

**UNITED STATES PATENT AND TRADEMARK OFFICE**

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**BEFORE THE PATENT TRIAL AND APPEAL BOARD**

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HESAI TECHNOLOGY CO., LTD.

*Petitioner*

v.

OUSTER, INC.

*Patent Owner*

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U.S. Patent No. 11,175,405

*Inter Partes Review* No. 2023-\_\_\_\_\_

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**DECLARATION OF JAMES F. SHANLEY, PH.D.**

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**EXHIBIT LIST**

| No.  | Short Name               | Exhibit                                                                                                                                                    |
|------|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1001 | '405 Patent              | U.S. Patent No. 11,175,405 to Pacala <i>et al.</i>                                                                                                         |
| 1002 | '405 Prosecution History | Prosecution history for U.S. Patent No. 11,175,405                                                                                                         |
| 1003 |                          | Intentionally Left Blank                                                                                                                                   |
| 1004 | Pacala                   | U.S. Patent Pub. No. 2014/0211194 to Pacala <i>et al.</i>                                                                                                  |
| 1005 | Spector                  | U.S. Patent No. 10,473,766 to Spector                                                                                                                      |
| 1006 | Droz                     | U.S. Patent No. 10,605,984 to Droz <i>et al.</i>                                                                                                           |
| 1007 | Villeneuve               | U.S. Patent No. 10,520,602 to Villeneuve <i>et al.</i>                                                                                                     |
| 1008 | Hall                     | U.S. Patent No. 9,983,297 to Hall <i>et al.</i>                                                                                                            |
| 1009 | Borowski                 | U.S. Patent Pub. No. 2013/0300840 to Borowski                                                                                                              |
| 1010 | Spector Provisional      | U.S. Provisional Appl. No. 62/470,706 to Spector                                                                                                           |
| 1011 | NIST                     | <i>Performance Analysis of Next-Generation LADAR for Manufacturing, Construction, and Mobility</i> , National Institute of Standards and Technology (2004) |
| 1012 | NOAA                     | Younkin <i>et al.</i> , <i>Velodyne VLP-16 Laser Scanner Acceptance</i> , NOAA Report, May 2016                                                            |
| 1013 | Pacala-2016              | U.S. Patent Pub. No. 2016/0047901 to Pacala <i>et al.</i>                                                                                                  |
| 1014 | Pacala-803               | U.S. Patent No. 10,036,803 to Pacala <i>et al.</i>                                                                                                         |
| 1015 | Hall-672                 | U.S. Patent No. RE46,672 to Hall                                                                                                                           |

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| No.  | Short Name                     | Exhibit                                                                                                                                                                   |
|------|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1016 | ITC Complaint                  | Complaint in ITC Inv. No. 337-TA-1363                                                                                                                                     |
| 1017 | Delaware Complaint             | Complaint in <i>Ouster, Inc. v. Hesai Group et al.</i> , No. 23-cv-00406 (D. Del.)                                                                                        |
| 1018 | Stay Order                     | Order Granting Stay in <i>Ouster, Inc. v. Hesai Group et al.</i> , No. 23-cv-00406 (D. Del.)                                                                              |
| 1019 | Joint Claim Construction Chart | Joint Claim Construction Chart in ITC Inv. No. 337-TA-1363 (July 7, 2023)                                                                                                 |
| 1020 | Termination Order              | Order Granting Motion to Terminate in ITC Inv. No. 337-TA-1363                                                                                                            |
| 1021 | Shanley CV                     | <i>Curriculum Vitae</i> of James F. Shanley                                                                                                                               |
| 1022 | Sensors 2020                   | Lee <i>et al.</i> , “Accuracy-Power Controllable LiDAR Sensor System with 3D Object Recognition for Autonomous Vehicle,” in <i>Sensors</i> , Vol. 20, Iss. 19 (Oct. 2020) |
| 1023 | Hipp-747                       | U.S. Patent No. 6,747,747 to Hipp                                                                                                                                         |
| 1024 | Weimer                         | U.S. Patent No. 8,736,818 to Weimer <i>et al.</i>                                                                                                                         |
| 1025 | Borowski-838                   | U.S. Patent Pub. No. 2013/0300838 to Borowski                                                                                                                             |
| 1026 | DGC                            | <i>Report to Congress: DARPA Prize Authority</i> (2006)                                                                                                                   |
| 1027 | Team DAD                       | Hall <i>et al.</i> , <i>Team DAD Technical Paper</i> , DARPA Grand Challenge (2005)                                                                                       |
| 1028 | Marino                         | Marino <i>et al.</i> , <i>A compact 3D imaging laser radar system using Geiger-mode APD arrays: system and measurements</i> , MIT Lincoln Lab (2003)                      |

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| No.  | Short Name | Exhibit                                                                                                  |
|------|------------|----------------------------------------------------------------------------------------------------------|
| 1029 | Matsubara  | Matsubara <i>et al.</i> , <i>Development of Next Generation LiDAR</i> , R&D Review of Toyota CRDL (2012) |
| 1030 | Hall-877   | U.S. Patent No. 10,393,877 to Hall <i>et al.</i>                                                         |

## I. INTRODUCTION

1. My name is Dr. James F. Shanley. I have been retained by Quinn Emanuel Urquhart & Sullivan LLP on behalf of Petitioner Hesai Technology Co., Ltd. (“Hesai”). I understand that Hesai is petitioner in an *inter partes* review (“IPR”) of U.S. Patent No. 11,175,405 (the “‘405 patent”) (Ex. 1001) before the Patent Trial and Appeal Board (“PTAB” or “Board”). I understand the ‘405 patent is assigned to Patent Owner Ouster, Inc. (“Ouster”). I have been asked to provide my independent analysis of the ‘405 patent in light of the materials cited below and my knowledge and experience in this field during the relevant period. I have been asked to consider what a person of ordinary skill in the art at the time of the alleged invention of the ‘405 patent (a “POSITA”; refer to ¶¶75-80) would have understood from the teachings of the ‘405 patent, including scientific and technical knowledge related to the ‘405 patent. I have also been asked to consider whether the references relied on by Hesai render obvious claims 21 and 23-34 of the ‘405 patent.

2. I am being compensated at my standard consulting rate for my time providing my independent analysis, plus reasonable out-of-pocket expenses. I have received no additional compensation for my work in this matter, and my compensation does not depend upon the content of my opinions, any testimony that

I may provide, or the ultimate outcome of the matter. All of the opinions set forth in this declaration are my own.

## **II. BACKGROUND AND QUALIFICATIONS**

3. Full descriptions of my educational background, professional work, qualifications, and publications are set forth more fully in my *curriculum vitae*, which is attached to this declaration as Exhibit 1021. Here, I provide a summary of my background and qualifications.

4. I received my bachelor's degree in physics from Clarkson University in 1996. Afterwards, I received my master's degree in physics in 1970 and my doctorate degree in electrical engineering and physics in 1980, both from the University of Massachusetts, Amherst.

5. Over 40 years after I received my doctorate degree, I have accumulated broad in-depth knowledge and experience in the theory, system analysis, design and build of optics, lasers, diode lasers, photodetectors, opto-mechanical, electrical and electronics hardware associated with LiDAR systems operating at infrared to UV wavelengths. I also have substantial experience in atmospheric physics, algorithm development, signal processing and analysis of LiDAR systems. My experience includes designing and building receiver detectors, transceiver optics and associated electronics as well as gas, solid state, and diode laser transmitters. I have also fabricated a range of photodetectors using III-V, II-VI, and silicon materials.

6. I have 12 patents or pending patent applications, and over 45 peer-reviewed publications in the areas of lasers, semiconductor lasers, optical and infrared (IR) imaging systems, laser ranging and imaging systems, light emitting diodes (LEDs), and electro-optic systems.

7. I am involved in a number of professional organizations related to electrical engineering, optical engineering, physics, and electro-optical systems, including American Physical Society, Institute of Electrical and Electronics Engineers (IEEE), Society of Photo-Optical Industrial Engineers (SPIE), Society for Information Display, and American Institute of Aeronautics & Astronautics (AIAA).

8. Because of my research and achievements in the general areas of electrical engineering, optical engineering, and physics, I have received a number of honors and awards. These include the AIAA Sensors Award, Honeywell Technical Achievement Award, and Polaroid Outstanding Engineer C. I was also the editor for two SPIE books on IR Surveillance Technologies, the Chairman of Several SPIE Imaging Conference Sessions, and was an invited lecturer at Hong Kong Science and Technical University.

9. Through my working experiences with various companies over the years, I was also personally involved designing and building a number of LiDAR systems. The first LiDAR system I participated in designing, building, and testing was when I was working at Honeywell Electro-Optics Center during 1976-1985.

The system was a coherent CO<sub>2</sub> Laser Radar for the detection and imaging of military platforms. This system could provide Doppler information as well as range and image of the object being illuminated. Further embellishments of the system were for nape of the earth flight, helicopter wire detection and IFF (identification friend or foe). In addition, I fabricated the 4 and 12 element photodiode arrays for these LiDAR's.

10. While working at General Electric's (GE) Space Systems Division during 1985-1989, I was responsible for building and integrating electro-optic sensors and systems on spacecraft for both military and civilian (NASA and NOAA) applications. As part of this responsibility, we built a prototype CO<sub>2</sub> Laser Radar for a satellite-based system for measuring global wind velocity. This prototype was packaged and taken to NOAA in Boulder, Colorado to make wind measurement and to verify wind velocity models. The prototype was part of a NASA program called LAWS (Laser Atmospheric Wind Sounder) to set the systems requirements for a future satellite system. We employed several distinct types of algorithms for atmospheric measurements including linear regression, second order regression and several types of proprietary fitting schemes. While at GE, I also led a group developing and fabricating diode lasers for various LiDAR applications. This included fabricating high power diode lasers arrays and multi-mode diode laser

arrays for pumping solid stated laser materials such as Nd:YAG, erbium, etc. for use in LiDAR applications being developed on internal GE IRAD.

11. While at GE, I was also involved in development of holographic gratings (diffractive optics) for collimating the output beams of diode laser arrays for higher laser output power, improved single mode emission, and beam steering. The work also included developing external cavity diode lasers using Bragg gratings. These laser sources were being developed for a variety of future LiDAR, earth resources sensing and military applications. Some examples include submarine acoustic detection using blue green laser LiDAR scattering of particulate in seawater and SLCSAT submarine laser communication satellite using high power blue green lasers.

