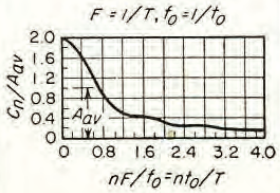


FIG. 1-7. Improvement in co-channel interference as a function of the offset frequency ("difference frequency"), for line-scanning frequency of 15,750 cps. (*After Kell.*)

When the interleaved signals arise in separate studio equipment (as in offset operation of co-channel stations carrying different programs), such precision is not feasible, but it is still possible to interleave the components less accurately with benefit. For example, in operating three or more stations in offset fashion on the same channel, it is not feasible to employ half the line-scanning frequency as the offset, since this would displace the carrier frequencies of two or more of the stations by the *whole* line-scanning frequency, the most disadvantageous value. As a compromise, the FCC offsets stations by 10,000 cps, which is approximately two-thirds the line-scanning

Table 1.9 Spectra of Commonly Encountered Waveforms
(From "Reference Data for Radio Engineers," by permission)

Time function	Frequency function	Equations
Rectangular wave 		$A_{avg} = A\,t_0/T$ $A_{rms} = A\sqrt{t_0/T}$ $C_n = 2A_{avg}\left(\dfrac{\sin \pi \dfrac{nt_0}{T}}{\pi nt_0/T}\right)$ $= 2A_{avg}\left(\dfrac{\sin \pi \dfrac{nF}{f_0}}{\pi nF/f_0}\right)$
Isosceles-triangle wave 		$A_{avg} = A\,t_1/T$ $A_{rms} = A\sqrt{2t_1/3T}$ $C_n = 2A_{avg}\left(\dfrac{\sin \pi \dfrac{nt_1}{T}}{\pi nt_1/T}\right)^2$ $= 2A_{avg}\left(\dfrac{\sin \pi \dfrac{nF}{f_1}}{\pi nF/f_1}\right)^2$
Clipped saw-tooth wave 		$A_{avg} = \dfrac{A}{2}\dfrac{t_0}{T}$ $\quad A_{rms} = A\sqrt{\dfrac{t_0}{3T}}$ $C_n = \dfrac{4A_{avg}}{\left(\dfrac{2\pi nt_0}{T}\right)^2}\left[2\left(1 - \cos\dfrac{2\pi nt_0}{T}\right) + \dfrac{2\pi nt_0}{T}\left(\dfrac{2\pi nt_0}{T} - 2\sin\dfrac{2\pi nt_0}{T}\right)\right]^{1/2}$ $= \dfrac{4A_{avg}}{\left(2\pi\dfrac{nF}{f_0}\right)^2}\left[2\left(1 - \cos 2\pi\dfrac{nF}{f_0}\right) + 2\pi\dfrac{nF}{f_0}\left(2\pi\dfrac{nF}{f_0} - 2\sin 2\pi\dfrac{nF}{f_0}\right)\right]^{1/2}$

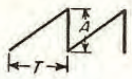
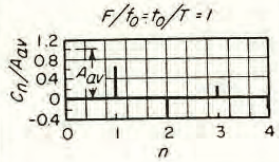
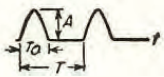
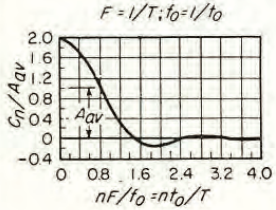
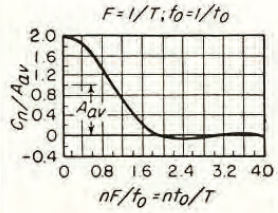
Saw-tooth wave		 $A_{avg} = \frac{A}{2}$ $A_{rms} = \frac{A}{\sqrt{3}}$ $C_n = -2A_{avg}\left(\frac{\cos \pi n}{\pi n}\right)$
Half sine wave		 $A_{avg} = \frac{2A}{\pi}\frac{t_0}{T}$ $\qquad A_{rms} = A\sqrt{\frac{t_0}{2T}}$ $C_n = \frac{\pi}{2}A_{avg}\left[\frac{\sin\frac{\pi}{2}\left(1-\frac{2nt_0}{T}\right)}{\frac{\pi}{2}\left(1-\frac{2nt_0}{T}\right)} + \frac{\sin\frac{\pi}{2}\left(1+\frac{2nt_0}{T}\right)}{\frac{\pi}{2}\left(1+\frac{2nt_0}{T}\right)}\right]$ $= \frac{\pi}{2}A_{avg}\left[\frac{\sin\frac{\pi}{2}\left(1-\frac{2nF}{f_0}\right)}{\frac{\pi}{2}\left(1-\frac{2nF}{f_0}\right)} + \frac{\sin\frac{\pi}{2}\left(1+\frac{2nF}{f_0}\right)}{\frac{\pi}{2}\left(1+\frac{2nF}{f_0}\right)}\right]$
Full sine wave		 $A_{avg} = \frac{A}{2}\frac{t_0}{T}$ $\qquad A_{rms} = \frac{A}{2}\sqrt{\frac{3t_0}{2T}}$ $C_n = A_{avg}\left[2\frac{\sin\pi\frac{nt_0}{T}}{\pi\frac{nt_0}{T}} + \frac{\sin\pi\left(1-\frac{nt_0}{T}\right)}{\pi\left(1-\frac{nt_0}{T}\right)} + \frac{\sin\pi\left(1+\frac{nt_0}{T}\right)}{\pi\left(1+\frac{nt_0}{T}\right)}\right]$ $= A_{avg}\left[2\frac{\sin\pi\frac{nF}{f_0}}{\pi\frac{nF}{f_0}} + \frac{\sin\pi\left(1-\frac{nF}{f_0}\right)}{\pi\left(1-\frac{nF}{f_0}\right)} + \frac{\sin\pi\left(1+\frac{nF}{f_0}\right)}{\pi\left(1+\frac{nF}{f_0}\right)}\right]$

Table 1.9 Spectra of Commonly Encountered Waveforms (*Continued*)

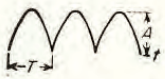
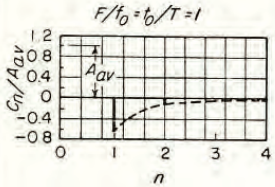
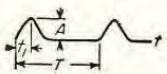
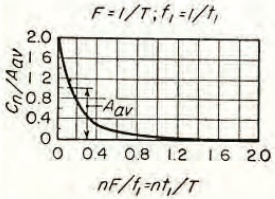
Time function	Frequency function	Equations
Full-wave-rectified sine wave 		$A_{avg} = \frac{2}{\pi} A \qquad A_{rms} = \frac{A}{\sqrt{2}}$ $C_n = \frac{\pi}{2} A_{avg} \left[\frac{\sin^2 \frac{\pi}{2}(1-2n)}{\frac{\pi}{2}(1-2n)} + \frac{\sin^2 \frac{\pi}{2}(1+2n)}{\frac{\pi}{2}(1+2n)} \right]$
Critically dumped exponential wave 		$y(t) = \frac{A\epsilon}{t_1} t\epsilon^{-t/t_1}$ for $T > 10t_1$, where $\epsilon = 2.718$ $A_{avg} = \frac{A\epsilon t_1}{T} \qquad A_{rms} = \frac{A\epsilon}{2}\sqrt{\frac{t_1}{T}}$ $C_n = 2A_{avg}\left[\frac{1}{1+\left(2\pi\frac{nt_1}{T}\right)^2}\right] = 2A_{avg}\left[\frac{1}{1+\left(2\pi\frac{nF}{f_1}\right)^2}\right]$ $= 2A_{avg}\cos^2\frac{\theta_n}{2}$ $\frac{\theta_n}{2} = \tan^{-1}\left(2\pi\frac{nt_1}{T}\right) = \tan^{-1}\left(2\pi\frac{nF}{f_1}\right)$

Table 1.9 Spectra of Commonly Encountered Waveforms (*Continued*)

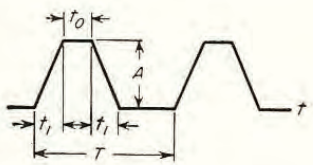
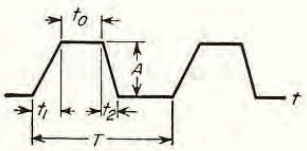
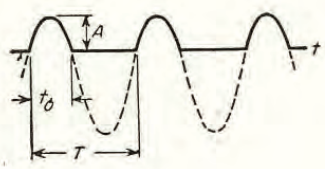
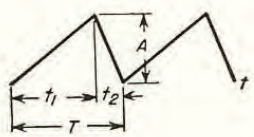
Time function	Equations
Symmetrical trapezoid wave 	$A_{avg} = A\dfrac{t_0 + t_1}{T}$ $\qquad A_{rms} = A\sqrt{\dfrac{3t_0 + 2t_1}{3T}}$ $C_n = 2A_{avg}\left[\dfrac{\sin \pi \frac{nt_1}{T}}{\pi \frac{nt_1}{T}}\right]\left[\dfrac{\sin \pi \frac{n(t_0 + t_1)}{T}}{\pi \frac{n(t_0 + t_1)}{T}}\right]$ $= 2A_{avg}\left[\dfrac{\sin \pi \frac{nF}{f_1}}{\pi \frac{nF}{f_1}}\right]\left[\dfrac{\sin \pi nF\left(\frac{1}{f_0} + \frac{1}{f_1}\right)}{\pi nF\left(\frac{1}{f_0} + \frac{1}{f_1}\right)}\right]$
Unsymmetrical trapezoid wave 	$A_{avg} = \dfrac{A}{T}\left[t_0 + \dfrac{t_1}{2} + \dfrac{t_2}{2}\right]$ $\qquad A_{rms} = A\sqrt{\dfrac{3t_0 + t_1 + t_2}{3T}}$ If $t_1 \approx t_2$ $C_n = 2A_{avg}\left[\dfrac{\sin \pi \frac{nt_1}{T}}{\pi \frac{nt_1}{T}}\right]\left[\dfrac{\sin \pi \frac{n(t_0 + t_1)}{T}}{\pi \frac{n(t_0 + t_1)}{T}}\right]\left[\dfrac{\sin \pi \frac{n(t_2 - t_1)}{T}}{\pi \frac{n(t_2 - t_1)}{T}}\right]$ $= 2A_{avg}\left[\dfrac{\sin \pi \frac{nF}{f_1}}{\pi \frac{nF}{f_1}}\right]\left[\dfrac{\sin \pi nF\left(\frac{1}{f_0} + \frac{1}{f_1}\right)}{\pi nF\left(\frac{1}{f_0} + \frac{1}{f_1}\right)}\right]\left[\dfrac{\sin \pi nF\left(\frac{1}{f_2} - \frac{1}{f_1}\right)}{\pi nF\left(\frac{1}{f_2} - \frac{1}{f_1}\right)}\right]$

Table 1.9 Spectra of Commonly Encountered Waveforms (*Continued*)

Time function	Equations
Fractional sine wave 	$A_{avg} = \dfrac{A\left(\sin \pi \frac{t_0}{T} - \pi \frac{t_0}{T} \cos \pi \frac{t_0}{T}\right)}{\pi\left(1 - \cos \pi \frac{t_0}{T}\right)}$ $A_{rms} = \dfrac{A}{\left(1 - \cos \pi \frac{t_0}{T}\right)} \left[\dfrac{1}{2\pi}\left(\pi \frac{t_0}{T} + \tfrac{1}{2} \sin^2 \pi \frac{t_0}{T} - 4 \cos \pi \frac{t_0}{T} \sin \pi \frac{t_0}{T} + 2\pi \frac{t_0}{T} \cos^2 \pi \frac{t_0}{T}\right)\right]$ $C_n = \dfrac{A_{avg}\, \pi \frac{t_0}{T}}{n\left(\sin \pi \frac{t_0}{T} - \pi \frac{t_0}{T} \cos \pi \frac{t_0}{T}\right)} \left[\dfrac{\sin \pi (n-1) \frac{t_0}{T}}{\pi (n-1) \frac{t_0}{T}} - \dfrac{\sin \pi (n+1) \frac{t_0}{T}}{\pi (n+1) \frac{t_0}{T}}\right]$ $= \dfrac{A_{avg}\, \pi \frac{F}{f_0}}{n\left(\sin \pi \frac{F}{f_0} - \pi \frac{F}{f_0} \cos \pi \frac{F}{f_0}\right)} \left[\dfrac{\sin \pi (n-1) \frac{F}{f_0}}{\pi (n-1) \frac{F}{f_0}} - \dfrac{\sin \pi (n+1) \frac{F}{f_0}}{\pi (n+1) \frac{F}{f_0}}\right]$
Saw-tooth wave 	$A_{avg} = \dfrac{A}{2} \qquad A_{rms} = \dfrac{A}{\sqrt{3}}$ $C_n = \dfrac{2\, A_{avg}}{\pi^2 n^2 \frac{t_1}{T}\left(1 - \frac{t_1}{T}\right)} \sin \pi \frac{t_1}{T}$ $= \dfrac{2 A_{avg}}{\pi^2 n^2 \frac{F}{f_1}\left(1 - \frac{F}{f_1}\right)} \sin \pi \frac{F}{f_1}$

frequency. Figure 1-7 shows the improvement in co-channel interference for various values of the offset frequency. Maximum benefit (about 20 db) results when the offset frequency is half the line-scanning frequency or some multiple of this value. The 10,000-cps value is about 4 db less effective.