12. While working at McDonnell Douglas during 1980-2005, I participated in developing laser and LiDAR systems, diode pumped solid state lasers and diode lasers for programs that included MOLA (Mars Observer Laser Altimeter), NEAR (Near Earth Asteroid Rendezvous), and Satellite Laser Communication. I worked in a group developing laser diode technology for extremely high-power diode lasers used for weapons, X-Ray lithography and laser fusion.

13. While working at Scram Technologies during 2005-2011, I was involved in building a small handheld infrared LiDAR for target designation, range

and range rate determination. The key features of this LiDAR device were the miniature transceiver optics, high power diode laser and compact electronics.

### **III. MATERIALS REVIEWED AND CONSIDERED**

14. In forming the opinions expressed in this Declaration, I relied upon my education and experience in the relevant field of the art, and have considered the viewpoint of a POSITA (refer to ¶¶75-80) at the time of the alleged invention. I have also reviewed and considered the documents listed in the Exhibit List of this declaration. Although this declaration refers to selected portions of the cited references for the sake of brevity, it should be understood that these are examples, and that a POSITA would have viewed the references cited herein in their entirety and in combination with other references cited herein or cited within the references themselves. The references used in this declaration, therefore, should be viewed as being considered herein in their entireties.

### **IV. LEGAL UNDERSTANDING**

15. I understand that issues such as invalidity and claim construction are analyzed based on certain legal standards. Counsel for Hesai has provided me with an understanding of these standards, and I have applied them in my analysis set forth in this declaration.

**A. The Person of Ordinary Skill in the Art**

16. I understand that a person of ordinary skill in the art (“POSITA”) is a hypothetical person who is presumed to be aware of all pertinent prior art, thinks along conventional wisdom in the art, and is a person of ordinary creativity—not an automaton.

17. I understand the level of ordinary skill in the art is evaluated based on various factors, including: the level of education and work experience of persons in the field; the type of problems encountered in the field; and the sophistication of the technology at issue.

**B. Claim Construction**

18. I understand that, as a general rule, the claim terms of a patent are understood to have their ordinary and customary meaning to a POSITA at the time of the invention when read in the context of the patent and its prosecution history. I understand that there are certain exceptions to the general rule, including lexicography and disavowal, but I have not been asked to analyze those exceptions in connection with this proceeding.

**C. Obviousness**

19. I understand a patent claim is still invalid if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole

would have been obvious at the time the invention was made to a person of ordinary skill in the pertinent art.

20. I understand an obviousness determination includes the consideration of various factors, including the scope and content of the prior art, the differences, if any, between the prior art and the claimed subject matter, the level of ordinary skill in the art, and the existence of objective indicia of obviousness or non-obviousness.

21. I understand an obviousness determination can be based on a single prior art reference or a combination of multiple prior art references and the knowledge of a POSITA. I understand the prior art itself may provide a suggestion, motivation, or reason to combine or modify the teachings of the prior art, or that such a reason may come from other sources, such as the knowledge of a POSITA, common sense, and market forces. However, I understand it is impermissible to rely on hindsight or to use the claimed invention as a roadmap to reach a finding of obviousness.

22. I understand the following rationales may support a finding of obviousness:

- Combining prior art elements according to known methods to yield predictable results;
- Simple substitution of one known element for another to obtain predictable results;

- Use of known technique to improve similar devices (methods, or products) in the same way;
- Applying a known technique to a known device (method or product) ready for improvement to yield predictable results;
- “Obvious to try” – choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;
- Known work in one field of endeavor may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations are predictable to one of ordinary skill in the art;
- Some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

23. I understand an obviousness finding requires a reasonable expectation of success in achieving the claimed invention. The expectation of success need only be reasonable; a perfect implementation or commercial embodiment of the invention is not required.

24. I understand that objective indicia of obviousness or non-obviousness may include commercial success attributable to the alleged invention; a long-felt but unmet need for the alleged invention; praise of the alleged invention by others in the field; and skepticism towards the alleged invention by experts. I understand that any secondary considerations must bear a nexus to the alleged invention. I understand the nexus requirement is not satisfied if, for example, the purported commercial

success is tied to features of a product that were known in the prior art rather than the alleged invention.

## **V. SUMMARY OF OPINIONS**

25. For purposes of this declaration, I have been asked to analyze claims 21 and 23-34 of the ‘405 Patent (“the Challenged Claims”) in view of the prior art. In my opinion, the Challenged Claims are obvious based on the following grounds:

**Ground 1:** Claims 21, 23, 26-31, and 34 are obvious based on U.S. Patent Publication No. 2014/0211194 (“Pacala”) in combination with U.S. Patent No. 10,605,984 (“Droz”).

**Ground 2:** Claims 24-25 and 32-33 are obvious based on Pacala, Droz, and U.S. Patent No. 10,520,602 (“Villeneuve”).

**Ground 3:** Claims 21 and 23-33 are obvious based on U.S. Patent No. 9,983,297 (“Hall”) in combination with U.S. Patent Publication No. 2013/0300840 (“Borowski”) and U.S. Patent No. 10,473,766 (“Spector”).

**Ground 4:** Claim 34 is obvious based on Hall, Borowski, Spector, and Droz.

26. I provide the bases for my opinions in the following sections.

## **VI. TECHNOLOGY BACKGROUND**

27. In this section, I provide an overview of technical concepts and design principles underlying the ‘405 Patent.

**A. Overview of LiDAR and Time-of-Flight**

28. The '405 Patent and the prior art discussed in this declaration all generally relate to systems that use LiDAR (which stands for “Light Detection and Ranging”) to measure distance to objects.

29. The concept of using LiDAR to probe distant objects had its humble origins in 1930, when Irish physicist E. H. Synge proposed using light to probe the earth’s atmosphere and to measure cloud distance. Synge’s rudimentary apparatus used a searchlight as the multi-spectral high-power light source to measure atmospheric particulate scattering and to determine distance to clouds. Through appropriate spectral filtering, he was able to isolate individual light wavelengths to investigate light scattering from atmospheric molecules and particulate. Synge determined that he could measure the distance to clouds using the same light reflection techniques.

30. After Synge’s discovery, various types of light sources with appropriate spectral filters were employed to isolate specific wavelengths for light scattering measurements. However, the technology was not sufficiently advanced for these systems to be useful in practical applications. It wasn’t until a single coherent monochromatic light source was developed that LiDAR became practical—in other words, the laser was the critical missing piece.

31. The advent of the laser in early 1960 at Hughes Aircraft was followed shortly by the development of the first true coherent light detecting and ranging system, originally named “COLIDAR,” and later shortened to just “LIDAR.” This first system was used for tracking satellites and other celestial bodies. Today, several different types of lasers are known and commercially available, operating at various power levels. These include gas, solid state and semiconductor lasers, operating at wavelengths ranging from deep Ultraviolet (UV), Visible, Infrared (IR), to Submillimeter.

32. The terms “LiDAR” and “LaDAR” are both used to refer to light-based distance measurement and object probing systems. “LiDAR” stands for “light detection and ranging,” whereas “LaDAR” stands for and laser detection and ranging (Ladar) systems. Presently, the terms LiDAR and LaDAR are frequently used interchangeably. Conventionally, however, LiDAR typically referred to systems requiring lower power, shorter range, and optionally using light-emitting diodes (LEDs) as the light source. LaDAR, on the other hand, typically referred to applications using higher power lasers for longer ranges and for geospatial, space, planetary, and other imaging applications requiring long range and high resolution.

33. The number and types of LiDAR applications has increased substantially since its early uses in the 1960s, due at least in part to the availability and variety of lasers, LED light sources, and photodetector receivers. Consequently,

many compact high-sensitivity systems are commercially and publicly available, featuring a variety of lasers and detectors operating at different wavelengths and power levels. There are now literally hundreds of uses for the technology.

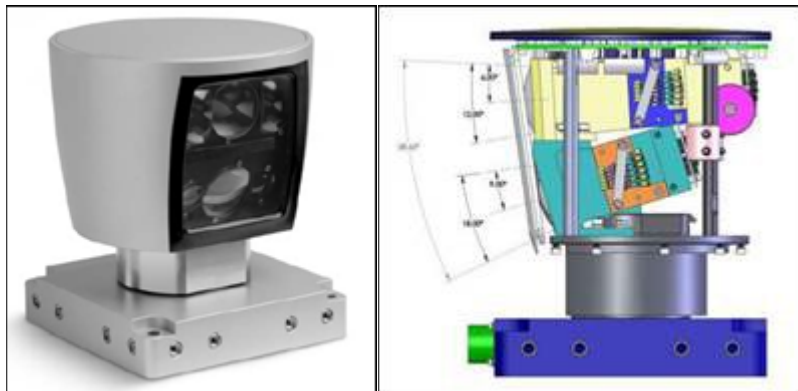
Representative examples include the following:

- Helicopter, airplane and missile fire avoidance and terrain following;
- Planetary and asteroid topographical mapping and distance measurement;
- Earth resource sensing and pollution detection;
- Satellite wind velocity measurements for improved weather forecasting;
- Commercial airplane pitot tube replacement for altitude and air speed measurement;
- Laser altimetry; and
- Autonomous vehicles and robotics.

34. As one example of the evolution of LiDAR, in 2005, a company called Velodyne Acoustics developed a LiDAR device for autonomous-vehicle navigation. Ex. 1027, 1-2. Velodyne developed its LiDAR device as part of the 2005 DARPA Grand Challenge, a government-sponsored event intended to encourage the development of autonomous-vehicle technology. Ex. 1026. The Velodyne team, which called itself Team DAD, designed the system to use 64 pairs of transmitters and detectors, mounted on a rotating platform powered by a built-in motor. Ex. 1027, 8-9. The rotating platform enabled the device to have a 360-degree field-of-

view horizontally, and the spacing of the transmitters and detector supported a 20-degree field-of-view vertically. *Id.* This allowed the device to generate a “very high-density profile map of the surrounding environment.” *Id.* On-board software then used this information to make autonomously navigation the terrain.