1.310 Spectra of Various Waveforms. Fourier analysis of repetitive waveforms gives the average and root-mean-square values of the wave and the amplitude and

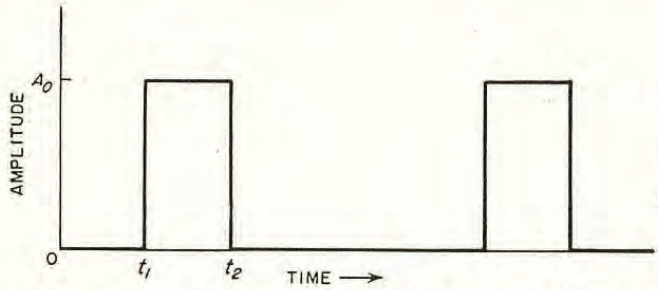


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FIG. 1-8. Rectangular wave used in examining transient response of transmission systems.

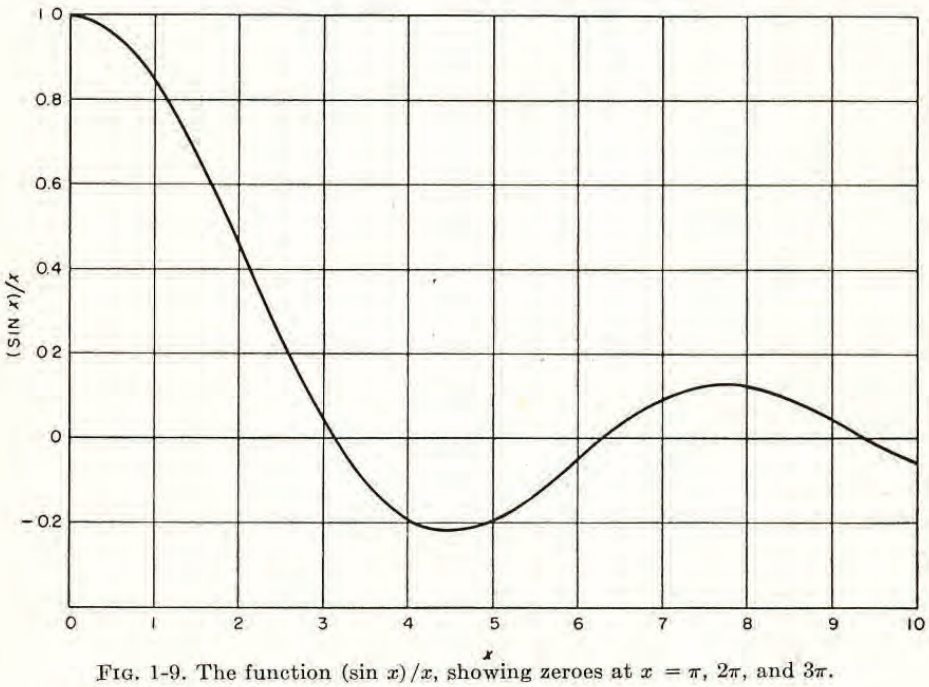

FIG. 1-9. The function $(\sin x)/x$, showing zeroes at $x = \pi$, 2π, and 3π.

phase of the harmonics. Table 1.9 presents these data for several waveforms commonly encountered in television engineering.

1.311 Transient Response of Video Transmission Systems. The transient performance of a video transmission system is revealed by the distortions suffered by a rectangular waveform (Fig. 1-8) in passing through the system. Useful information may be obtained from the quantity $(\sin x)/x$, which expresses the amplitude spectrum of the rectangular wave, and its integral $Si(x) = \int_0^x (\sin u)/u \, du$, which expresses the sum of the spectrum components, that is, the waveform after passage through a transmission system having uniform amplitude and phase characteristics up to a cutoff

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Table 1.10 The Quantities $(\sin x)/x$ and $Si(x)$
(x in radians)

x	$(\sin x)/x$	$Si(x)$	x	$(\sin x)/x$	$Si(x)$	x	$(\sin x)/x$	$Si(x)$
0.0	1.0000	0.0000	3.5	−0.1002	1.8331	7.0	0.0939	1.4546
0.1	0.9983	0.0999	3.6	−0.1229	1.8220	7.1	0.1027	1.4644
0.2	0.9933	0.1996	3.7	−0.1432	1.8086	7.2	0.1102	1.4751
0.3	0.9851	0.2985	3.8	−0.1610	1.7933	7.3	0.1165	1.4864
0.4	0.9735	0.3965	3.9	−0.1764	1.7765	7.4	0.1214	1.4983
0.5	0.9589	0.4931	4.0	−0.1892	1.7582	7.5	0.1251	1.5107
0.6	0.9411	0.5881	4.1	−0.1996	1.7387	7.6	0.1274	1.5233
0.7	0.9203	0.6812	4.2	−0.2075	1.7184	7.7	0.1283	1.5361
0.8	0.8967	0.7721	4.3	−0.2131	1.6973	7.8	0.1280	1.5489
0.9	0.8704	0.8605	4.4	−0.2163	1.6758	7.9	0.1264	1.5617
1.0	0.8415	0.9461	4.5	−0.2172	1.6541	8.0	0.1237	1.5742
1.1	0.8102	1.0287	4.6	−0.2160	1.6325	8.1	0.1197	1.5864
1.2	0.7767	1.1081	4.7	−0.2127	1.6110	8.2	0.1147	1.5981
1.3	0.7412	1.1840	4.8	−0.2075	1.5900	8.3	0.1087	1.6093
1.4	0.7039	1.2562	4.9	−0.2005	1.5696	8.4	0.1017	1.6198
1.5	0.6650	1.3247	5.0	−0.1918	1.5499	8.5	0.0939	1.6296
1.6	0.6247	1.3892	5.1	−0.1815	1.5313	8.6	0.0854	1.6386
1.7	0.5833	1.4496	5.2	−0.1699	1.5137	8.7	0.0762	1.6467
1.8	0.5410	1.5058	5.3	−0.1570	1.4973	8.8	0.0665	1.6538
1.9	0.4981	1.5578	5.4	−0.1431	1.4823	8.9	0.0563	1.6599
2.0	0.4546	1.6054	5.5	−0.1283	1.4687	9.0	0.0458	1.6650
2.1	0.4111	1.6487	5.6	−0.1127	1.4567	9.1	0.0351	1.6691
2.2	0.3675	1.6876	5.7	−0.0966	1.4462	9.2	0.0242	1.6721
2.3	0.3242	1.7222	5.8	−0.0801	1.4374	9.3	0.0134	1.6739
2.4	0.2814	1.7525	5.9	−0.0634	1.4302	9.4	0.0026	1.6747
2.5	0.2394	1.7785	6.0	−0.0466	1.4247	9.5	−0.0079	1.6745
2.6	0.1983	1.8004	6.1	−0.0299	1.4209	9.6	−0.0182	1.6732
2.7	0.1583	1.8182	6.2	−0.0134	1.4187	9.7	−0.0280	1.6708
2.8	0.1196	1.8321	6.3	0.0027	1.4182	9.8	−0.0374	1.6676
2.9	0.0825	1.8422	6.4	0.0182	1.4192	9.9	−0.0462	1.6634
3.0	0.0470	1.8487	6.5	0.0331	1.4218	10.0	−0.0544	1.6584
3.1	0.0134	1.8517	6.6	0.0472	1.4258	10.1	−0.0619	1.6525
3.2	−0.0182	1.8514	6.7	0.0604	1.4312	10.2	−0.0686	1.6460
3.3	−0.0478	1.8481	6.8	0.0727	1.4379	10.3	−0.0745	1.6388
3.4	−0.0752	1.8419	6.9	0.0838	1.4457	10.4	−0.0796	1.6311
						∞	0.0000	1.5708

frequency beyond which the system has zero response. Figures 1-9 and 1-10 are plots of the respective quantities. Table 1.10 gives the values of the ordinates to four decimals. Figure 1-11 shows the $Si(x)$ function plotted as the output waveform in relation to the unit-step input waveform, and identifies the cutoff and delay characteristics of the transmission system.

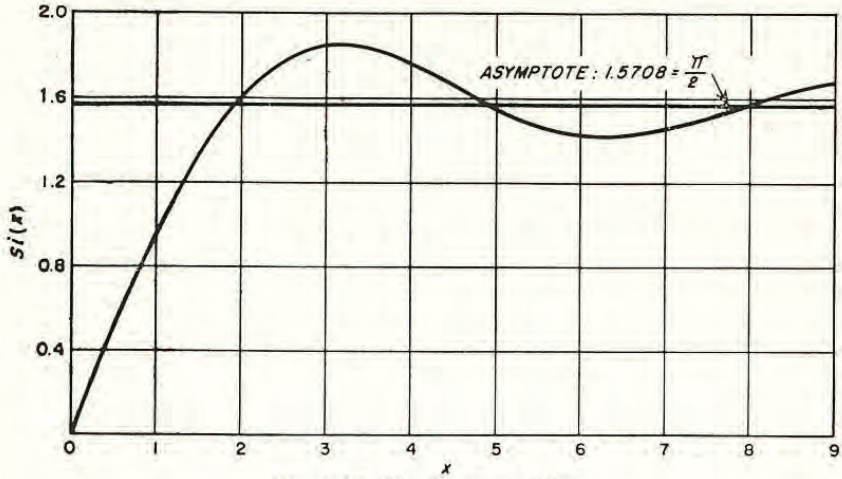

FIG. 1-10. The function $Si(x)$.

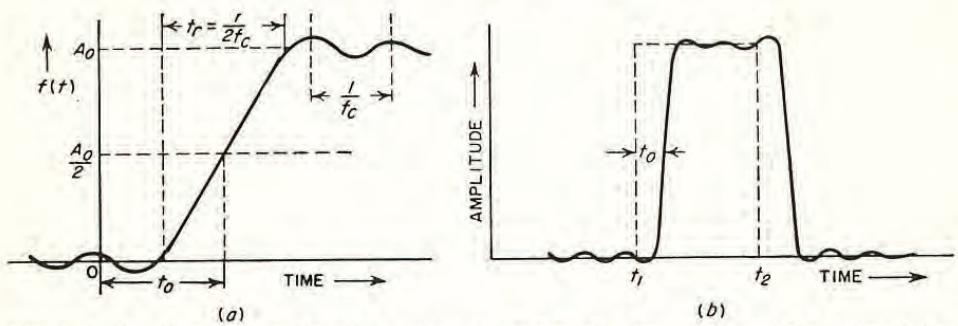

FIG. 1-11. (*a*) The leading edge of a rectangular pulse, after passage through a transmission system having a sharp cutoff at f_c and a time delay of t_o; (*b*), the whole pulse shown in relation to the input pulse (dashed lines).

1.4 NUMERICAL CONSTANTS OF VISION

1.401 Visual Acuity. The ability of the eye to distinguish between small objects (and hence to resolve the details of an image) is known as visual acuity and is expressed in reciprocal minutes of the angle subtended at the eye by two objects which can just be separately identified. When the objects and background are displayed in black-and-white (as in monochrome television), at 100 per cent contrast, the range of visual acuity extends from 0.2 to about 2.5 reciprocal minutes (5 to 0.4 minutes of arc, respectively). An acuity of 1 reciprocal minute is usually taken as the basis of television system design; at this value, stationary white points on two scanning lines separated by an intervening line, the remainder of the scanning pattern being dark, can be resolved at a distance of about 20 times the picture height. Adjacent scanning lines cannot ordinarily be distinguished at distances greater than about six times the picture height.

Visual acuity varies markedly with (1) the luminance of the background, (2) the contrast of the image, (3) the luminance of the area surrounding the image, and (4) the luminosity to which the eye is adapted. The acuity is approximately proportional to the logarithm of the background luminance, increasing from about 1 reciprocal minute at 1 ft-lambert background brightness and 100 per cent contrast, to about 2 reciprocal minutes at 100 ft-lamberts. Figure 1-12 shows experimental data on visual acuity as a function of luminance, when the contrast is nearly 100 per cent, using

incandescent lamps as the illumination. These data apply to details viewed in the center of the field of view, i.e., by cone vision near the fovea of the retina. The acuity of rod vision, outside the foveal region, is poorer by a factor of about five times (i.e., about 0.2 reciprocal minute at 1 ft-lambert background luminance and 100 per cent contrast).