35. Velodyne’s first commercial LiDAR device, based on the design described above, was called the HDL-64E, images of which are shown below:



Velodyne continues to make LiDAR devices today, incorporating more recent improvements in LiDAR technology. For example, in 2016, Velodyne released its “Puck” design LiDAR sensor, the VLP-16, an image of which is shown below. Versions of the VLP-16 are still sold by Velodyne today. The Hall reference (U.S. Patent No. 9,983,297) that I discuss in my opinions on obviousness below is a Velodyne patent that appears to describe the technology used in the VLP-16 (or a related design).

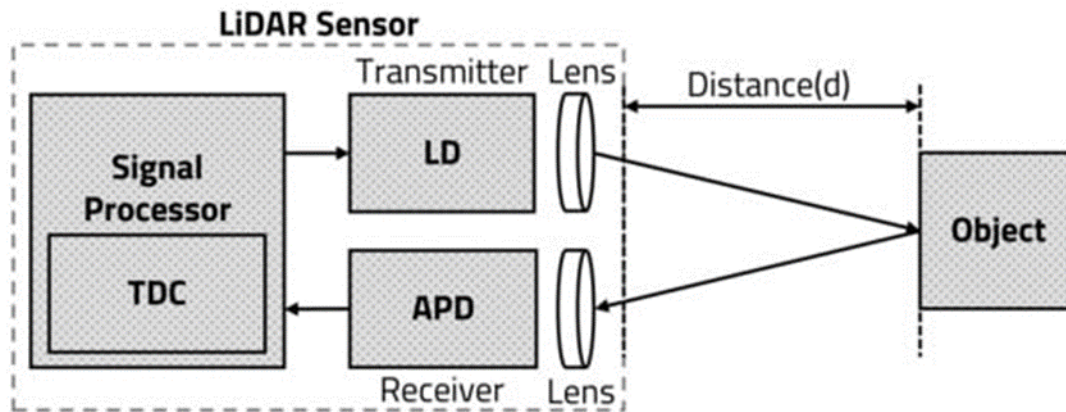


36. Many other companies have emerged in the market for LiDAR for autonomous vehicles, employing a range of different technologies to develop better LiDAR devices that can detect objects at longer ranges and under more difficult lighting or weather conditions, and that are more accurate and less sensitive to stray light and other noise.

37. As one example, Waymo, the self-driving car company, develops its own LiDAR detection modules. For example, the Droz reference (U.S. Patent No. 10,605,984) that I discuss in my opinions on obviousness below is a Waymo patent that describes various detector-side techniques that Waymo had incorporated into its LiDAR system to minimize erroneous readings, such as optical filters to block stray light and waveguides to minimize cross-talk.

## **B. LiDAR Basics**

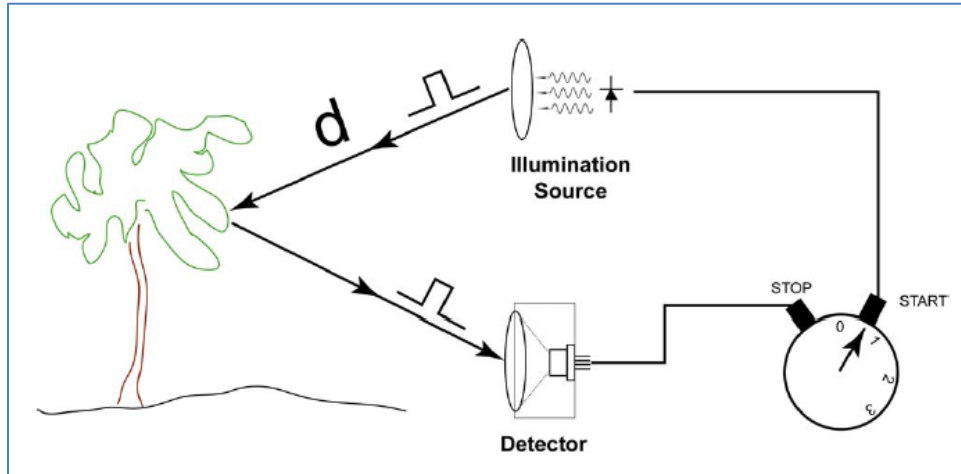
38. The basic components of a conventional LiDAR system are shown in the figure below:



Ex. 1022, Fig. 2. The basic components include the following:

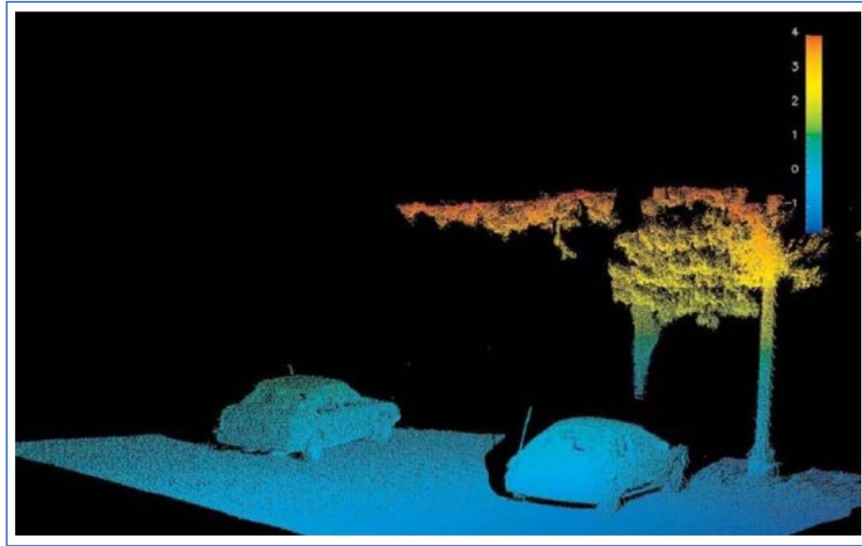
- The transmitter (a light source): usually a laser, and depending on the power required may be either a semiconductor or a solid-state laser. LEDs may be used for lower power and lower resolution applications.
- Transmitter optics: optical components (such as a lens) to collimate the output beam and direct it to the interrogated object.
- Receiver optics: optical components that capture the reflected signal light and have the appropriate filters and baffles to reject or absorb stray light or any other non-signal light.
- The receiver: detects the signal light. In conventional systems the receiver is typically one of the following types of photodetectors: photoconductors, photodiodes, avalanche photodiodes (APDs), or single- photon avalanche photodiodes (SPADs). A single photodetector or arrays of photodetectors may be used depending on system requirements.
- An electronics module: includes circuitry and other electronics for controlling the lasers and synchronizing the pulsed laser with the received return signal. The time-to-digital-converters (TDC) (used to measure the time of flight, discussed below) and signal processing electronics are typically also contained in this module.

39. The operating principles of the basic lidar system are illustrated in the figure below.



Ex. 1011 at 2.3. The illumination source (*e.g.*, a laser) emits narrow light pulses, and the echoes that are reflected from the target are detected to measure distance. The distance is determined based on the time elapsed between the emission and the detection. Specifically, the distance is the time difference multiplied by the speed of light, divided by two, or:  $x = c\Delta t / 2$ . For example, if the time between emission and detection is one microsecond, then the distance measured is  $(1 \times 10^{-6} \text{ s}) / 2 \times 2.99 \times 10^8 \text{ m/s} = 149.5 \text{ meters}$ . This measurement technique is referred to as “time-of-flight” or “TOF.”

40. When multiple distance measurements are processed for the different points in the environment, the resulting information can be combined to generate a three-dimensional map of the environment, also referred to as a “point cloud,” an example of which is shown below:



*Id.*, at Fig. 6.3.

### **C. LiDAR System Design and Elements**

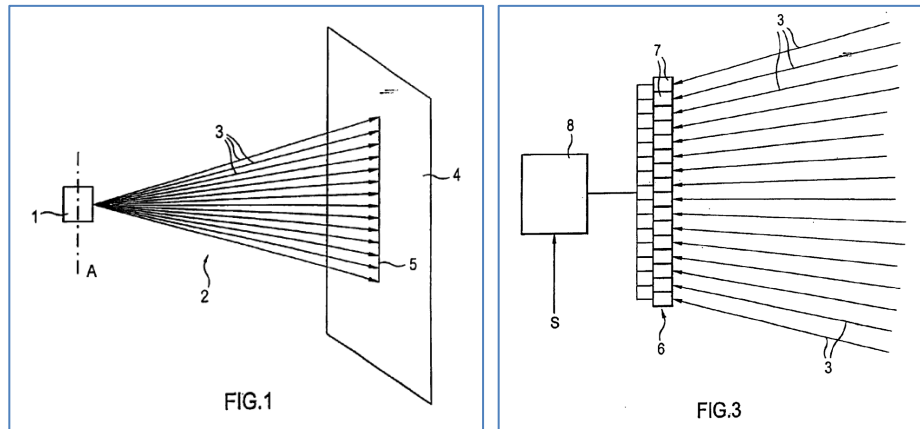
#### **1. Single-Beam and Multi-Beam Systems**

41. As I discussed above, early LiDAR devices were focused first on detecting satellites and celestial bodies, and shortly thereafter, on military applications, for example, for determining the distance to a target. These systems were much simpler than modern LiDAR systems, and typically did not need to generate a map of an entire 3-D environment—they only needed to measure the distance to a point, or the distance of objects in a two-dimensional plane. These tasks could be accomplished using a single laser that scans a target or field.

42. As the technology progressed, however, researchers and engineers in the field realized that a more detailed map of the environment could be achieved by using multiple transmitters, emitting multiple beams of light, each paired with a

corresponding detector. The transmitter/detector pairs could then be moved or rotated to scan a large area.