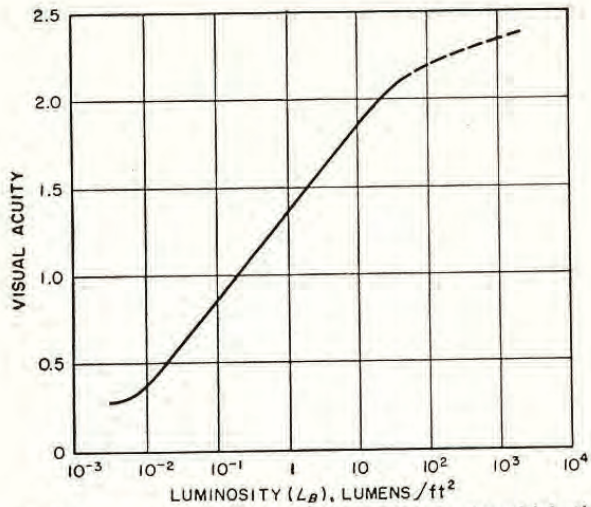

FIG. 1-12. Visual acuity as a function of the luminosity L_B to which the eye is adapted. (*After Lythgoe.*)

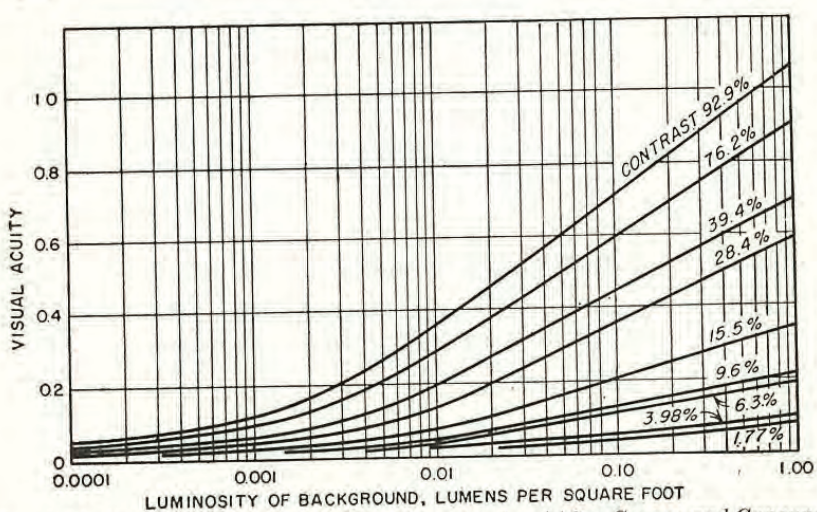

FIG. 1-13. Visual acuity as a function of contrast. (*After Conner and Ganoung.*)

Visual acuity falls off rapidly as the contrast of the image decreases. Under typical conditions (1 ft-lambert background luminance), the acuity increases from about 0.2 reciprocal minute at 10 per cent contrast to about 1.0 reciprocal minute at 100 per cent contrast, the acuity being roughly proportional to the per cent contrast. Figure 1-13 shows experimental measurements of this effect.

When colored images are viewed, visual acuity depends markedly on the color. Acuity is higher for objects illuminated by monochromatic light (i.e., from a sodium lamp) than for those illuminated by a source of the same color having an extended spectrum; this improvement results from the lack of chromatic aberration in the eye.

In a colored image reproduced by primary colors the acuity is highest for the green primary and lowest for the blue primary. This is explained only in part by the relative luminances of the primaries. The acuity for blue and red images is approximately two-thirds that for a white image of the same luminance (Baldwin[3]). For the green primary the acuity is about 90 per cent that of a white image of the same luminance. When the effect of the relative contributions to luminance of the standard FCC–NTSC color primaries (approximately, green:red:blue = 6 to 3 to 1) is taken into account, the acuities for the primary images are in the approximate ratio green:red:blue = 8 to 3 to 1.

Visual acuity is also affected by glare, that is, regions in or near the field of view whose luminance is substantially greater than that of the object viewed. In television viewing acuity for an image fails rapidly if the area surrounding the image is brighter than the background luminance of the image. Acuity also decreases slightly if the image is viewed in darkness, that is, if the surround luminance is substantially lower than the average image luminance. Acuity is not adversely affected if the surround luminance has a value in the range from 0.1 to 1.0 times the average image luminance.

1.402 Contrast Sensitivity. The ability of the eye to distinguish between the luminances of adjacent areas is known as contrast sensitivity; it is expressed as the ratio of the luminance to which the eye is adapted (usually the same as the background luminance) to the least perceptible luminance difference between the background luminance of the scene and the object luminance.

Two forms of contrast vision must be distinguished. In *rod vision*, which occurs at background luminance less than about 0.01 ft-lambert, the contrast sensitivity ranges from 2 to 5 (the average luminance is twice to five times the least perceptible luminance difference), increasing slowly as the background luminance increases from 0.0001 to 0.01 ft-lambert. In *cone vision*, which takes place above about 0.01 ft-lambert, the contrast sensitivity increases proportionately to background luminance from a value of 30 at 0.01 ft-lambert to 150 at 10 ft-lamberts. The latter figure indicates that a luminance difference of 0.07 ft-lambert can be distinguished at a background luminance of 10 ft-lamberts. Contrast sensitivity does not vary markedly with the color of the light. It is somewhat higher for blue light than for red at low background luminance; the reverse at higher luminance. Contrast sensitivity, like visual acuity, is reduced if the surround is brighter than the background. Figures 1-14 and 1-15 illustrate experimental data on contrast sensitivity.

1.403 Flicker. The perceptibility of flicker varies so widely with viewing conditions* that it is difficult to describe quantitatively. In one respect, however, flicker phenomena are readily compared: when the viewing situation is constant (no change in the image or surround other than a proportional change in the luminance of all their parts, and no change in the conditions of observation), the luminance at which flicker just becomes perceptible varies logarithmically with the luminance (the Ferry-Porter law). The numerical relationship is: a positive increment in the flicker frequency of 12.6 cps raises the luminance of flicker threshold ten times. In television scanning the applicable flicker frequency is the field frequency, i.e., the rate at which the *area* of the image is successively illuminated. Table 1.11 gives the flicker-threshold luminance for various flicker frequencies, based on 180 ft-lamberts for 60 fields per second.

1.404 Illumination and Brightness. The input quantity to a television camera is the radiance of the various parts of the scene; that to the eye viewing the resulting television image is the luminance of the corresponding parts of the image. If the spectral response of the camera has been adjusted to approximate that of the eye (this is roughly the case in modern monochrome cameras, more precisely true of color cameras), it is appropriate to consider the camera input and the image output as the respective luminances (in common engineering parlance "brightness" is often used to mean luminance; see definitions in Sec. 1.5). The unit of luminance is the foot-lambert.

* Among the factors affecting the flicker threshold are luminance of the flickering area, its color, the solid angle subtended by it at the eye, its absolute size, the luminance of the surround, the variation of luminance with time and position within the flickering area, and the adaptation and training of the observer.

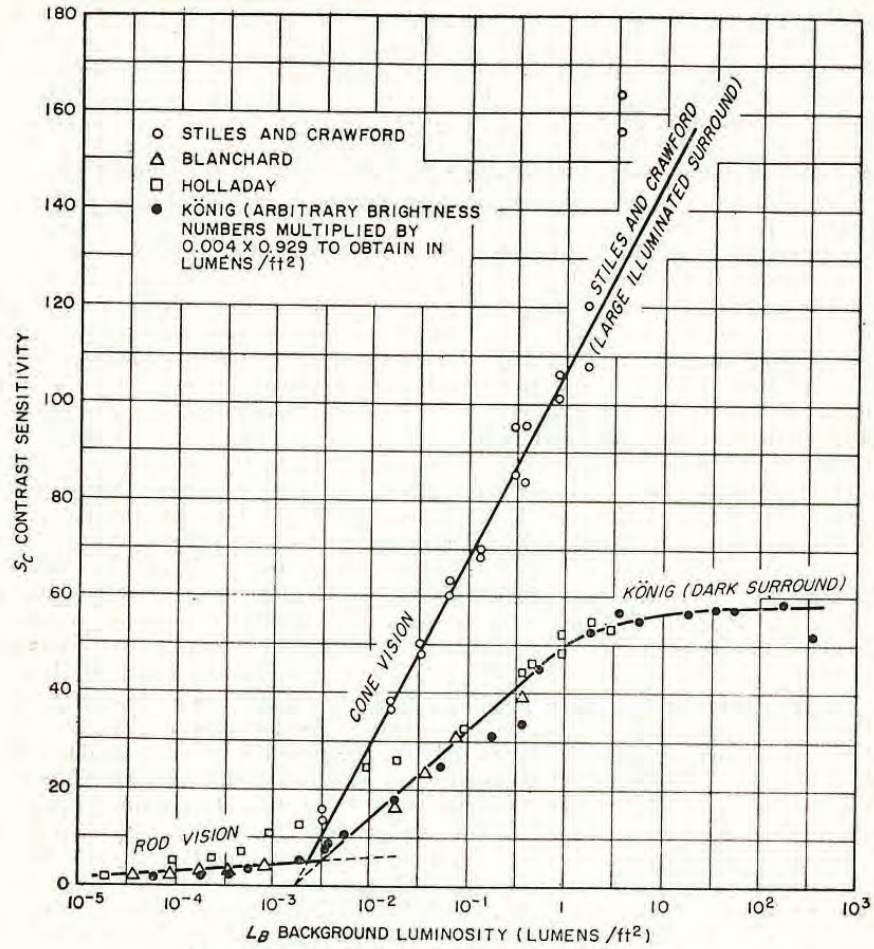

FIG. 1-14. Contrast sensitivity. (*After Moon.*)

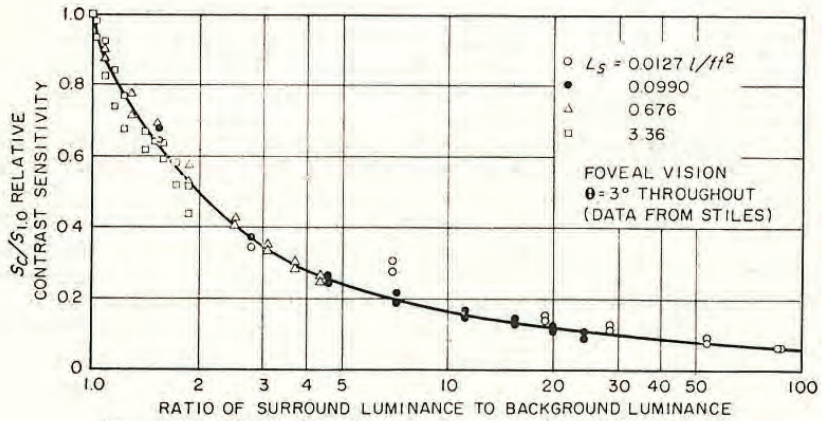

FIG. 1-15. Effect of luminance of surround. (*After Moon.*)

The luminance of a scene is inherent in those portions that are self-luminous; typical examples are a candle flame and an incandescent lamp. More commonly, the light enters the camera after reflection from a surface. The luminance, as viewed by the camera, then depends on the luminous radiation from the source in the direction of the surface, the position of the surface relative to the light source, and the reflectance of the surface (which is often a function of the angles from which it is illuminated and viewed). In view of the many variables affecting the luminance of reflecting objects, it is customary to dispense with calculations and to measure luminance with a light meter. In studio design it is necessary to know the candlepower of typical light sources and the distribution of light flux, as well as the reflectances of typical materials used in sets and costumes.

Table 1.11 Relative Flicker-threshold Luminances*

Flicker frequency, cps	System	Frames per second	Flicker-threshold luminance, ft-lamberts
48	Home movies	16	20
48	Professional movies	24	20
50	Television scanning	25	29
60	Television scanning	30	180

* The luminances tabulated have only relative significance; they are based on a value of 180 ft-lamberts for a flicker frequency of 60 cps, which is typical performance under the American television standards.

Table 1.12 Luminance of Self-luminous Sources

Source	Luminance in foot-lamberts	Source	Luminance in foot-lamberts
Sun, at meridian	4.8×10^8	Tungsten filament	3,500,000
Sun, near horizon	1,750,000	Inside-frosted 60-watt bulb	27,000
Moon	750	Fluorescent-lamp 40-watt, T-12 tube	1,800
Clear sky	2,300	High-intensity carbon arc	2×10^8
Overcast sky	650		
Candle flame	2,900		

Table 1.12 gives the luminance of self-luminous sources.

Table 1.13 gives the output in lumens and the efficiencies in lumens per watt of typical incandescent and fluorescent lamps.

1.405 Luminance Distortion and Gamma Correction. When the luminances of a television image are directly proportional to the corresponding luminances of the televised scene, the system is said to be free of luminance distortion. Since such proportionality is not obtained in many of the transducers of a television system (notably the camera, picture tube, and high-level video amplifiers), most television systems display luminance distortion, unless the nonlinearity is specifically compensated. The basis of luminance-distortion compensation (usually called "gamma correction") is the specific nonlinearity of the picture tube. The light output of typical picture tubes versus control electrode voltage above cutoff is approximately a power function, the light output varying between the second and third power of the voltage. The gamma-correction systems applicable to the NTSC color television system are based on an exponent of 2.2. To compensate for the picture-tube charac-

Table 1.13 Luminous Outputs and Efficiencies

Type and wattage of lamp	Initial lumens output	Initial lumens per watt
Incandescent:		
40-watt	465	11.7
60-watt	835	13.9
100-watt	1,630	16.3
200-watt	3,650	18.3
300-watt	5,900	19.6
500-watt	9,950	19.9
1,000-watt	21,500	21.5
1,000-watt, spot	22,500	22.5
5,000-watt, studio lighting	164,000	32.7
10,000-watt, studio lighting	325,000	32.7
Fluorescent:*		
15-watt	600	40
20-watt	860	43
30-watt	1,380	46
40-watt	2,100	43
100-watt	4,000	40

* Hot-cathode type, 4500°K white.

teristic, the amplitude of the luminance signal, as measured against black in the carrier envelope, is arranged to vary as the 2.2 root of the input luminance to the camera.

1.406 Wavelengths of Various Radiations. The wavelengths of the various regions of the radiant-energy spectrum, spectral primary colors, and spectral lines are given in Table 1.14.

Table 1.14 Wavelengths of Various Radiations
(In millimicrons)

Spectrum region or line	Wavelength	Spectrum region or line	Wavelength
Ultraviolet	200–400	Peak of $\bar{x}$ distribution coefficient	600
Visible region (CIE limits)	380–780	Peak of $\bar{z}$ distribution coefficient	445
Visible region (practical limits)	400–700	Peak of $\bar{r}$ distribution coefficient	605
		Peak of $\bar{g}$ distribution coefficient	545
Violet region	400–450	Peak of $\bar{b}$ distribution coefficient	445
Blue region	450–490	Fraunhofer lines:	
Green region	490–550	*A*	766.1
Yellow region	550–590	*B* (oxygen)	687.0
Orange region	590–630	*C* (hydrogen)	656.28
Red region	630–700	D_1 (sodium)	589.59
Near infrared	700–3,000	D_3 (helium)	587.56
CIE red spectral primary	700	*E* (iron)	526.96
CIE green spectral primary	564.1	*F* (hydrogen)	486.14
		G (iron, calcium)	430.79
CIE blue spectral primary	435.8	*H* (calcium)	396.84
Peak of luminosity function ($\bar{y}$)	555	*K* (calcium)	393.36

1.407 Luminosity Function. The relative luminosities of the colors of the spectrum, that is, their relative luminance as evaluated by the average eye, is expressed in the *luminosity function*. This function, shown in Fig. 1-16, extends from 380 to 780 mμ; its peak occurs at about 555 mμ. The ordinates of this curve, at intervals of 10 mμ, are given to four decimals in Table 1.16, under the distribution coefficient $\bar{y}$.

1.408 Relative Luminances of Primaries. When colors are reproduced by mixtures of primary colors, the contribution of each primary to the luminance of the mixture can be computed from their chromaticity coordinates (Table 1.17). Table 1.15 gives the relative contributions to luminance of typical primary colors in mixtures matched to Illuminant C (the NTSC reference white) and Illuminant E (equal-energy white).

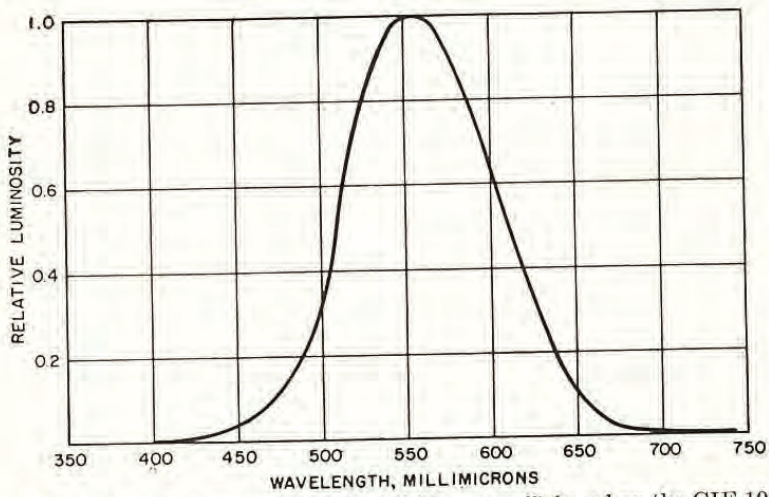

FIG. 1-16. Standard luminosity function ("visibility curve") based on the CIE 1931 standard observer.

1.409 CIE Chromaticity Specifications. The CIE system of color specification is based on three standard monochromatic (spectral) primaries having the following wavelengths in millimicrons: red, 700; green, 546.1; blue, 435.8 (Table 1.14). Any given color may be specified by three numbers, R, G, and B, called the *tristimulus values*. These are the respective amounts (lumens or watts) of the three standard primaries needed to match the given color, each divided by the respective amount (lumens or watts) of the primary needed to match the standard reference-white light (equal-energy white, Illuminant E). To make the specification independent of the luminance of the given color, the tristimulus values are normalized to obtain the *chromaticity coordinates* (also known as "trichromatic coefficients")

$$r = \frac{R}{R + G + B} \qquad g = \frac{G}{R + G + B} \qquad b = \frac{B}{R + G + B}$$

Since $r + g + b = 1$, only two of the chromaticity coordinates (say r and g) are needed to specify the hue and saturation of any color. These may be plotted in the *RGB chromaticity diagram* (Fig. 1-17). The values of r and g which specify the monochromatic colors of the spectrum define the spectrum locus on this diagram. The coordinates of this locus are given under r and g in Table 1.16.

The color-mixture data, that is, the relative amounts of the primaries needed at each wavelength to match the equal-energy spectrum, are known as the distribution coefficients $\bar{r}$, $\bar{g}$, and $\bar{b}$. The distribution coefficients are in the same ratio as the chromaticity coordinates for any given spectral color; that is, $\bar{r}:\bar{g}:\bar{b} = r:g:b$. The $\bar{r}$, $\bar{g}$, and $\bar{b}$ values are listed in Table 1.16. Negative values of $\bar{r}$ and $\bar{g}$ occur; these

imply that the primary in question is added to Illuminant E to match the mixture of the remaining two primaries.

To avoid the negative values on the *RGB* chromaticity diagram, and to simplify colorimetric computations in other ways, the *RGB* diagram is linearly transformed to the *XYZ chromaticity diagram* (Fig. 1-18). The latter diagram is the accepted international standard of color specification. The quantities X, Y, and Z are tristimulus values analogous to the R, G, and B values described above; that is, they

Table 1.15 Contributions to Luminance of Typical Primary Colors

Primary-color designation	Relative luminance when matching Illuminant C	Relative luminance when matching Illuminant E
CIE spectral primaries:		
Red	0.1536	0.1769
Green	0.8338	0.8125
Blue	0.0126	0.0106
	1.0000	1.0000
NTSC receiver primaries:		
Red	0.299	0.326
Green	0.587	0.578
Blue	0.114	0.096
	1.000	1.000
Field-sequential (low-flicker) primaries:		
Red	0.309	0.331
Green	0.474	0.487
Blue	0.217	0.182
	1.000	1.000
Phosphor primaries:		
Red (zinc phosphate)	0.327	
Green (willemite)	0.475	
Blue (silicate)	0.198	
	1.000	
Red (zinc-lead sulfide)	0.250	
Green (short-persistence willemite)	0.632	
Blue (zinc sulfide)	0.118	
	1.000	

represent the amounts of three nonphysical ("fictitious") primaries required to match a given color, each divided by the respective amount needed to match Illuminant E. The normalized values of these quantities (chromaticity coordinates) are $x = X/(X + Y + Z)$; $y = Y/(X + Y + Z)$; $z = Z/(X + Y + Z)$. The sum of the chromaticity coordinates of any color is unity; that is, $x + y + z = 1$. The XYZ diagram is customarily plotted in x and y; the z coordinate may be obtained from $z = 1 - (x + y)$.

The primaries on which the XYZ diagram is based lie outside the spectrum locus and hence do not correspond to physically realizable colors. They are, rather, mathematical abstractions which represent linear transformations of the *RGB* color-mixture data. The values of x and y specifying the spectrum locus are given in Table 1.16. The distribution coefficients $\bar{x}$, $\bar{y}$, and $\bar{z}$ are analogous to $\bar{r}$, $\bar{g}$, and $\bar{b}$; they represent the

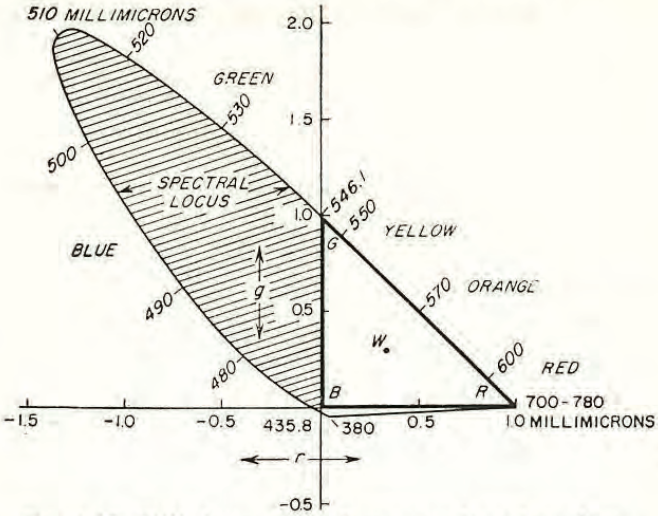

FIG. 1-17. *RGB* chromaticity diagram and spectrum locus.

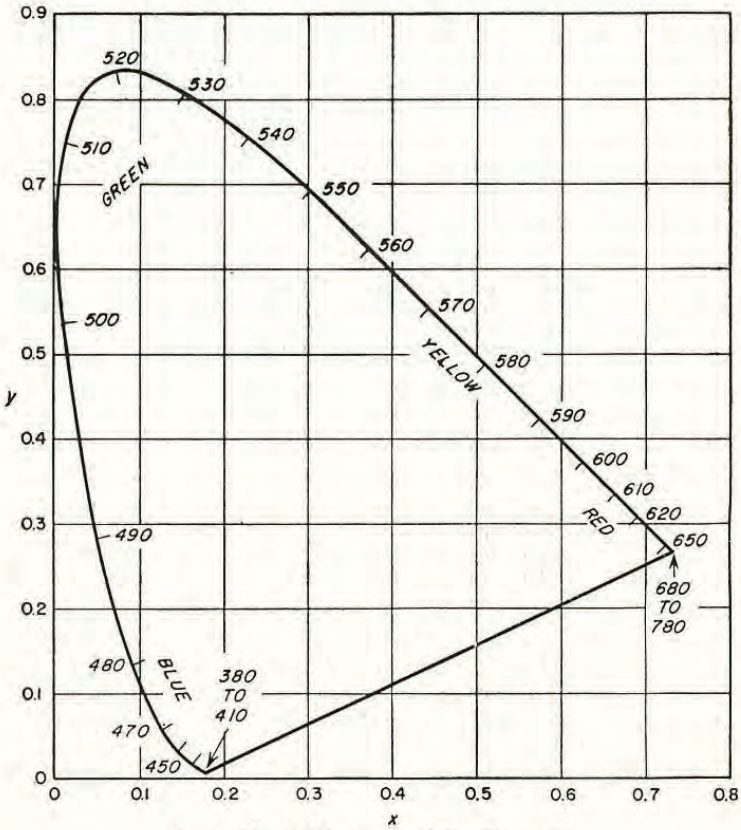

FIG. 1-18. *XYZ* chromaticity diagram.

Table 1.16 CIE Colorimetric Data (1931 Standard Observer)

Wavelength in millimicrons	Trichromatic coefficients		Distribution coefficients, equal-energy stimulus			Energy distributions of standard illuminants A, B, C			Wavelength in millimicrons
	r	g	$\bar{r}$	$\bar{g}$	$\bar{b}$	E_A	E_B	E_C	
380	0.0272	−0.0115	0.0000	0.0000	0.0012	9.79	22.40	33.00	380
390	0.0263	−0.0114	0.0001	0.0000	0.0036	12.90	31.30	47.40	390
400	0.0247	−0.0112	0.0003	−0.0001	0.0121	14.71	41.30	63.30	400
410	0.0225	−0.0109	0.0008	−0.0004	0.0371	17.68	52.10	80.60	410
420	0.0181	−0.0094	0.0021	−0.0011	0.1154	21.00	63.20	98.10	420
430	0.0088	−0.0048	0.0022	−0.0012	0.2477	24.67	73.10	112.40	430
440	−0.0084	0.0048	−0.0026	0.0015	0.3123	28.70	80.80	121.50	440
450	−0.0390	0.0218	−0.0121	0.0068	0.3167	33.09	85.40	124.00	450
460	−0.0909	0.0517	−0.0261	0.0149	0.2982	37.82	88.30	123.10	460
470	−0.1821	0.1175	−0.0393	0.0254	0.2299	42.87	92.00	123.80	470
480	−0.3667	0.2906	−0.0494	0.0391	0.1449	48.25	95.20	123.90	480
490	−0.7150	0.6996	−0.0581	0.0569	0.0826	53.91	96.50	120.70	490
500	−1.1685	1.3905	−0.0717	0.0854	0.0478	59.86	94.20	112.10	500
510	−1.3371	1.9318	−0.0890	0.1286	0.0270	66.06	90.70	102.30	510
520	−0.9830	1.8534	−0.0926	0.1747	0.0122	72.50	89.50	96.90	520
530	−0.5159	1.4761	−0.0710	0.2032	0.0055	79.13	92.20	98.00	530
540	−0.1707	1.1628	−0.0315	0.2147	0.0015	85.95	96.90	102.10	540
550	0.0974	0.9051	0.0228	0.2118	−0.0006	92.91	101.00	105.20	550
560	0.3164	0.6881	0.0906	0.1970	−0.0013	100.00	102.80	105.30	560
570	0.4973	0.5067	0.1677	0.1709	−0.0014	107.18	102.60	102.30	570
580	0.6449	0.3579	0.2543	0.1361	−0.0011	114.44	101.00	97.80	580
590	0.7617	0.2402	0.3093	0.0975	−0.0008	121.73	99.20	93.20	590
600	0.8475	0.1537	0.3443	0.0625	−0.0005	129.04	98.00	89.70	600
610	0.9059	0.0949	0.3397	0.0356	−0.0003	136.34	98.50	88.40	610
620	0.9425	0.0580	0.2971	0.0183	−0.0002	143.62	99.70	88.10	620
630	0.9649	0.0354	0.2268	0.0083	−0.0001	150.83	101.00	88.00	630
640	0.9797	0.0205	0.1597	0.0033	0.0000	157.98	102.20	87.80	640
650	0.9888	0.0113	0.1017	0.0012	0.0000	165.03	103.90	88.20	650
660	0.9940	0.0061	0.0593	0.0004	0.0000	171.96	105.00	87.90	660
670	0.9966	0.0035	0.0315	0.0001	0.0000	178.77	104.90	86.30	670
680	0.9984	0.0016	0.0169	0.0000	0.0000	185.43	103.90	84.00	680
690	0.9996	0.0004	0.0082	0.0000	0.0000	191.93	101.60	80.20	690
700	1.0000	0.0000	0.0041	0.0000	0.0000	198.26	99.10	76.30	700
710	1.0000	0.0000	0.0021	0.0000	0.0000	204.41	96.20	72.40	710
720	1.0000	0.0000	0.0011	0.0000	0.0000	210.36	92.90	68.30	720
730	1.0000	0.0000	0.0005	0.0000	0.0000	216.12	89.40	64.40	730
740	1.0000	0.0000	0.0003	0.0000	0.0000	221.66	86.90	61.50	740
750	1.0000	0.0000	0.0001	0.0000	0.0000	227.00	85.20	59.20	750
760	1.0000	0.0000	0.0001	0.0000	0.0000	232.11	84.70	58.10	760
770	1.0000	0.0000	0.0000	0.0000	0.0000	237.01	85.40	58.20	770
780	1.0000	0.0000	0.0000	0.0000	0.0000	241.67	87.00	59.10	780