43. For example, U.S. Patent No. 6,747,747 (“Hipp-747”), a 2002 patent, summarized the then-known devices using light “for determining a distance profile,” and noted that the “disadvantages of the apparatuses described consist of the fact that in each case only a limited region can be monitored.” Ex. 1023, 1:7-13, 1:33-41. Hipp-747 explained that conventional LiDAR devices can be improved through “the simultaneous transmission of a plurality of light signal in the direction of a plurality of reflection/remission points disposed, spaced apart from one another,” along with a “light receiver [that] includes a plurality of photodiodes for the reception of light signals reflected/remitted by the reflection/remission points.” *Id.*, 1:52-58. Hipp-747 explained that “Due to the simultaneous transmission of a plurality of light rays in different directions, a larger region, namely the region covered by the totality of the simultaneously emitted light rays, can be monitored [rather] than with the transmission of an individual light ray which only allows the monitoring of a line extending along this one light ray.” *Id.*, 1:66-2:16. In Hipp-747’s exemplary embodiment, the transmitters and detectors were arranged in a fan shape, as shown in Figures 1 and 3:



*Id.*, Figs. 1, 3. Hipp-747 further explained that one could use a well-known “light deflection unit to deflect a fan-shaped light bundle,” which “makes it possible in comparison with scanners known from the prior art to monitor not only a plane, but also a space.” *Id.*, 2:62-3:4.

## 2. Receiver Detectors

44. As stated above, there are many types of light detectors available. These include photoconductors, photodiodes, avalanche photodiodes (APDs) and single-photon avalanche photodiodes (SPADs). LiDAR devices, and particularly compact, mobile LiDAR devices, such as those used in autonomous vehicles, require highly sensitive receivers capable of low noise and high signal-to-noise ratios. Under these design constraints, APDs and SPADs represent the two best options, and have been known and used in LiDAR systems well before May 2017. SPADs, in particular, are considered to be optimal in many applications because they can attain a high gain which enables them to detect a single photon.

45. Early LiDAR devices, such as LiDAR-based rangefinders, employed avalanche photodiodes (“APDs”). The basic operation of an APD uses the “avalanche” effect to create a larger gain. When photons enter the APD, they excite electrons within the semiconductor, which are accelerated by a reverse bias voltage to free other electrons. The process accelerates through further electron collisions, and generates a current. As more photons are received at the diode, a more current flows, which makes for a more perceptible and detectable electrical signal. If the diode receives too much reverse bias, however, it can break down and generate such a large current that the device may fail. Thus, in traditional APDs (also sometimes referred to as “linear-mode” APDs), the diode is reverse biased toward that breakdown voltage, but not beyond it. When operating below the breakdown voltage, there is a linear relationship between the number of photons detected and the current generated.

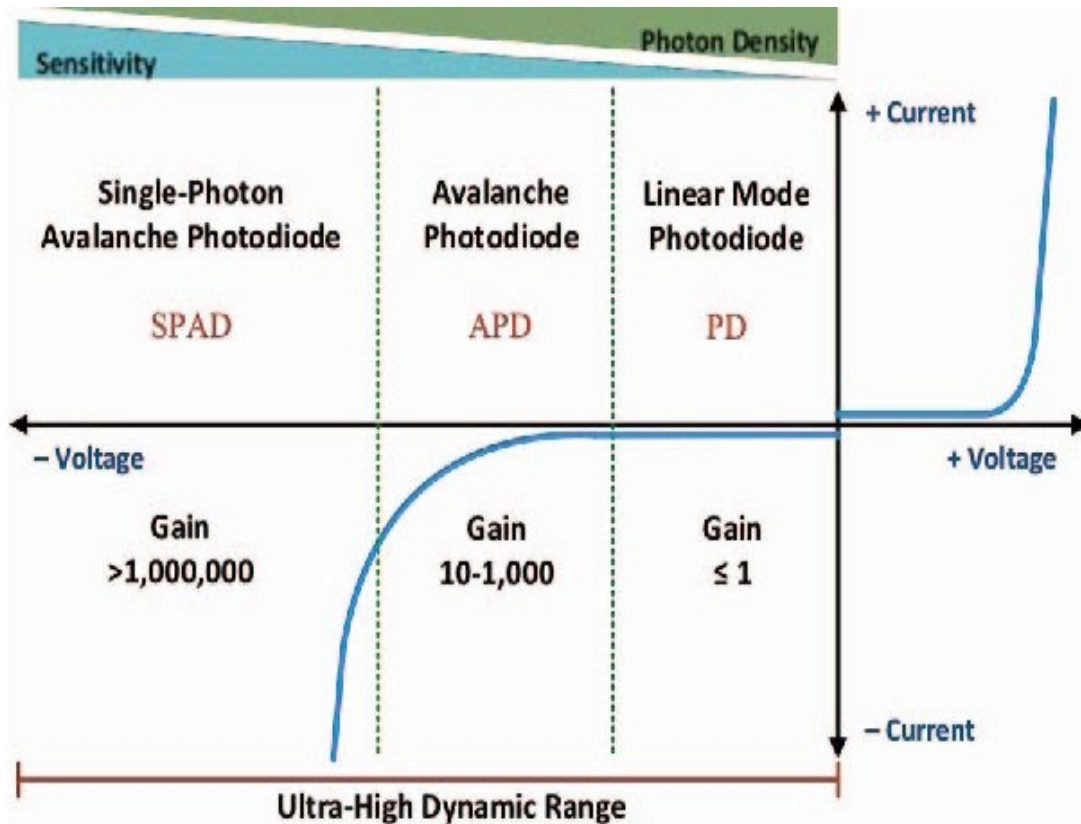
46. SPADs are related to APDs in operation, and have a similar current-voltage characteristic. Indeed, SPADs are sometimes even referred to as “Geiger-mode” APDs. But unlike APDs, which operate at a reverse bias below the breakdown voltage, SPADs are designed to operate *above* the breakdown voltage, by applying a high reverse-bias and designing the photodiode structure so that it can operate without damage even at very high gains. As a result, when even a single photon is received, a SPAD triggers a very strong avalanche effect and outputs a

relatively large current. SPADs thus generate a signal that is the equivalent of a binary state representing photon detection: either no photon is detected, and no current is generated, or a photon is detected, and a large current is generated. Using SPADs in a LiDAR system allows the system to detect objects even at large ranges or under poor conditions, when the intensity of the reflected light may be weak.

47. The image below helps illustrate the different operating regions and gains associated with APDs and SPADs<sup>1</sup>:

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<sup>1</sup> This image is reproduced from <https://4sense.medium.com/apple-lidar-demystified-spad-vcsel-and-fusion-aa9c3519d4cb>. The article is describing the LiDAR technology used in certain specific mobile devices, but the figure accurately describes the operation of APDs and SPADs more generally.



Because APDs and SPADs use a reverse-bias voltage, the voltage of interest is negative. Hence, the figure above begins close to the zero voltage range (at the y-axis) and shows the current generated with respect to photon density as the voltage becomes more negative (*i.e.*, as the reverse-bias increases). In the APD operating range, the gain increases with the reverse-bias up to the breakdown voltage (the vertical dotted green line). Beyond the breakdown voltage, the gain increases dramatically, even for a very low photon density (*i.e.*, a single photon).

48. One additional important aspect of SPADs is the need for a quenching circuit. In a linear-mode APD, the breakdown voltage is never reached, and so the output current remains linear relative to the number of detected photons. In SPADs,

however, even a single photon causes such a large avalanche effect, and generates such a high current, that additional photons no longer have an effect on the output. In order to detect additional photons, a special circuit, called a “quenching circuit,” is used to reduce the voltage below breakdown. The time it takes to “quench” the SPAD may be referred to as the recovery period or recovery time, and is the time it takes to reset the SPAD so that it can detect another photon.

49. Because SPADs are effectively inoperable to detect photons during their recovery period, in real-time detection applications, the use of a single SPAD can be problematic, as incoming photons will not be detected during the recovery period. Thus, in practical applications, multiple SPADs, in a one- or two-dimensional array, may be used to detect photons corresponding to a single point in space or a single transmitter on the transmit side. By using a plurality of SPADs to detect photons corresponding to a particular point of interest or field of view, the array of SPADs can collectively detect and process multiple photons, even if any one particular SPAD is in a recovery period at a given point in time.

### **3. Noise and Interference**

50. Because LiDAR systems are designed to detect information about objects and environments outside of the system, there is a high potential for noise and interference to affect the system—specifically, in the form of light that gives rise to erroneous measurements. Noise and interference can affect the sensitivity of

the system—for example, the ability of the LiDAR device to accurately detect objects at longer ranges, or in poor weather conditions. They may be particularly problematic in systems that employ SPADs, because even a single errant photon may cause a false positive detection, while also rendering the SPAD inoperable until it is quenched. Two particularly well-known noise conditions affecting LiDAR systems are stray light and cross-talk.

51. Stray light is defined as any light that is unwanted and interferes with the performance of an optical system's intended function. Stray light can originate from the object the optical system is capturing or from unintended external or internal emitters. Examples of stray light include:

- Light reflections off mechanical mounting surfaces inside the optical system
- Light leaking through a gap in the system enclosure
- Light scattering off dust and other imperfections on the system's optical surfaces
- Man-made and natural light sources, such as municipal lights, the sun, or the moon.

52. Stray light can usually be described as one of two types: (1) ghosts or and (2) glare. Ghosts arise in imaging systems when light from an object in the image field undergoes several unwanted reflections and then falls on the imaging device, creating an unwanted “ghost” image of the object. Flare, or veiling glare, occurs when light scatters inside the optical system either off imperfections in the

optical surfaces, or off mechanical elements in the system. Atmospheric reflection of light such as haze or sky glow can also cause glare.

53. Unwanted stray light can reduce the contrast of images and reduce the sensitivity of detection systems. There are a number of well-known ways to reduce the impact of stray light, including the following:

- Black paint: using black anodized surfaces or absorptive black paint on all optical mounting surfaces.
- Optical filters: filters that only allow light at certain wavelengths (*e.g.*, signal light from the transmitter) to pass through the system. Depending on system requirements, these can pass either a narrow- or wide-band width.
- Reduced apertures: limits the amount of light reaching the detector from surrounding reflections.
- Baffles: obstacles placed in the optical path that prevent light from propagating where it is not wanted.
- Absorptive filters: placed in front of the detectors to absorb unwanted stray light and can help to reduce the effects of scattered light, which can cause veiling glare.