amounts of the nonphysical primaries required to match Illuminant E at each wavelength. These values, all positive, are listed in Table 1.16. The $\bar{y}$ distribution coefficient has been chosen (by virtue of the choice of the transformation equations between *RGB* and *XYZ*) to be identical to the standard luminosity function, Sec. 1.407. On this account the tristimulus value Y of any color is numerically equal to its luminance.

1.410 *RGB-XYZ* **Transformation Equations.** The transformations from *RGB* quantities to *XYZ* quantities and vice versa are expressed in simultaneous equations which relate the tristimulus values R, G, and B of any color in the *RGB* system to the

Table 1.16 CIE Colorimetric Data (1931 Standard Observer) (*Continued*)

Wavelength in millimicrons	Trichromatic coefficients		Distribution coefficients, equal-energy stimulus			Distribution coefficients weighted by Illuminant C			Wavelength in millimicrons
	x	y	$\bar{x}$	$\bar{y}$	$\bar{z}$	$E_C\bar{x}$	$E_C\bar{y}$	$E_C\bar{z}$	
380	0.1741	0.0050	0.0014	0.0000	0.0065	0.0036	0.0000	0.0164	380
390	0.1738	0.0049	0.0042	0.0001	0.0201	0.0183	0.0004	0.0870	390
400	0.1733	0.0048	0.0143	0.0004	0.0679	0.0841	0.0021	0.3992	400
410	0.1726	0.0048	0.0435	0.0012	0.2074	0.3180	0.0087	1.5159	410
420	0.1714	0.0051	0.1344	0.0040	0.6456	1.2623	0.0378	6.0646	420
430	0.1689	0.0069	0.2839	0.0116	1.3856	2.9913	0.1225	14.6019	430
440	0.1644	0.0109	0.3483	0.0230	1.7471	3.9741	0.2613	19.9357	440
450	0.1566	0.0177	0.3362	0.0380	1.7721	3.9191	0.4432	20.6551	450
460	0.1440	0.0297	0.2908	0.0600	1.6692	3.3668	0.6920	19.3235	460
470	0.1241	0.0578	0.1954	0.0910	1.2876	2.2878	1.0605	15.0550	470
480	0.0913	0.1327	0.0956	0.1390	0.8130	1.1038	1.6129	9.4220	480
490	0.0454	0.2950	0.0320	0.2080	0.4652	0.3639	2.3591	5.2789	490
500	0.0082	0.5384	0.0049	0.3230	0.2720	0.0511	3.4077	2.8717	500
510	0.0139	0.7502	0.0093	0.5030	0.1582	0.0898	4.8412	1.5181	510
520	0.0743	0.8338	0.0633	0.7100	0.0782	0.5752	6.4491	0.7140	520
530	0.1547	0.8059	0.1655	0.8620	0.0422	1.5206	7.9357	0.3871	530
540	0.2296	0.7543	0.2904	0.9540	0.0203	2.7858	9.1470	0.1956	540
550	0.3016	0.6923	0.4334	0.9950	0.0087	4.2833	9.8343	0.0860	550
560	0.3731	0.6245	0.5945	0.9950	0.0039	5.8782	9.8387	0.0381	560
570	0.4441	0.5547	0.7621	0.9520	0.0021	7.3230	9.1476	0.0202	570
580	0.5125	0.4866	0.9163	0.8700	0.0017	8.4141	7.9897	0.0147	580
590	0.5752	0.4242	1.0263	0.7570	0.0011	8.9878	6.6283	0.0101	590
600	0.6270	0.3725	1.0622	0.6310	0.0008	8.9536	5.3157	0.0067	600
610	0.6658	0.3340	1.0026	0.5030	0.0003	8.3294	4.1788	0.0029	610
620	0.6915	0.3083	0.8544	0.3810	0.0002	7.0604	3.1485	0.0012	620
630	0.7079	0.2920	0.6424	0.2650	0.0000	5.3212	2.1948	0.0000	630
640	0.7190	0.2809	0.4479	0.1750	0.0000	3.6882	1.4411	0.0000	640
650	0.7260	0.2740	0.2835	0.1070	0.0000	2.3531	0.8876	0.0000	650
660	0.7300	0.2700	0.1649	0.0610	0.0000	1.3589	0.5028	0.0000	660
670	0.7320	0.2680	0.0874	0.0320	0.0000	0.7113	0.2606	0.0000	670
680	0.7334	0.2666	0.0468	0.0170	0.0000	0.3657	0.1329	0.0000	680
690	0.7344	0.2656	0.0227	0.0082	0.0000	0.1721	0.0621	0.0000	690
700	0.7347	0.2653	0.0114	0.0041	0.0000	0.0806	0.0290	0.0000	700
710	0.7347	0.2653	0.0058	0.0021	0.0000	0.0398	0.0143	0.0000	710
720	0.7347	0.2653	0.0029	0.0010	0.0000	0.0183	0.0064	0.0000	720
730	0.7347	0.2653	0.0014	0.0005	0.0000	0.0085	0.0030	0.0000	730
740	0.7347	0.2653	0.0007	0.0003	0.0000	0.0040	0.0017	0.0000	740
750	0.7347	0.2653	0.0003	0.0001	0.0000	0.0017	0.0006	0.0000	750
760	0.7347	0.2653	0.0002	0.0001	0.0000	0.0008	0.0003	0.0000	760
770	0.7347	0.2653	0.0001	0.0000	0.0000	0.0003	0.0000	0.0000	770
780	0.7347	0.2653	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	780

corresponding tristimulus values X, Y, and Z in the XYZ system. These transformations are based on the CIE primaries matched to the equal-energy spectrum (Illuminant E). The equations are:

$$X = 0.490R + 0.310G + 0.200B \tag{1.4}$$
$$Y = 0.177R + 0.813G + 0.011B \tag{1.5}$$
$$Z = 0.000R + 0.010G + 0.990B \tag{1.6}$$
$$R = 2.365X - 0.897Y - 0.468Z \tag{1.7}$$
$$G = -0.515X + 1.426Y + 0.089Z \tag{1.8}$$
$$B = 0.005X - 0.014Y + 1.009Z \tag{1.9}$$

For the spectral colors, the particular values of the tristimulus values are the distribution coefficients $\bar{x}$, $\bar{y}$, and $\bar{z}$ and $\bar{r}$, $\bar{g}$, and $\bar{b}$, respectively. Accordingly Eqs. (1.4)–(1.9) may be used to transform one set of distribution coefficients to the other.

A different set of transformation equations applies to the NTSC–FCC standard color system since different primaries are used and the color matching is based on Illuminant C. The equations relating the two sets of tristimulus values in the NTSC–FCC colorimetric system are:

$$X = 0.607R + 0.174G + 0.201B \tag{1.10}$$
$$Y = 0.299R + 0.587G + 0.114B \tag{1.11}$$
$$Z = 0.000R + 0.066G + 1.117B \tag{1.12}$$
$$R = 1.910X - 0.533Y - 0.288Z \tag{1.13}$$
$$G = -0.985X + 2.000Y - 0.028Z \tag{1.14}$$
$$B = 0.058X - 0.118Y + 0.896Z \tag{1.15}$$

It should be noted that the actual colorimetric measurements of tristimulus values must be performed in terms of the real primaries R, G, and B, since the nonphysical primaries X, Y, and Z cannot be realized. The corresponding tristimulus values, distribution coefficients and chromaticity coordinates in the XYZ sysem are then computed by the equations given in this section and Sec. 1.409.

From the tristimulus values the corresponding chromaticity coordinates are found by the definitions given in Sec. 1.409. The RGB and XYZ chromaticity diagrams are given in Figs. 1-17 and 1-18, showing the location of the CIE primaries, the equal-energy white point W (Illuminant E), and the spectrum locus.

1.411 Chromaticity Coordinates of Typical Sources. The x, y, and z chromaticity coordinates of typical illuminants, primary colors, and natural and artificial light sources are given in Table 1.17.

1.412 Standard Illuminants. The CIE has set up three standard illuminants, representative of incandescent light (Illuminant A), noon sunlight (Illuminant B), and north-sky daylight (Illuminant C). The relative energy distributions of these illuminants are given in Table 1.16 and their chromaticity coordinates in Table 1.17. Illuminant C is the reference white of the FCC–NTSC compatible color system (see Sec. 2.305). Accordingly, the chromaticity coordinates of an object illuminated by this white are of particular interest in color television. Table 1.16 gives the product of the Illuminant C energy ordinates and the $\bar{x}$, $\bar{y}$, and $\bar{z}$ distribution coefficients under the headings $E_C\bar{x}$, $E_C\bar{y}$, and $E_C\bar{z}$. To find the chromaticity coordinates of a material illuminated by Illuminant C whose reflectance R_λ is known at wavelength intervals of 10 mμ, the following relationships are employed

$$X = \tfrac{1}{98} \sum_{\lambda=380}^{\lambda=780} R_\lambda (E_C\bar{x})_\lambda \tag{1.16}$$

$$Y = \tfrac{1}{100} \sum_{\lambda=380}^{\lambda=780} R_\lambda (E_C\bar{y})_\lambda \tag{1.17}$$

$$Z = \tfrac{1}{118} \sum_{\lambda=380}^{\lambda=780} R_\lambda (E_C\bar{z})_\lambda \tag{1.18}$$

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z} \tag{1.19}$$

Table 1.17 Chromaticity Coordinates (Trichromatic Coefficients) of Illuminants and Primaries

Designation	x	y	z
Illuminant A	0.4476	0.4075	0.1450
Illuminant B	0.3484	0.3516	0.3000
Illuminant C	0.3101	0.3162	0.3738
Illuminant E (equal-energy white)	0.3333	0.3333	0.3333
Planckian radiator:			
2000°K	0.5266	0.4133	0.0601
2848°K	0.4475	0.4075	0.1450
3500°K	0.4052	0.3907	0.2041
5000°K	0.3450	0.3516	0.3034
7500°K	0.3003	0.3103	0.3894
10,000°K	0.2806	0.2883	0.4311
Sunlight	0.336	0.350	0.314
Average daylight	0.313	0.328	0.359
North-sky daylight	0.277	0.293	0.430
Zenith sky	0.263	0.278	0.459
White-flame carbon arc	0.315	0.332	0.353
Fluorescent lamp (4500°K)	0.539	0.363	0.278
Fluorescent lamp (3500°K)	0.404	0.396	0.200
CIE standard red primary (700 mμ)	0.7347	0.2653	0.0000
CIE standard green primary (546.1 mμ)	0.2738	0.7174	0.0088
CIE standard blue primary (435.6 mμ)	0.1666	0.0089	0.8245
NTSC primaries:			
Red	0.67	0.33	0.00
Green	0.21	0.71	0.08
Blue	0.14	0.08	0.78
Field-sequential (low-flicker) primaries:			
Red	0.674	0.326	0.000
Green	0.227	0.694	0.079
Blue	0.122	0.142	0.736
Phosphor primaries:			
Red (zinc phosphate)	0.652	0.348	0.000
Red (zinc-lead sulfide)	0.683	0.317	0.000
Green (willemite, medium persistence)	0.270	0.730	0.000
Green (willemite, short persistence)	0.250	0.685	0.065
Blue (silicate)	0.163	0.126	0.711
Blue (zinc sulfide)	0.141	0.082	0.777

1.5 DEFINITIONS OF TERMS

The following terms from the fields of television, photometry, and colorimetry have been compiled from lists of official definitions or standards. The abbreviations following each definition refer to the following sources:

AAPL: The American Artists Professional League
APA: American Psychological Society
CGPS: Colour Group of the Physical Society (London)
FCC: Federal Communications Commission, Rules Governing Television Broadcast Stations, Section 3.681, December, 1953
IES: Illuminating Engineering Society

IRE, 1948: Standards on Television, Definitions of Terms, 1948, Institute of Radio Engineers

IRE, 1953: Standards on Television, Definitions of Color Terms, 1953, Institute of Radio Engineers

IRE, 1955: Standards on Television, Definitions of Color Terms, 1955, Institute of Radio Engineers

NTSC: Final Report, Panel 19, National Television System Committee, 1953

OSA: Optical Society of America

RETMA, 1948: Radio-Electronics-Television Manufacturers Association, Standard TR-106, "Electrical Performance Standards for Television Relay Facilities," 1948

RETMA, 1949: RETMA Standard TR-104-A, "Electrical Performance Standards for Television Broadcast Transmitters, Channels 1-13," 1949

RETMA, 1951: RETMA Standard REC-129-C, "Radiation Rating of Television and F-M Broadcast Receivers," 1951

RETMA, 1952: RETMA Standards Proposal 378, "Proposed Electrical Performance Characteristics of Television Studio Facilities," 1952

SMPTE: Society of Motion Picture and Television Engineers

USP: United States Pharmacopoeial Convention

Accommodation. Adjustment of the focus of the eye for a given distance. (APA)

Achromatic Locus (Achromatic Region). Chromaticities which may be acceptable reference standards under circumstances of common occurrence are represented in a chromaticity diagram by points in a region which may be called the "achromatic locus."