54. In many LiDAR systems, combinations of these techniques may be used to prevent stray light from reaching a detector.

55. Cross-talk is a type of interference that occurs when a signal from one communication channel is inadvertently transferred to a different communication channel. In the context of LiDAR systems, cross-talk typically manifests as optical cross-talk—*e.g.*, light intended for one detector may inadvertently also be detected

at an adjacent detector. The problem of optical cross-talk between adjacent detectors in a SPAD array, in particular, may impose a substantial limit on the density of arrays. Because cross-talk increases as the distance between adjacent detectors is reduced, tightly packed arrays will be more prone to cross-talk, and thus less accurate.

56. Other than reducing the density of the SPAD array—which has the disadvantage of either increasing the size of the device, or reducing the number of SPADs (and thus the sensitivity/accuracy)—several techniques are known and employed to minimize optical cross-talk. These techniques are typically designed to reduce the likelihood that a photon from one channel or one SPAD will be detected at an adjacent channel or SPAD. For example, to prevent incoming light at one detector channel from bleeding into an adjacent channel, apertures may be provided on the surface of the device or the surface of the SPAD array, reducing the field of view of individual detectors so that light from adjacent channels is less likely to be received.

\* \* \*

57. In my opinion, the Challenged Claims of the '405 Patent represent obvious combinations of the features and technologies described above, and represented in the prior art I discuss below.

## **VII. THE ‘405 PATENT**

58. In this section, I provide an overview of the ‘405 Patent and a summary of the prosecution history.

59. The ‘405 Patent is titled “*Spinning LiDAR Unit with Micro-Optics Aligned Behind Stationary Window*.” Ex. 1001. The underlying application was filed on May 14, 2018, and is related to Provisional Application Nos. 62/506,449, 62/506,437, and 62/506,445, all filed on May 15, 2017, and Provisional Application No. 62/515,291, filed on June 5, 2017. *Id.*

60. For purposes of my analysis, I have been informed that the priority date of the ‘405 patent is no earlier than the filing date of its earliest provisional application—May 15, 2017. I have been informed that references in the proposed grounds (below) qualify as prior art under 35 U.S.C. § 102(a) because each of those references was filed and/or published before that date, or (in the case of Spector) claims priority to a provisional application filed before that date. I understand that claims of the ‘405 Patent may not be entitled to the effective filing date of May 15, 2017, and Hesai may challenge the priority date of the claims in other proceedings.

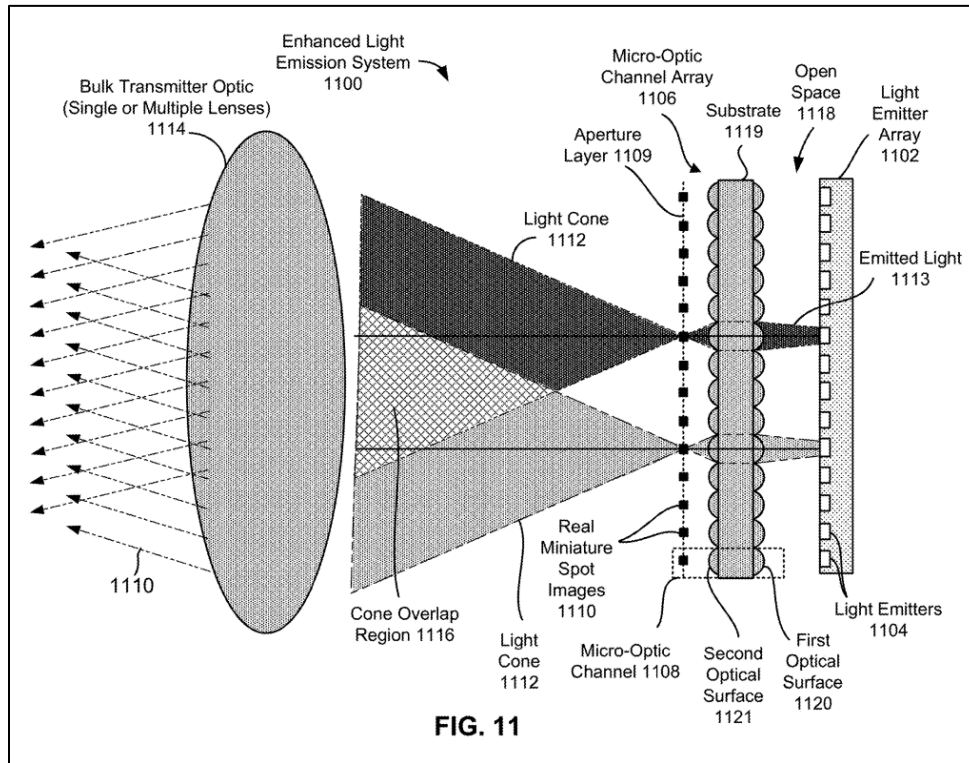
### **A. Specification**

61. The specification of the ‘405 Patent is directed to “optical imagers” with “a light emission system” and a “light detection system,” where the system is “configured to emit light into the field such that emitted light is reflected off surfaces

of an object in the field and received by the light detection system.” Ex. 1001, Abstract. The ‘405 Patent explains that such imagers have “many applications including ... LIDAR.” *Id.*, 2:12-14.

62. In certain embodiments, the ‘405 Patent describes “active optical imager systems,” which “emit their own light into a field and detect the emitted light after it has reflected off surface(s) of an object in the field.” *Id.*, 16:15-20. These systems include “a light transmission (Tx) module ... and a light sensing (Rx) module.” *Id.*, 16:27-32. “Ranging data can be generated by [the] light ranging device [] by transmitting one or more light pulses [] from the light transmission module [] to objects in a field of view surrounding [the] light ranging device.” *Id.*, 16:33-36. “Reflected portions [] of the transmitted light are then detected by [the] light sensing module [] after some delay time.” *Id.*, 16:36-38.

63. The light transmission module “includes an emitter array [], which can be a one-dimensional or two-dimensional array of emitters, and a Tx optical system.” *Id.*, 16:42-45. The “Tx optical system [] can include a bulk transmitter optic.” *Id.*, 16:46-47. One example of a light transmission module is illustrated in Figure 11:



*Id.*, Fig. 11.

64. The example shown in Figure 11 includes an array of emitters (1102) with standard emitters that emit light, such as “LEDs, laser diodes, VCSELs, or the like.”<sup>2</sup> *Id.*, 28:62-65. Light from the emitters passes through the bulk transmitter optic 1114, which “accepts divergent light cone(s) 1112 and outputs a collimated beam.” *Id.*, 31:15-16. In other words, the bulk transmitter optic takes the light from the various emitters, which may be divergent, and outputs a collimated (parallel)

<sup>2</sup> “VCSEL” stands for “vertical-cavity surface-emitting laser.” It is a type of semiconductor laser where the laser beam is emitted from the top surface of the diode. The Challenged Claims do not require any particular type of emitter, so I have not included a detailed discussion of the different types of emitters and lasers in this declaration.

beam. The bulk transmitter optic will typically “include either a single lens or a cluster of lenses [that] function together.” *Id.*, 30:20-22. Figure 11 also shows a number of other optional elements that are not recited in the Challenged Claims of the ‘405 patent, such as a substrate with optical surfaces, a micro-optic channel array, and an aperture layer.<sup>3</sup>

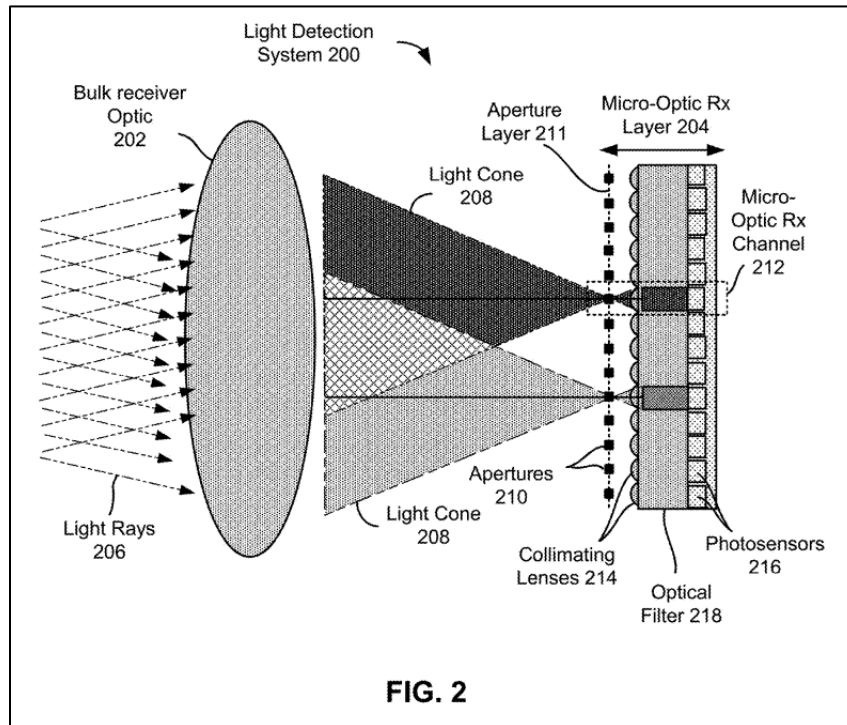
65. The light sensing module of the ‘405 Patent includes a “sensor array.” *Id.*, 11:37-39. The specification equates each sensor (or “photosensor”) in the array with a “pixel.” *Id.*, 11:39-41. That is, each sensor corresponds to one or more detectors and associated circuitry and logic which processes detected light and generates a single point (*i.e.*, “pixel”) in an image of the environment. Each sensor “can include a collection of photodetectors, e.g., SPADs or the like, or a sensor can be a single photon detector (e.g., an APD).” *Id.*, 11:39-43. If multiple photodetectors are used for a single sensor, the combined outputs of the detectors would be used to determine the value (color, intensity, etc.) of the corresponding pixel in the image—for example, by adding together or averaging the signals from each detector.

66. The light sensing module may also include various other optical components, such as “a bulk receiver optic,” an “aperture layer,” and an “optical

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<sup>3</sup> The Challenged Claims recite an aperture layer only at the light sensing module.

filter,” which can be used to separate received light into different “receiver channels” that each correspond to a pixel in the image of the field. *Id.*, 11:46-53. One example of the light sensing module is illustrated in Figure 2:



*Id.*, Fig. 2.