Note: The boundaries of the achromatic locus are indefinite, depending on the tolerances in any specific application. Acceptable reference standards of illumination (commonly referred to as "white light") are usually represented by points close to the locus of Planckian radiators having temperatures higher than about 2000°K. While any point in the achromatic locus may be chosen as the reference point for the determination of dominant wavelength, complementary wavelength, and purity for specification of object colors, it is usually advisable to adopt the point representing the chromaticity of the luminator. Mixed qualities of illumination, and luminators with chromaticities represented very far from the Planckian locus, require special consideration. Having selected a suitable reference point, dominant wavelength may be determined by noting the wavelength corresponding to the intersection of the spectrum locus with the straight line drawn from the reference point through the point representing the sample. When the reference point lies between the sample point and the intersection, the intersection indicates the complementary wavelength. Any point within the achromatic locus, chosen as a reference point, may be called an "achromatic point." Such points have also been called "white points." (IRE, 1953)

Achromatic Region. The part of a chromaticity diagram that represents chromaticities that are perceived as having no hue under circumstances of common occurrence.

Note: The achromatic region includes portions of the chromaticity diagram on both sides of the Planckian locus for temperatures higher than about 2360°K. Any point in the achromatic region may be chosen as representative of achromatic for the determination of dominant wavelength, complementary wavelength, and purity. For specification of object colors it is usually advisable to adopt the point representing the chromaticity of the illuminant. Mixed qualities of illumination and illuminants with chromaticities represented very far from the black-body locus require special consideration. (OSA)

A-c Transmission. In a-c transmission a fixed setting of the controls makes any instantaneous value of signal correspond to the same value of brightness only for a short time.

Note: Usually, this time is not longer than one field period, and may be as short as one line period.

Note: If the signal is considered to be an a-m wave, then "instantaneous value of signal" should be interpreted as "instantaneous value of envelope."

Note: If the signal is considered to be an f-m wave, then "instantaneous value of

signal" should be interpreted as "instantaneous frequency of the modulated wave." (IRE, 1948)

Additive Mixture. The mixture of light stimuli in such a manner that they enter the eye simultaneously or in rapid succession, and are incident on the same area of the retina or enter in the form of a mosaic which the eye cannot resolve. (CGPS)

Additive Primaries. Certain dyes, pigments, or other secondary or primary sources of light (e.g., monochromatic radiations) giving rise to stimuli predominantly confined to one part of the spectrum, which by additive mixture of the stimuli in varying proportions can be made to match a large range of colors. Generally three in number; a red, a green, and a blue.

Note: It is recommended that the term "primaries" should be reserved for the dyes and pigments used in color-reproduction processes. (CGPS)

Amplitude Modulation (AM). A system of modulation in which the envelope of the transmitted wave contains a component similar to the waveform of the signal to be transmitted. (FCC)

Modulation in which the amplitude of a wave is the characteristic subject to variation. (IRE, 1948)

A-m Noise Level on Carrier (Aural Transmitter). The ratio of the rms value of the a-m component (50 to 15,000 cycles) of the carrier envelope to the rms carrier value in the absence of applied modulating voltage. (RETMA, 1949)

Amplitude versus Frequency Characteristic. A description by means of a graph of the ratio of sine-wave output voltage to input voltage applied to a four-terminal network. In the case of a transmitter this characteristic is taken between the transmitter input terminals and the output terminals of an assumed ideal linear detector. (RETMA, 1949)

Antenna Height above Average Terrain. The average of the antenna heights above the terrain from 2 to 10 miles from the antenna for the eight directions spaced evenly for each 45 deg of azimuth starting with true north. (In general, a different antenna height will be determined in each direction from the antenna. The average of these various heights is considered the antenna height above the average terrain. In some cases less than eight directions may be used.) (FCC)

Antenna Pattern (Free Space)–Relay System. The pattern of a relay antenna is a plot of free-space radiation field intensity at a fixed distance versus angle, taken in a plane passing through the center of the antenna. Ordinarily the horizontal and vertical planes adequately define the pattern in space. (RETMA, 1948)

Antenna Power Gain. The square of the ratio of the r-m-s free-space field intensity produced at 1 mile in the horizontal plane, in millivolts per meter for 1 kw antenna input power to 137.6 mv per meter. This ratio should be expressed in decibels (db). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.) (FCC)

Antenna Power Gain–Relay System. The ratio of power radiated in the desired direction by the antenna in question compared with the power radiated in the direction of maximum radiation by a half-wave dipole with the same input power. (RETMA, 1948)

Apparent Candlepower. The apparent candlepower of an extended source of light measured at a specified distance is the candlepower of a point source of light which would produce the same illumination at that distance. (IES, OSA)

Aspect Ratio. The ratio of picture width to picture height as transmitted. (FCC)

The ratio of the frame width to the frame height. (IRE, 1948; RETMA, 1952)

Audio-frequency Harmonic Distortion (Aural Transmitter). The change in harmonic content of the input signal as a result of passing through the transmitter. The standard 75 μsec preemphasis shall be employed in the transmitter. (RETMA, 1949)

Audio-frequency Response (Frequency-modulated Transmitter). A description by means of a graph or a specification of the ratio of input voltages (expressed in decibels) required to obtain a constant frequency swing at all audio frequencies between 50 and 15,000 cycles, referred to a 1,000-cycle standard. (RETMA, 1949)

Audio-input Level for 100 Per Cent Modulation. The audio input expressed in dbm necessary to obtain 100 per cent modulation. One hundred per cent modulation

is represented by ±25-kc swing. The term dbm is defined as decibels referred to 1 mw, single frequency, sine wave. (RETMA, 1949)

Aural Center Frequency. The average frequency of the emitted wave when modulated by a sinusoidal signal. The frequency of the emitted wave without modulation. (FCC)

Aural Transmitter. The radio equipment for the transmission of the aural signal only. (FCC; IRE, 1948)

The r-f circuits and modulation equipment required to deliver the standard output signal as defined by RETMA standards into a nonreactive load when a standard aural-transmitter input signal is applied. (RETMA, 1949)

Bandwidth. The number of cycles per second expressing the difference between the limiting frequencies of a frequency band. (IRE, 1948)

Black-and-white. See Monochrome. (IRE, 1955)

Beer's Law. Radiant transmittance of a solution is a function of the product of the concentration times the thickness of the layer.

Note: Beer's law can apply only to solutions in which the solvent has zero absorptivity, and does not apply even to all such solutions. Furthermore, it is expected to apply only to irradiation of solutions by energy restricted to a wavelength range within which the solution is a nonselective absorber. (OSA)

Black Body. A temperature radiator of uniform temperature whose radiant flux in all parts of the spectrum is the maximum obtainable from any temperature radiator at the same temperature. Such a radiator is called a black body because it will absorb all the radiant energy that falls upon it. All other temperature radiators may be classed as nonblack bodies. They radiate less in some or all wavelength intervals than a black body of the same size and the same temperature. (IES)

Black Level. The instantaneous amplitude of the television signal which corresponds to a black area in the received picture.

Note: The brightness of the received picture in the black area may not be the same from scene to scene.

Note: If the signal is considered to be an a-m wave, then "instantaneous value of signal" should be interpreted as "instantaneous value of envelope."

Note: If the signal is considered to be an f-m wave, then "instantaneous value of signal" should be interpreted as "instantaneous frequency of the modulated wave." (IRE, 1948)

Black Peak. The maximum excursion of the picture signal in the black direction at the time of observation. (RETMA, 1952)

Blanking. The substitution for the picture signal, during prescribed intervals, of a signal whose instantaneous amplitude is such as to make the return trace invisible. (IRE, 1948)

Blanking Level. The level of the signal during the blanking interval, except the interval during the scanning synchronizing pulse and the chrominance-subcarrier synchronizing burst. (FCC)

The level in a composite picture signal that separates the range of the composite picture signal containing picture information from the range containing synchronizing information. (IRE, 1948)

The level of the signal during the blanking interval. It coincides with the level of the base of the synchronizing pulse. (RETMA, 1952)

Blanking Signal. A wave constituted of recurrent pulses, related in time to the scanning process, used to effect blanking. (IRE, 1948)

Blind Spot. An irregular area in the retina which is not sensitive to light stimulation because it lacks rods and cones. The blind spot is around 6.5 deg of visual angle in diameter and is situated about 15 deg to the nasal side of the center of the retina, corresponding to the place of exit of the optic nerve. The blind spot explains the substantial gap in the temporal side of the monocular visual space. Sometimes called Mariotte's spot, from its discoverer. (APA, OSA)

Brightness. The attribute of visual perception in accordance with which an area appears to emit more or less light.

Note: Luminance is recommended for the photometric quantity, which has been

called "brightness." Luminance is a purely photometric quantity. Use of this name permits "brightness" to be used entirely with reference to the sensory response. The photometric quantity has been often confused with the sensation merely because of the use of one name for two distinct ideas. Brightness will continue to be used, properly, in nonquantitative statements, especially with reference to sensations and perceptions of light. Thus, it is correct to refer to a brightness match, even in the field of a photometer, because the sensations are matched and only by inference are the photometric quantities (luminances) equal. Likewise, a photometer in which such matches are made will continue to be called an "equality-of-brightness" photometer.

A photoelectric instrument, calibrated in foot-lamberts, should not be called a "brightness meter." If correctly calibrated it is a "luminance meter." A troublesome paradox is eliminated by the proposed distinction of nomenclature. The luminance of a surface may be doubled, yet it will be permissible to say that the brightness is not doubled, since the sensation which is called "brightness" is generally judged to be not doubled. (IRE, 1953; NTSC)

The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction.

$$B = dI\ (dA \cos \theta)$$

Note: In the defining equation θ is the angle between the direction of observation and the normal to the surface. In practice no surface follows exactly the cosine formula of emission or reflection; hence, the brightness of a surface generally is not uniform but varies with the angle at which it is viewed. Brightness can be measured not only for sources and illuminated surfaces, but also for virtual surfaces such as the sky.

In common usage the term brightness usually refers to the intensity of *sensation* which results from viewing surfaces or spaces from which light comes to the eye. This sensation is determined in part by the definitely measurable "brightness" defined above and in part by conditions of observation such as the state of adaptation of the eye. (IES)

Brightness Channel. Deprecated (see Monochrome Channel). (NTSC)

Brightness Control. The manual bias control of a picture tube.

Note: The brightness control affects both the average brightness and the contrast of the picture. (IRE, 1948)

Brightness Signal. Deprecated. See Luminance Signal. (IRE, 1955)

Burst Pedestal (Color-burst Pedestal). The rectangular pulselike component which may be part of the color burst. The amplitude of the color-burst pedestal is measured from the a-c axis of the sine-wave portion to the horizontal pedestal. (NTSC)

Bypass Mixed Highs. The mixed-highs signal that is shunted around the chrominance-subcarrier modulator or demodulator. (NTSC)

Bypass Monochrome Signal. A monochrome signal that is shunted around the chrominance-subcarrier modulator or demodulator. (NTSC)

Bypassed Monochrome. Deprecated (see Shunted Monochrome). (NTSC)

Camera Spectral Characteristic. The sensitivity of each of the camera color-separation channels with respect to wavelength.

Note 1: It is necessary to state the camera terminals at which the characteristics apply.

Note 2: Because of nonlinearity the spectral characteristics of some kinds of cameras depend upon the magnitude of radiance used in their measurement.

Note 3: Nonlinearizing and matrixing operations may be performed within the camera. (NTSC)

Camera Taking Characteristics Deprecated (see Camera Spectral Characteristic). (NTSC)

Camera Tube. An electron-beam tube in which an electron current or charge-density image is formed from an optical image and scanned in a predetermined sequence to provide an electrical signal. (IRE, 1948)

Candle. The unit of luminous intensity. One candle is defined as the luminous intensity of 1/60 sq cm of a black-body radiator operating at the temperature of solidification of platinum. Values for standards having other spectral distributions are derived by the use of accepted luminosity factors. (IRE, 1953)

Candle, New. As from Jan. 1, 1948, the unit of luminous intensity will be such that the luminance of a complete radiator at the temperature of solidification of platinum shall be 60 units of intensity per square centimeter.

Note: This unit will be called the New Candle (resolution of the Comité International des Poids et Mesures, Paris, June, 1937). (OSA, APA)

Candlepower. Luminous intensity expressed in candles. (IRE, 1953; IES)

Luminous intensity expressed in candles. Also called candle, e.g., "the intensity of a source is 60 candles," "the candlepower of a source is 60." (APA)

Carrier. A wave suitable for modulation by a modulating wave.

Note: Examples of carriers are a sine wave and a recurring series of pulses. (IRE, 1948)

Carrier-chrominance Signal. The sidebands of the modulated chrominance subcarrier (plus the chrominance subcarrier, if not suppressed) which are added to the monochrome signal to convey color information. (NTSC)

Carrier Frequency. In a periodic carrier, the reciprocal of its period.

Note: The frequency of a periodic pulse carrier often is called the pulse-repetition frequency (prf). (IRE, 1948)

Carrier-frequency Range of a Transmitter. The range of frequencies to which the transmitter may be adjusted for normal operation. (IRE, 1948)

Carrier-frequency Stability of a Transmitter. A measure of the ability of the transmitter to maintain an assigned average frequency. (IRE, 1948; RETMA, 1949)

Carrier-power Output Rating (Aural Transmitter). The power available at the output terminals of the transmitter when the output terminals are connected to the normal load circuit or to a circuit equivalent thereto. (RETMA, 1949)

Carrier Reference-white Level. The carrier amplitude corresponding to reference-white level. (RETMA, 1949)

Center Frequency. See Carrier Frequency. Center frequency is commonly used only for aural transmitters. (IRE, 1948)

Center-frequency Stability (Aural Transmitter). The ability of the transmitter to maintain an assigned center frequency in the absence of modulation. The center-frequency stability is expressed as the maximum number of cycles deviation from the assigned frequency, within the limits of normal operation conditions. (RETMA, 1949)

Chroma (Munsell Chroma). The dimension of the Munsell system of color which corresponds most closely to saturation. (APA; IRE, 1953)

Note: Chroma is frequently used, particularly in English works, as the equivalent of Saturation (*q.v.*). (IRE, 1953)

Chromatic Aberration. In an optical system the failure of rays of light from a given point to come to a focus at a point, owing to the fact that light from different parts of the spectrum is refracted unequally (APA)

Chromaticity. The color quality of light definable by its chromaticity coordinates, or by its dominant (or complementary) wavelength and its purity taken together. (IRE, 1953)

The quality of color specified by dominant wavelength and purity (alternatively complementary wavelength and purity) taken together.

Note: Chromaticity is equivalent to the common concept of quality as distinguished from quantity of light. Chromaticity may be specified in other ways than by dominant (alternatively complementary) wavelength and purity, such as by the chromaticity coordinates (x,y) of the standard CIE coordinate system. (OSA)

Chromaticity Coordinate. The ratio of any one of the tristimulus values of a sample to the sum of the three tristimulus values. (IRE, 1953)

The ratio of any one of the color-mixture data for a sample to the sum of the color-mixture data.

Note: Any pair of these three coordinates may be used to define a point in a plane

representing the chromaticity of the sample. This term is sanctioned by usage only; the official term is Trichromatic Coordinate. (OSA)

Chromaticity Diagram. A plane diagram formed by plotting one of the three chromaticity coordinates against another.

Note: The most common chromaticity diagram at present is the CIE (x,y) diagram plotted in rectangular coordinates (see Fig. 1-19). (IRE, 1953)

A plane diagram formed by plotting one of any set of three chromaticity coordinates against another.

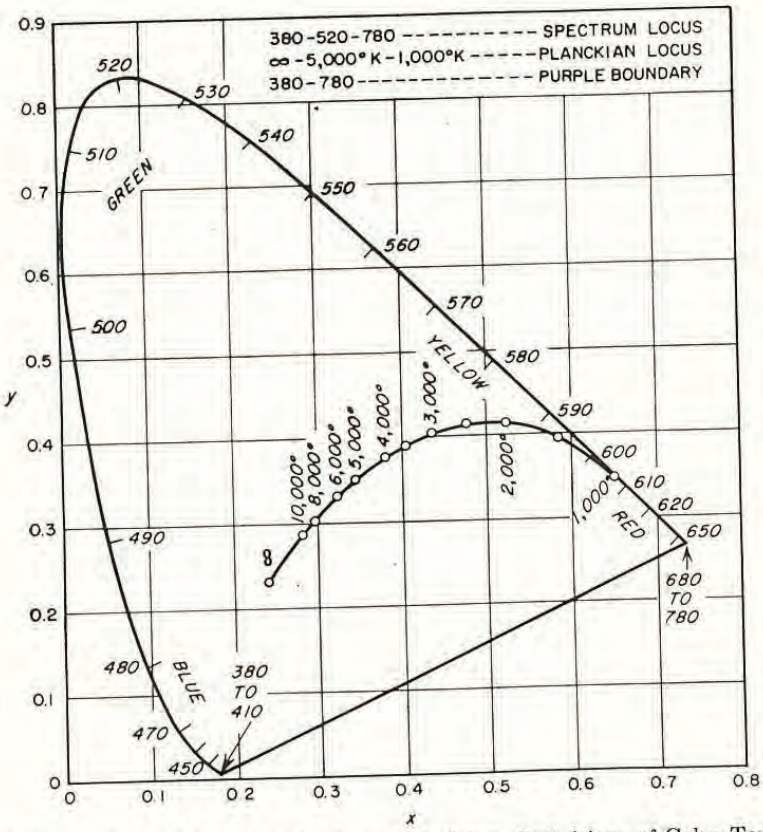

FIG. 1-19. Figure 1 of the IRE Standards on Television, Definitions of Color Terms, 1953.

Note: Any four chromaticities (no one of which can be matched by a mixture of any pair of the others) may be represented by any four points on a plane (provided that no three of the points are on a single straight line). Assignment of the points representative of the four basic qualities determines completely the entire chromaticity diagram and the location of the point that represents any chromaticity for an observer of known properties such as the standard observer. Either rectangular or oblique coordinates may be used, the most common at present being the CIE (x,y) diagram plotted in rectangular coordinates. (OSA)

Chromaticity Flicker. That flicker which results from fluctuation of chromaticity only. (IRE, 1955)

Chromatopsia. An abnormal state of vision in which colorless objects appear colored. For example, yellow after overdoses of santonin, red after snow blindness. (APA)

Chrominance. The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specific chromaticity. (FCC)

The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specified chromaticity.

Note: In NTSC transmission the specified chromaticity is the zero-subcarrier chromaticity, which is that of Illuminant C. (NTSC)

The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specified chromaticity.

Note 1: In three-dimensional color space, chrominance is a vector which lies in a plane of constant luminance. In that plane it may be resolved into components, called chrominance components.

Note 2: In color television transmission, for example, the chromaticity of the reference color, may be that of a specified white. (IRE, 1955)

Chrominance Bandwidth. See Chrominance-channel Bandwidth. (NTSC)

Chrominance Carrier. See Chrominance Subcarrier. (NTSC)

Chrominance-carrier Reference. A continuous signal having the same frequency as the chrominance subcarrier and having fixed phase with respect to the color burst. This signal is the reference with which the phase of the carrier-chrominance signal is compared for the purpose of modulation or demodulation. (NTSC)

Chrominance Channel. In a color television system any path which is intended to carry the carrier-chrominance signal. (NTSC)

Chrominance-channel Bandwidth. The bandwidth of the path intended to carry the carrier-chrominance signal.

Note: The sum of the video bandwidths of the two color-difference signals may approach but not exceed the total chrominance bandwidth of the two signals. (NTSC)

Chrominance Component. Any component of the two-dimensional chrominance vector.

Note: In the NTSC transmission it is common practice to resolve the chrominance vector along specified axes lying in a plane of constant luminance. (NTSC)

Chrominance Demodulator. A demodulator used in color television reception for deriving video frequency-chrominance components from the chrominance signal and a sine wave of the chrominance subcarrier frequency. (IRE, 1955)

Chrominance Modulator. A modulator used in color television transmission for generating the chrominance signal from the video frequency-chrominance components and the chrominance subcarrier. (NTSC; IRE, 1955)

Chrominance Primary. One of the two nonphysical transmission primaries which have zero luminance. Refer to Transmission Primaries. (NTSC)

A transmission primary which is one of two whose amounts determine the chrominance of a color.

Note: Chrominance primaries have zero luminance and are nonphysical. (IRE, 1955)

Chrominance Signal. See Carrier-chrominance Signal. (NTSC)

(Carrier-chrominance signal.) The sidebands of the modulated chrominance subcarrier which are added to the monochrome signal to convey color information. (IRE, 1955)

Chrominance-signal Component. A component of the chrominance signal, produced when a chrominance primary signal suitably modulates a subcarrier voltage of the proper phase.

Note: In the NTSC signal specification, the chrominance-signal component representing the amount of the fine chrominance primary is transmitted in vestigial sideband fashion about the subcarrier frequency. The chrominance-signal component representing the amount of the coarse chrominance primary is transmitted in double-sideband fashion so as to allow completely independent detection of the two signals. (NTSC)

Chrominance Subcarrier. The carrier whose modulation sidebands are added to the monochrome signal to convey chrominance information. (NTSC; IRE, 1955)

The carrier which is modulated by the chrominance information. (FCC)

Chrominance-subcarrier Reference. See Chrominance-carrier Reference. (NTSC)

CIE. Abbreviation for Commission Internationale de l'Eclairage.

Note: These are the initials of the official French name of the International Commission on Illumination. This translated name is approved for usage in English-speaking countries, but at its 1951 meeting the Commission recommended that only the initials of the French name be used. The initials "ICI" which have been used commonly in this country are deprecated because they conflict with an important trademark registered in England and because the initials of the name translated into other languages are different. (IRE, 1953)

Coarse Chrominance Primary. A zero-luminance transmission primary associated with the minimum bandwidth of chrominance transmission and chosen for its relatively small importance in contributing to the subjective sharpness of the color picture.

Note: In the NTSC signal specification the coarse chrominance primary signal, representing the amount of the coarse chrominance primary, is transmitted in a narrower bandwidth appropriate to its smaller contribution to the subjective sharpness of the color picture. Refer to Fine Chrominance Primary. (NTSC)

In the color television system at present standardized for broadcasting in the United States, that one of the two chrominance primaries which is associated with the lesser transmission bandwidth. (IRE, 1955)

Color. The characteristics of light other than spatial and temporal inhomogeneities.

Note 1: The measure of color is three-dimensional. One of the many ways of measuring color is in terms of luminance, dominant wavelength, and purity.

Note 2: Inhomogeneities, for example, particular distributions and variations of light, and characteristics of objects which are revealed by variations such as gloss, luster, sheen, texture, sparkle, opalescence, and transparency are not included among the color characteristics of objects. (IRE, 1953)

The characteristics of light other than spatial and temporal inhomogeneities (light being that aspect of radiant energy of which a human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye). (OSA)

Color Breakup. Any spurious color caused by a difference in the condition of observation from one field to the next. (NTSC)

Any fleeting and partial separation of a color picture into its display primary components caused by a rapid change in the condition of viewing.

Note: Illustrations of rapid changes in the condition of viewing are (1) fast movement of the head, (2) fast interruption of the line of sight, (3) blinking of the eyes. (IRE, 1955)

Color Burst. That portion of the composite color signal comprising the few sine-wave cycles of chrominance-subcarrier frequency which is used to establish a reference for demodulating the chrominance signal. (IRE, 1955)

Color Carrier. See the preferred term Chrominance Subcarrier. (NTSC)

Color-carrier Reference. See Chrominance-carrier Reference. (NTSC)

Color Coder. In color television transmission, an apparatus for generating the color picture signal (and possibly the color burst) from camera signals and the chrominance subcarrier. (NTSC; IRE, 1955)

Color Coordinate Transformation. Computation of the tristimulus values of colors in terms of one set of primaries from the tristimulus values of the same colors in another set of primaries.

Note: This computation may be performed electrically in a color television system. (NTSC; IRE, 1955)

Color Decoder. In color television reception, an apparatus for deriving the receiver primary signals from the color picture signal and the color burst. (NTSC; IRE, 1955)

Color-difference Signal. An electrical signal which when added to the monochrome signal produces a signal representative of one of the tristimulus values (with respect to a stated set of primaries) of the transmitted color. (NTSC; IRE, 1955)

Color Edging. Spurious color at the boundaries of differently colored areas in the picture.