67. The example shown in Figure 2 includes a bulk receiver optic, which, like the bulk transmitter optic, would typically be a lens. However, unlike the bulk transmitter optic, the bulk receiver optic focuses the incoming light onto the photosensors and their associated micro-optic layer. *Id.*, 13:39-42 (“During operation, light rays 206 enter bulk receiver optic 202 from multiple directions and get focused by bulk receiver optic 202 to form light cones 208.”).

68. After being focused by the bulk receiver optic, light “pass[es] through apertures 210 in an aperture layer 211.” *Id.*, 13:57-59. The aperture layer “include[es] an optically transparent aperture [] and optically non-transparent stop region [] configured to define a narrow field of view.” *Id.*, 37:18-23. In other words, light focused onto the transparent aperture in the aperture layer will pass through to a corresponding photosensor, while light focused on regions between the apertures will be blocked. The aperture layer “can serve various functions,” including to “(1) constrain the pixel FOV so it has tight spatial selectivity despite a large pitch at the photosensor plane, (2) provide a small point-like source at the collimating lens’s focal plane to achieve tight collimation of rays before passing through the filter, ... and (3) reject stray light.” *Id.*, 14:1-9. The first function essentially narrows the field of view of a photosensor that may otherwise be capable of detecting light over a larger field-of-view (because only light from a narrower field-of-view will pass through the aperture). This allows the system to limit the fields-of-view of individual photosensors so that they do not overlap, and allows the system to capture a more accurate image of the environment. The second function relates to the optical filter, which I discuss below. The third function—rejecting stray light—is a common goal that I described above in the section on Noise and Interference (Section VI.C.3).

69. Light that passes through the aperture layer then further passes through an optical filter. The optical filter “blocks unwanted wavelengths of light.” *Id.*, 14:10-12. As I explained above, the use of such filters was a well-known and common technique for filtering stray light before it reaches a detector. For example, one of ordinary skill in the art would be familiar with the use of standard dichroic filters or band pass filters to allow only desired light (*i.e.*, light within a range of wavelengths corresponding to the transmitters) to pass through to the detectors. The ‘405 Patent also explains that optical filters “tend to exhibit strong angle dependence in their performance,” *id.*, which relates back to the second function of the aperture layer referenced above. That is, the aperture layer will block rays of light that have been deflected along a wider range of angles, so the light that passes through to the optical filter consists primarily of collimated rays that enter the optical filter at a small angle of incidence.

70. The ‘405 Patent explains that the aperture layer and optical filter in the light sensing module helps mitigate “receiver channel cross-talk,” *i.e.*, “stray light” that “bleed[s] into neighboring channels, thereby resulting in inaccurate readings of reflected light for each pixel in the field.” *Id.*, 36:53-63.

**B. Prosecution History**

71. The application that issued as the ‘405 Patent was filed on May 14, 2018, with twenty claims. Ex. 1002. The Challenged Claims were all added by amendment after the initial application. *See id.*

72. There was only one rejection by the Patent Examiner, directed only to the original set of claims, and relying primarily on U.S. Patent Publication No. 2016/0282453 (“Pennecot”) and U.S. Patent Publication No. 2014/0320843 (“Steuber”) in finding the claims obvious. *Id.* Ouster then amended each independent claim to require an aperture layer comprising a plurality of apertures separated by a stop region, and added several new claims, including the claims are presently claims 21 and 23-25. *Id.* The Examiner issued a Notice of Allowance shortly thereafter allowing all of the claims subject to several agreed-upon amendments. *Id.*

73. After the claims were allowed, Ouster added nine new claims, specifically, the claims that ultimately issued as present claims 26-34. *Id.* The Examiner then issued a second Notice of Allowance, finding all the claims (including the newly added ones) patentable. *Id.* The examiner did not provide any reason for his determination that the claims were patentable over the prior art.

### C. Claims

74. I understand that Hesai challenges claims 21 and 23-34 of the '405 patent, which I reproduce below:

| <b>Claim 21</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 21(a)           | An optical system for performing distance measurements, the optical system comprising:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 21(b)           | a stationary housing having a base, a top and an optically transparent window disposed between the base and the top and extending fully around a periphery of the stationary housing;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 21(c)           | a light ranging device disposed within the housing and comprising:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 21(d)           | a platform;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 21(e)           | a light transmission module coupled to the platform and comprising a bulk transmitter optic and a plurality of optical emitters, each optical emitter in the plurality of optical emitters configured to generate and transmit pulses of radiation through the bulk transmitter optic and through the optically transparent window into a field external to the optical system; and                                                                                                                                                                                                                                                                                                                                                                          |
| 21(f)           | a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field, and an optical filter disposed between the bulk receiver optic and the plurality of photosensors and configured to allow a band of radiation, including an operating wavelength of the plurality of optical emitters, to pass through the filter to the plurality of photosensors while blocking radiation outside the band from reaching the plurality of photosensors; and |
| 21(g)           | a motor disposed within the housing and operatively coupled to spin the platform and the light ranging device within the housing;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 21(h)           | wherein: each photosensor in the plurality of photosensors comprises a plurality of single photon avalanche diodes (SPADs);                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 21(i)           | the plurality of apertures comprises at least first, second, third and fourth apertures;                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 21(j)           | the plurality of photosensors comprises at least first, second, third and fourth photosensors; and the light sensing module includes a first optical path to the first photosensor through the first aperture, a second optical path to the second photosensor through the second aperture, a third optical path to the third photosensor through the third aperture, and a fourth optical path to the fourth photosensor through the fourth aperture.                                                                                                           |
| <b>Claim 23</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 23              | The optical system for performing distance measurements according to claim 21 wherein the system generates distance data based on times between transmission of pulses of light from the plurality of optical emitters and detection of photons from the pulses of light by the plurality of photosensors.                                                                                                                                                                                                                                                       |
| <b>Claim 24</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 24              | The optical system for performing distance measurements according to claim 21 wherein the plurality of optical emitters are arranged to form a plurality of emitter channels having non-overlapping fields of view, and the plurality of photosensors are arranged to form a plurality of receiver channels having non-overlapping the fields of view and having a one-to-one relationship with the plurality of emitter channels such that the field of view for each receiver channel is coincident with the field of view of a corresponding emitter channel. |
| <b>Claim 25</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 25              | The optical system for performing distance measurements according to claim 21 wherein the plurality of emitters are configured to project a plurality of illuminating beams in the field external to the optical system according to an illumination pattern that substantially matches, in size and geometry across a range of distances from the system, a plurality of non-overlapping fields of view of the plurality of photosensors.                                                                                                                       |
| <b>Claim 26</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 26(a)           | An optical system for performing distance measurements, the optical system comprising:                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 26(b)           | a stationary housing having a base, a top and an optically transparent window disposed between the base and the top and extending fully around a periphery of the stationary housing;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 26(c)           | a light ranging device disposed within the housing and comprising:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 26(d)           | a platform;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 26(e)           | a light transmission module coupled to the platform and comprising a bulk transmitter optic and a plurality of optical emitters, each optical emitter in the plurality of optical emitters configured to generate and transmit pulses of radiation through the bulk transmitter optic and through the optically transparent window into a field external to the optical system; and                                                                                                                                                                                                                                                                                                                                                                               |
| 26(f)           | a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field, and one or more optical filters disposed between the bulk receiver optic and the plurality of photosensors, each of the one or more optical filters configured to allow a set of wavelengths of radiation, including an operating wavelength of the plurality of optical emitters, to pass through the one or more optical filters while blocking radiation outside that set; and |
| 26(g)           | a motor disposed within the housing and operatively coupled to spin the platform and the light ranging device within the housing;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 26(h)           | wherein: each photosensor in the plurality of photosensors comprises a plurality of single photon avalanche diodes (SPADs);                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 26(i)           | the plurality of apertures comprises at least first, second, third and fourth apertures;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 26(j)           | the plurality of photosensors comprises at least first, second, third and fourth photosensors; and the light sensing module includes a first optical path to the first photosensor through the first aperture, a second optical path to the second photosensor through the second aperture, a third optical path to the third photosensor through the third aperture, and a fourth optical path to the fourth photosensor through the fourth aperture.                                                                                                                                                                                                                                                                                                            |
| <b>Claim 27</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 27              | The optical system for performing distance measurements set forth in claim 26 wherein the one or more optical filters comprise a bandpass filter.                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Claim 28</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 28              | The optical system for performing distance measurements set forth in claim 26 wherein the one or more optical filters comprise a plurality of optical filters.                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Claim 29</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 29              | The optical system for performing distance measurements set forth in claim 28 wherein each of the plurality of optical filters is supported by an optically transparent substrate.                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Claim 30</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 30              | The optical system for performing distance measurements set forth in claim 29 wherein the plurality of optical filters are disposed in the first optical path.                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Claim 31</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 31              | The optical system for performing distance measurements according to claim 26 wherein the system generates distance data based on times between transmission of pulses of light from the plurality of optical emitters and detection of photons from the pulses of light by the plurality of photosensors.                                                                                                                                                                                                                                                   |
| <b>Claim 32</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 32              | The optical system for performing distance measurements according to claim 26 wherein the plurality of optical emitters are arranged to form a plurality of emitter channels having non-overlapping fields of view, and the plurality of photosensors are arranged to form a plurality of receiver channels having non-overlapping fields of view and having a one-to-one relationship with the plurality of emitter channels such that the field of view for each receiver channel is coincident with the field of view of a corresponding emitter channel. |
| <b>Claim 33</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 33              | The optical system for performing distance measurements according to claim 26 wherein the plurality of emitters are configured to project a plurality of illuminating beams in the field external to the optical system according to an illumination pattern that substantially matches, in size and geometry across a range of distances from the system, a plurality of non-overlapping fields of view of the plurality of photosensors.                                                                                                                                                                  |
| <b>Claim 34</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 34              | The optical system for performing distance measurements according to claim 26 wherein the one or more optical filters comprises a first optical filter disposed in the first optical path between the first photosensor and the first aperture, a second optical filter disposed in the second optical path between the second photosensor and the second aperture, a third optical filter disposed in the third optical path between the third photosensor and the third aperture, and a fourth optical filter disposed in the fourth optical path between the fourth photosensor and the fourth aperture. |

#### **VIII. LEVEL OF ORDINARY SKILL IN THE ART**

75. In my opinion, based upon my knowledge and experience in this area, a POSITA as of May 15, 2017 would have had an undergraduate degree in mechanical or electrical engineering or physics and two to three years of experience in the field of LiDAR design. Less work experience may be compensated by a higher level of education or vice versa. The following factors support my opinion. My analysis is thus based on the perspective of a POSITA having this level of knowledge and skill at the relevant time of the invention. For purposes of my analysis, I have been informed that the priority date of the '405 patent is no earlier than May 15, 2017, and I have applied this timeframe as being the relevant time for the perspective of a POSITA

76. First, the typical level of education for persons working in the field would include an undergraduate degree in mechanical or electrical engineering or physics. Time-of-flight sensors like LiDAR are a combination of optical, mechanical, and electrical design elements. For example, I would expect a typical engineer who works for an automotive LiDAR company to have an undergraduate degree in one of these fields. Certain engineers will have more advanced degrees, such as a masters or Ph.D. in a more-specialized area of optics or optoelectronics, but an undergraduate degree in mechanical or electrical engineering or physics would be the typical background and would provide engineers in the field with a baseline knowledge of the optical, electrical, and mechanical design principles underlying time-of-flight devices. I also note that while there is not typically an undergraduate degree specific to the field of optics, a student on track for a degree in mechanical or electrical engineering or physics would have sufficient exposure to optics principles to then work in that area.

77. Second, 2-3 years of experience in the field would be typical for a person deemed to have ordinary skill in the technology underlying the '405 Patent. This level of experience would provide an engineer with more specialized focus in optics, device structure, the use of different emitters and detectors, and processing circuitry to generate point-cloud data. He or she would have been familiar with the design principles and tradeoffs underlying the subject matter of the '405 Patent.

78. Third, the types of problems typically encountered in the field relate to improving detection speed, accuracy, range, and resolution. An engineer with a mechanical or electrical or physics background and 2-3 years of work experience with time-of-flight devices like LiDAR would have been familiar with these problems and working on solutions to address them. For example, a typical engineer at that level would be tasked with evaluating different emitters—e.g., EELs, LEDs, and VCSELs—and detectors—e.g., APDs and SPADs—to decide whether they improve accuracy and detection capability and are cost-effective. He or she would also be tasked with evaluating different optics elements such as lenses, absorption layers, and filters for the same reasons.

79. Fourth, the proposed level of skill is consistent with the sophistication of the technology claimed in the '405 Patent. The patent concerns LiDAR technology, including the use of certain detector types and optical components, and optical features like the arrangement of emitter-detector pairs.

80. For these reasons, it is my opinion that the appropriate level of skill in the art is an undergraduate degree in mechanical or electrical engineering or physics and 2-3 years of experience in time-of-flight sensor design, such as LiDAR.

## **IX. CLAIM CONSTRUCTION**

81. For purposes of this proceeding, I have applied the ordinary and customary meaning of the claim terms as they would have been understood to a

POSITA at the time of the alleged invention of the '405 Patent, and I have considered that meaning in the context of the patent and its prosecution history. Based upon my review of the '405 Patent and my knowledge and experience in this field, the claim language does not include specialized terms that require further explanation or elaborative definitions. The ordinary and customary meaning would have recognized and understood by a POSITA.

82. I understand that in the parallel ITC proceeding, Hesai and Ouster have submitted preliminary constructions for certain terms of the '405 Patent before that proceeding was terminated. Ex. 1022. For the reasons detailed in the element-by-element analysis below, each of the prior art combinations that I analyzed herein would have achieved a predictable result that is similar to the embodiments described in the '405 patent. Accordingly, based upon my review of the '405 Patent and the prior art combinations analyzed below, the Challenged Claims are rendered obvious regardless of whether any of those preliminary constructions from the now-terminated ITC proceeding were imposed in this proceeding. When the prior art combinations are rightfully understood, those preliminary constructions would not change the result in this proceeding.

## **X. OVERVIEW OF THE PRIOR ART**

83. In this section, I provide an overview of the prior art references that I have relied on to inform my opinions.

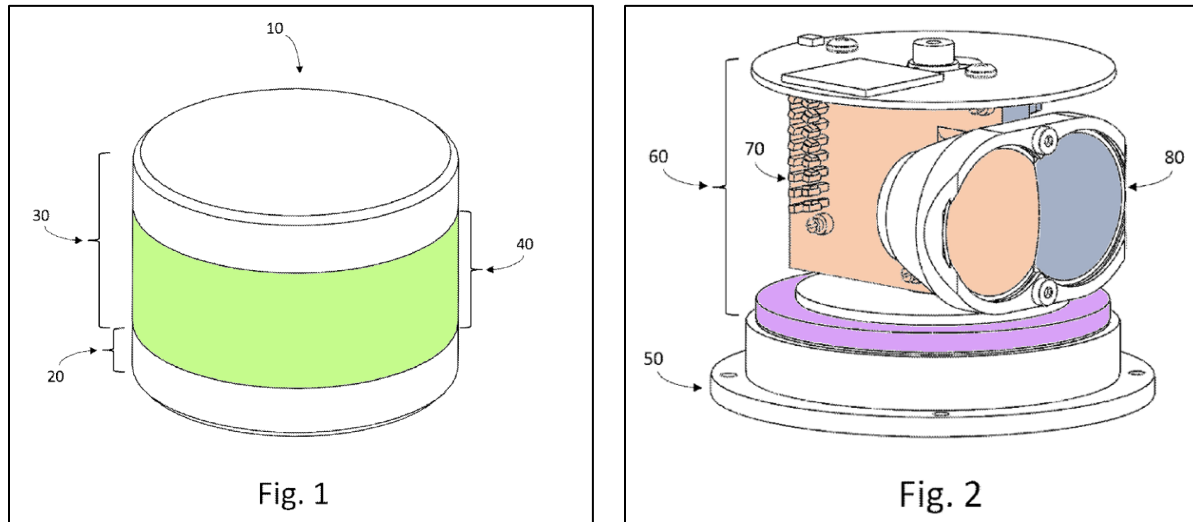
84. As I describe in this section, all of the references I rely upon in my obviousness analysis relate to LiDAR systems or techniques that may be used within LiDAR systems to improve their performance. Thus, all of these references would be obvious sources that a POSITA would have considered when building or seeking to improve a LiDAR system or device, as they all relate to the same field of endeavor, *i.e.*, the design of LiDAR systems.

**A. U.S. Patent Pub. No. 2014/0211194 (“Pacala”)**

85. Pacala is titled *Cost-effective lidar sensor for multi-signal detection, weak signal detection and signal disambiguation and method of using same*. Ex. 1004. Pacala was published on July 31, 2014.

86. Pacala lists as its assignee Quanergy Systems, Inc. (*id.*), a company that used to make LiDAR devices, and that I understand went bankrupt last year. I also understand that the lead inventor named on the face of Pacala—Angus Pacala—is also a named inventor on the ‘405 Patent, and in fact co-founded Ouster. Ex. 1001.

87. Pacala relates to “the use of cost-effective robust time-of-flight (ToF) lidar sensors for real-time wide-field-of-view three-dimensional mapping and object detection....” Ex. 1004, [0003]. One embodiment is provided, which is the LiDAR sensor shown in Figure 1 (external view) and Figure 2 (internal view), reproduced and annotated below:



*Id.*, Figs. 1-2 (annotated), [0012]-[0013].

88. Figure 1 shows “an external view of a lidar sensor 10” with “a static base 20 and static head assembly 30 that includes a window 40 [green] that is transparent at the wavelength of the laser used in each transmitter.” *Id.*, [0012]. Figure 2 shows the “internal view” of the sensor, with “a static base 50 that contains a motor and distributed electronics, and a spinning turret 60 that contains optoelectronic components 70 (including optical transmitters and receivers), collimation and focusing lenses 80 and distributed electronics.” *Id.*, [0013]. The turret sits on a platform (purple), which is rotated by a motor. *Id.* The optoelectronic components and lenses can be divided into two discrete modules, one for light transmission (blue) and one for light sensing (orange).<sup>4</sup> The optical receivers may

<sup>4</sup> Pacala does not expressly state that the light transmission and light sensing modules are separate, but as I explain in more detail in Section XI.A.2(e), other references from the same inventors confirm that the light transmission and light

include “a detector array (e.g., Single-Photon Avalanche Diode [SPAD] array).” *Id.*, [0014].

**B. U.S. Patent No. 10,605,984 (“Droz”)**

89. Droz is titled *Array of Waveguide Diffusers for Light Detection Using an Aperture*. Ex. 1006. Droz was filed on December 1, 2016. *Id.*

90. Droz is a Waymo patent, and describes a system that “relates to limitation of noise on light detectors using an aperture.” *Id.*, Abstract. Droz explains that light detectors, such as SPADs, can be “arranged into arrays connected in parallel” in order to “detect light over a substantial geometric area.” *Id.*, 1:10-18. In one example, an “array of SPADs can be connected in parallel to one another, which may allow combining the signals from the connected SPADs to improve the sensitivity of the system.” *Id.*, 3:63-67. These arrays of light detectors may be used in “a light detection and ranging (LIDAR) device [that] includes a LIDAR transmitter that illuminates a scene” and “a LIDAR receiver that receives light scattered by one or more objects within the scene.” *Id.*, 1:60-64; *see also id.*, 3:2-7 (explaining that the invention “may relate to devices, systems, and methods for reducing background light imparted onto an array of light detectors,” which “may be a sensing component of a light detection and ranging (LIDAR) device”).