Note: Color edging includes color fringing, misregistration, etc. (NTSC)

Color Encoder. See Color Coder. (NTSC; IRE, 1955)

Color Flicker. That flicker which results from fluctuation of both chromaticity and luminance. (IRE, 1955)

Color Fringing. Spurious colors introduced into the picture by the change in position of the televised object from field to field. (NTSC)

Spurious chromaticity at boundaries of objects in the picture.

Note: Color fringing can be caused by the change in relative position of the televised object from field to field or by misregistration, and, in the case of small objects, may even cause them to appear separated into different colors. (IRE, 1955)

Color-mixture Data. The amounts of the primaries required to establish a match with the sample, either by addition of all three, or addition of one primary to the sample to match any pair of primaries, or the addition of any pair to the sample to match the remaining primary.

Note: The amounts of the primaries mixed with the sample are recorded as negative quantities. Color-mixture data depend upon the choice of primaries and upon the individual observer for whom the match is satisfactory. Individual variations of color-mixture data are considerable. (OSA)

See Tristimulus Values, the preferred term. (IRE, 1953)

Color Negative. 1. A negative photographic record of the color values of the original object as obtained through a single primary filter. 2. A negative photographic image in color. (SMPTE)

Color Phase. The phase, with respect to the chrominance-carrier reference, of that component of the carrier-chrominance signal which corresponds to one of the chrominance primaries. (NTSC)

Color Phase Alternation (CPA). The periodic changing of the color phase of one or more components of the chrominance subcarrier between two sets of assigned values.

Note: It is recommended that the term "color phase alternation" be used in place of the terms Oscillating Color Sequence and Flip-flop which have been used with this same meaning. (NTSC)

Color Picture Signal. The electrical signal which represents color picture information, consisting of a monochrome component plus a subcarrier modulated with color information, excluding synchronizing signals. (NTSC)

The electrical signal which represents complete color picture information, excluding all synchronizing signals.

Note: One form of color picture signal consists of a monochrome component plus a subcarrier modulated with chrominance information. (IRE, 1955)

Color Positive. 1. A positive photographic (print) record of color values. 2. A positive photographic image in color. (SMPTE)

Color Signal. Any signal, exclusive of the luminance or monochrome signal, at any point in a color television system, for wholly or partially controlling the chromaticity values of a color television picture.

Note: This is a general term which encompasses many specific connotations, such as are conveyed by the words Color Picture Signal, Chrominance Signal, Carrier Color Signal, etc. (NTSC)

Any signal, at any point in a color television system, for wholly or partially controlling the chromaticity values of a color television picture.

Note: This is a general term which encompasses many specific connotations, such as are conveyed by the words Color Picture Signal, Chrominance Signal, Carrier Color Signal, Monochrome Signal (in color television), etc. (IRE, 1955)

Color Solid. A symbolic figure in three dimensions, which represents the relations of all possible colors with respect to their primary attributes of hue, brightness or lightness, and saturation. Usually brightness (lightness) appears as the vertical axis of the figure, with hue and saturation represented in polar coordinates about the brightness axis, saturation being radial. The boundaries of the solid are actually irregular, but it is sometimes represented as a cylinder, a sphere, a spindle, or a double pyramid with a common (square) base. (APA, OSA, USP-NF)

Color Subcarrier. See the preferred term, Chrominance Subcarrier. (NTSC)

Color-subcarrier Reference. See Chrominance-carrier Reference. (NTSC)

Color Sync Signal. A sequence of color bursts which is continuous except for a specified time interval during the vertical blanking period, each burst occurring at a fixed time with respect to horizontal sync. (NTSC)

Color Temperature. The color temperature of a source of light is the temperature at which a black body must be operated to give a color matching that of the source in question.

Note: Color temperatures should be assigned only for sources which have a chromaticity not greatly different from a black body at some temperature. (IES)

Color Threshold. The luminance below which color becomes no longer discernible. The level varies for different colors. (CGPS)

Color Transmission. The transmission of color television signals which can be reproduced with different values of hue, saturation, and luminance. (FCC)

In television the transmission of a signal wave for controlling both the luminance values and the chromaticity values in a picture. (NTSC; IRE, 1955)

The transmission of a signal wave which represents both the brightness values and the chromaticity values in the picture. (IRE, 1948)

Color Triangle. This is a chromaticity diagram which is (typically) in the form of an equilateral triangle with apexes representing R, G, and B primaries and the enclosed area representing all the chromaticities possible by additive mixture of the primaries. Characteristic of the color triangle is the adjustment of the primary scales so unit amounts will yield an achromatic mixture which is represented by the centroid of the triangle; and the relative amounts of the primaries necessary to yield each chromaticity are then indicated by corresponding distances on the triangle. Sometimes called Maxwell Triangle. (APA)

A triangle drawn on a chromaticity diagram, representing the entire range of chromaticities obtainable as additive mixtures of three prescribed primaries, represented by the corners of the triangle. (IRE, 1955)

Compatibility. That property of a color television system which permits substantially normal monochrome reception of the transmission by typical monochrome receivers. (IRE, 1955)

Complementary Color. Color that when combined with another color produces a mixture color matching some agreed upon achromatic color. (OSA, USP)

Complementary Wavelength. The wavelength of light of a single frequency, which matches the reference standard light when combined with a sample color in suitable proportions.

Note 1: The wide variety of purples which have no dominant wavelengths, including nonspectral violet, purple, magenta, and nonspectral red colors, are specified by use of their complementary wavelengths.

Note 2: Refer to Dominant Wavelength. (IRE, 1953)

Composite Color Signal. The color picture signal plus blanking and all synchronizing signals. (NTSC; IRE, 1955)

Composite Color Sync. The signal comprising all the sync signals necessary for proper operation of a color receiver. This includes the deflection sync signals to which the color sync signal is added in the proper time relationship. (NTSC; IRE, 1955)

Composite Picture Signal. A signal consisting of the blanked picture signal and the synchronizing signals. (IRE, 1948)

A signal consisting of the following individual signals: (1) picture signal (including horizontal and vertical components of the blanking signal), and (2) synchronizing signal (horizontal and vertical components). (RETMA, 1952)

Cone, Retinal. A type of minute structure found in the retina of the eye which constitutes a specific receptor for vision. Distinguish from retinal rods, another visual receptor; the cones are without visual purple and are believed to operate for both chromatic and achromatic (gray) visual qualities at higher levels of illumination, the rods for achromatic only at low (twilight) levels; the rods and cones form the second layer of the retina from the surface of the eyeball, lying just within the layer of pigmented cells; at the center of the retina the cones are long and slender and closely packed to the exclusion of rods; farther out they are shorter and thicker and interspersed among the more numerous rods, and their outer portion has become small and cone-shaped, whence their name; it is estimated that there are 7 million cones in the human retina. (APA)

Constant-luminance Transmission. A method of color transmission in which the carrier-chrominance signal controls the chromaticity of the produced image without affecting the luminance, the luminance being controlled by the monochrome signal. (NTSC)

That type of transmission in which the transmission primaries are a luminance primary and two chrominance primaries. (IRE, 1955)

Contrast. The ratio between the maximum and minimum brightness values in a picture.

Note: Contrast is sometimes used in a different sense in describing the characteristics of a photographic material. (IRE, 1948)

Intensification or emphasis, by juxtaposition of stimuli, of two contrary or opposing mental data. Contrast may be simultaneous, viz., between simultaneous impressions, or successive, viz., between impressions which closely follow each other. (APA)

Contrast, Color. The ratio of the intensities of the sensations caused by two colors. Sometimes the logarithm of this ratio. (SMPTE)

Contrast Control. The manual gain control for the picture signal.

Note: The contrast control affects both the brightness and the contrast of the picture. (IRE, 1948)

Critical Flicker Frequency. The minimum number of alternations per second of two different visual stimuli (or the frequency of any periodically variable stimulus) upon the same retinal area which will permit a constant effect in visual experience, as if from an invariable stimulus, i.e., which will result in the elimination of flicker. (APA)

Cross Color. Interference produced in the chrominance channel of a color television receiver by cross talk from the monochrome signal. (NTSC)

Crossfire. Interfering current in one signaling channel resulting from signaling currents in another channel. (IRE, 1948)

Cross Talk The sound heard in a receiver associated with a given telephone channel resulting from telephone currents in another telephone channel.

Note: In practice, cross talk may be measured either by the loudness of the overheard sounds or by the magnitude of the coupling between the disturbed and disturbing channels. In the latter case, to specify the loudness of the overheard sounds, the volume in the disturbing channel must also be given. (IRE, 1948)

Cross Talk (within Television Relay Signal). *Audio Signal.* Interference with the audio signal produced by other components of the television relay signal. (RETMA, 1948)

Composite Picture Signal. Interference with the composite picture signal produced by other components of the television relay signal. (RETMA, 1948)

Cyan. 1. The hue attribute of visual sensations typically evoked by stimulation of the normal human eye with radiation of wavelength approximately 494 mμ. 2. Any hue predominantly similar to that of the typical cyan. The complement of red. (APA)

Daylight. Total radiation from the sky and sun. For standardization of spectral quality, measurements are made at noon. The quality of daylight matches approximately that of a black body at 6500°K. (SMPTE)

D-c Restorer. A device, used in an a-c transmission system, to establish d-c transmission.

Note: A d-c restorer adds to the picture signal a l-f correcting signal including direct-current. The correcting signal is usually derived by sampling the picture signal at a time when its instantaneous value represents a known brightness. Because of the high sampling rate, the d-c restorer effectively reinserts the d-c component and reduces superposed l-f interference. (IRE, 1948)

D-c Transmission. In d-c transmission a fixed setting of the controls makes any instantaneous value of signal correspond to the same value of brightness at all times.

Note: If the signal is considered to be an a-m wave, then "instantaneous value of signal" should be interpreted as "instantaneous value of envelope."

Note: If the signal is considered to be a f-m wave, then "instantaneous value of signal" should be interpreted as "instantaneous frequency of the modulated wave." (IRE, 1948)

Deemphasis. The restoration of a preemphasized signal wave to its original form (see Preemphasis). (IRE, 1948)

Deflection Polarity of an Oscilloscope. The relationship between the direction of displacement and the polarity of the applied signal wave. (IRE, 1948)

Deflection Yoke. An assembly of one or more coils, whose magnetic field deflects an electron beam. (IRE, 1948)

Delay Distortion. That form of distortion which occurs when the envelope delay of a circuit or system is not constant over the frequency range required for transmission. (NTSC)

Desaturated Colors (Color Photography). Colors in which the saturation is noticeably decreased as compared with a standard. (This term is often applied to a color as reproduced, as compared with the original.) (CGPS)

Dichroic Filter. 1. A semitransparent mirror which selectively reflects some wavelengths more than others and so transmits selectively. 2. A filter transmitting two narrow regions of the spectrum. (SMPTE)

Dichromatic Vision. A form of defective color vision in which all colors can be matched by a mixture of only two suitably chosen stimuli.

Note: In dichromatic vision the spectrum is seen as comprising only two regions of different hue separated by an achromatic band. Dichromatic vision can be subdivided into three types—protanopia, deuteranopia, and tritanopia. Also called dichromatism, hence dichromat. (CGPS)

Difference Limen. The small amount of difference between two compared stimuli which gives rise (statistically) to a perceived difference as often as it does not. The difference limen is the same as the average just-noticeable difference. Also called differential threshold, threshold of difference. (APA)

Display Primaries (Receiver Primaries). The colors of constant chromaticity and variable luminance produced by the receiver or any other display device which, when mixed in proper proportions, are used to produce other colors.

Note: Usually three primaries are used: red, green, and blue. (IRE, 1955)

Dissector Tube. A camera tube having a continuous photocathode on which is formed a photoelectric emission pattern which is scanned by moving its electron-optical image over an aperture. (IRE, 1948)

Distribution Coefficients. The relative trichromatic coordinates of the spectral components of an equal-energy spectrum. Denoted by $\bar{x}$, $\bar{y}$, $\bar{z}$ in the CIE system and defined in a table of figures which represents the characteristics of the standard observer. (CGPS)

The tristimulus values of monochromatic radiations of equal power.

Note: Generally represented by overscored, lower-case letters, such as $\bar{x}$, $\bar{y}$, $\bar{z}$ in the CIE system. (IRE, 1955)

Dominant Wavelength. The wavelength of light of a single frequency, which matches a color when combined in suitable proportions with a reference standard light.

Note: Light of a single frequency is approximated in practice by the use of a range of wavelengths within which there is no noticeable difference of color. Although this practice is ambiguous in principle, the dominant wavelength is usually taken as the average wavelength of the band used in the mixture with the reference standard matching the sample. Many different qualities of light are used as reference standards under various circumstances. Usually the quality of the prevailing illumination is acceptable as the reference standard in the determination of the dominant wavelength of the colors of objects. (IRE, 1953)

Dominant Wavelength (Graphical Determination). The wavelength corresponding to the intersection with the spectrum locus, of the straight line drawn from the reference point and extended through the point representing the sample. (IES)

Dot-sequential. Pertaining to the association of the several primary colors in sequence with successive picture elements.

Examples: Dot-sequential pickup, dot-sequential display, dot-sequential system, dot-sequential transmission. (IRE, 1955)

Driving Signals. In television, signals that time the scanning at the pickup point. (IRE, 1948)