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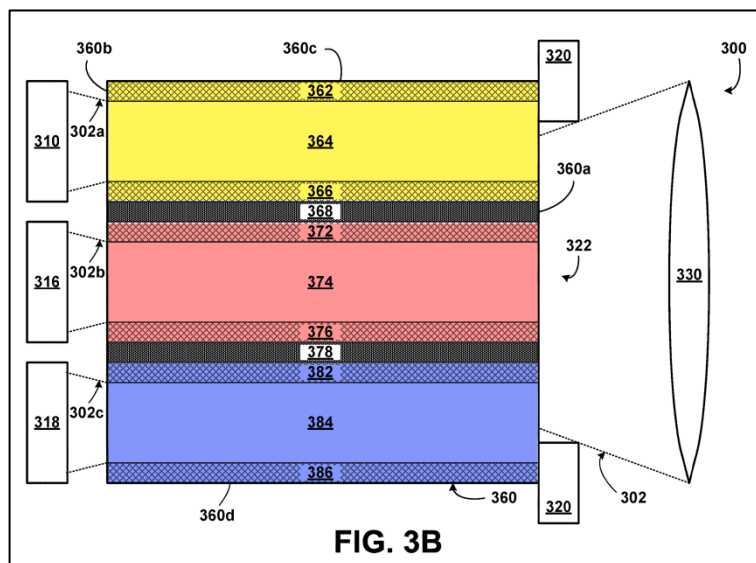
sensing components are separated, and it would have been obvious to POSITA that Pacala’s light transmission and light sensing modules are distinct.

91. Droz's arrangements of light detectors "are sensitive to relatively low intensities of light, thereby enhancing their detection qualities," but are also "disproportionately susceptible to adverse background effects" (e.g., noise and other interference). *Id.* 1:21-26. For example, as I discuss in Sections VI.C.2 and VI.C.3 above, stray light and cross-talk can be particularly problematic when using SPADs because of their ability to detect even a single photon, as well as the recovery time needed before another photon may be detected. Droz acknowledges this problem: "Once a SPAD absorbs a single photon ... the SPAD cannot detect additional photons until the SPAD is quenched (e.g., by restoring the reverse-bias voltage)," and "[i]f additional photons are arriving at time intervals approaching the recovery time ... the SPAD may begin to saturate, and the measurements by the SPAD may thus become less reliable." *Id.*, 11:2-10.

92. Droz provides techniques for mitigating different sources of stray light and cross-talk that may introduce measurement errors into a system. For example, Droz explains that light received at the system may "come, at least partially, from background sources." *Id.*, 4:56-57. Droz also explains that light arriving at the LiDAR device (including the reflected light) may "diverge and overlap prior to arriving at the array of light detectors." *Id.*, 4:12-14. If light intended for different arrays of detectors overlaps, it will "reduc[e] the SNR [signal-to-noise ratio] of the detected signal," which in turn increases the potential for errors. *Id.*, 12:50-55.

93. Droz teaches several discrete improvements, each of which mitigates a potential source of noise and interference. These techniques can be used together to substantially reduce the effect of stray light and cross-talk on the system.

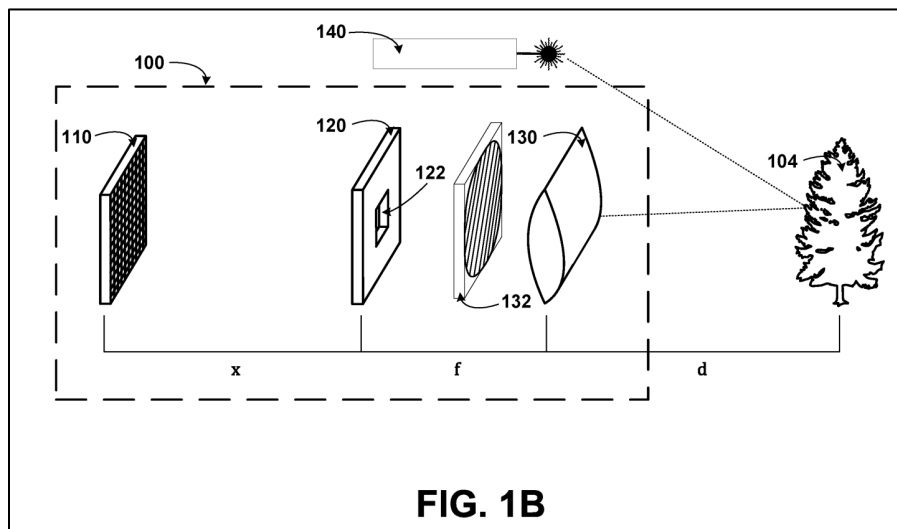
94. First, Droz teaches the use of “waveguides.” *See, e.g., id.*, 3:22-35. Waveguides generally are well known structures that, in the context of optics, may be used to guide light so that it does not travel outside of a desired path. Droz explains that incorporating waveguides into the light detection system provides a number of advantages, including “limit[ing] the divergence of a portion of the light guided,” so that light is directed to its corresponding array of light detector, and not to neighboring arrays of light detectors. *Id.*, 4:12-23. Figure 3B, reproduced and annotated below, illustrates an exemplary arrangement of three waveguides and light detector arrays:



*Id.*, Fig. 3B (annotated).

95. Second, Droz teaches using an “absorber ... positioned between adjacent waveguides to prevent guided light inside one waveguide from leaking into another.” *Id.*, 4:40-43. The absorber is shown as layers 368 and 378 in Figure 3B above.

96. Third, Droz teaches using an “optical filter configured to selectively transmit light within a predefined wavelength range” in order to “reduce ambient light or background light from adversely affecting measurements by array 110.” *Id.*, 7:51-64. One possible arrangement of the optical filter relative to the other light detection components (*e.g.*, a lens, an aperture, and the array of light detectors) is shown in Figure 1B, reproduced below (the optical filter is element 132):



*Id.*, Fig. 1B.

**C. U.S. Patent No. 10,520,602 (“Villeneuve”)**

97. Villeneuve is titled, *Pulsed laser for lidar system*. Ex. 1007. Villeneuve was filed on November 12, 2013. *Id.*

98. As the title suggests, Villeneuve “generally relates to lidar systems,” and, more specifically, to a “laser system” used in a LiDAR system. *Id.*, Abstract, 1:19, 1:38-52. Although much of Villeneuve is devoted to the laser system, Villeneuve also includes a detailed discussion of the light receiver and associated light detection components, as well as the correlation between the laser system and the light detection system (*i.e.*, the size and shape of the emitted light relative to the field of view of the light detector). *See generally id.*, 55:37-65:25.

99. At a high level, Villeneuve’s LiDAR system is equipped with one or more “sensor heads,” each of which is configured to “scan pulses of light across a field of regard of the sensor head.” *Id.*, 14:12-17; *see also id.*, 15:6-13, 16:57-65 (examples with multiple sensor heads).

100. As the sensor scans light across the field of regard, the field of view of the light source and receiver will be scanned across the field of regard. *Id.*, 55:37-41. Villeneuve provides an example where “a light-source field of view may refer to an angular cone illuminated by the light source 110 at a particular instant of time,” and “the receiver field of view may refer to an angular cone over which the receiver 140 may receive or detect light at a particular instant of time, and any light outside

the receiver field of view may not be received or detected.” *Id.*, 55:41-47. In practice, emitted light “may be sent in the direction that the FOV<sub>L</sub> is pointing at the time the pulse is emitted,” and “the receiver 140 may receive and detect a portion of the scattered light that is directed along or contained within the FOV<sub>R</sub>.” *Id.*, 55:47-55. This notion of light source field of view (referred to in Villeneuve as FOV<sub>L</sub>) and receiver fields of view (referred to in Villeneuve as FOV<sub>R</sub>), represented as angular cones, is one with which a POSITA would be well acquainted.

101. A POSITA would also understand that because light outside of the receiver field of view is not detected, it is important for the light source’s field of view to coincide with the receiver’s field of view. Villeneuve recognizes this need as well, teaching that that the FOV<sub>R</sub> “follows substantially the same path at the same scanning speed” as the FOV<sub>L</sub>, and “the FOV<sub>L</sub> and FOV<sub>R</sub> may maintain the same relative position to one another as they are scanned across the field of regard.” *Id.*, 55:62-56:2. For example, “the FOV<sub>L</sub> may be substantially overlapped with or centered inside the FOV<sub>R</sub>.” *Id.*, 56:2-6. In at least some embodiments, the size and shape of the FOV<sub>L</sub> and FOV<sub>R</sub> are “approximately equal,” and the FOV<sub>L</sub> and FOV<sub>R</sub> “may be substantially coincident with one another and may have an angular overlap of approximately 100%.” *Id.*, 56:31-33, 57:4-7. One such example is shown in Figure 34, reproduced below, in which the FOV<sub>L</sub> and FOV<sub>R</sub> “are approximately the same size and have an angular overlap of approximately 90%”:

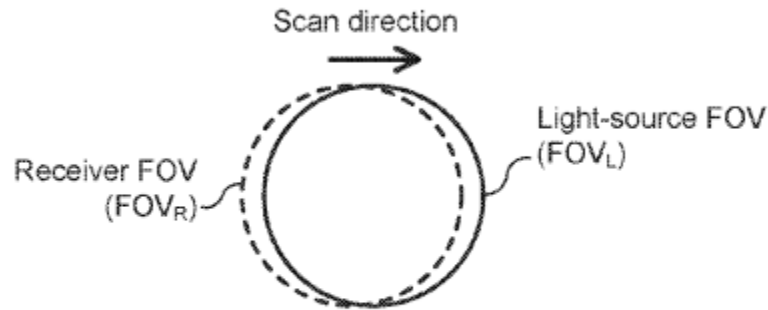


**Figure 34**

*Id.*, Fig. 34, 57:4-9.

102. The FOV<sub>L</sub> and FOV<sub>R</sub> may also be substantially the same size and shape, but “offset” from each other (accounting for the fact that the FOV<sub>L</sub> and FOV<sub>R</sub> are scanned across the scene, and thus some movement will occur between emission of a light pulse and detection of scattered light). *Id.*, 57:10-15. In this way, Villeneuve teaches that the LiDAR system can detect objects at different ranges relative to the LiDAR system. *Id.*, 57:31-59.

**D. U.S. Patent No. 9,983,297 (“Hall”)**

103. Hall is titled *LIDAR based 3-D imaging with varying illumination field density*. Ex. 1008. Hall was filed on March 20, 2017. *Id.*

104. Hall is a Velodyne patent, and generally relates to “LIDAR based 3-D point cloud measuring systems.” Ex. 1008, 1:16-17. It appears to be related to Velodyne’s more recent LiDAR sensors, such as the VLP-16, based on the cylindrical design (shown and described in more detail below). Hall explains that

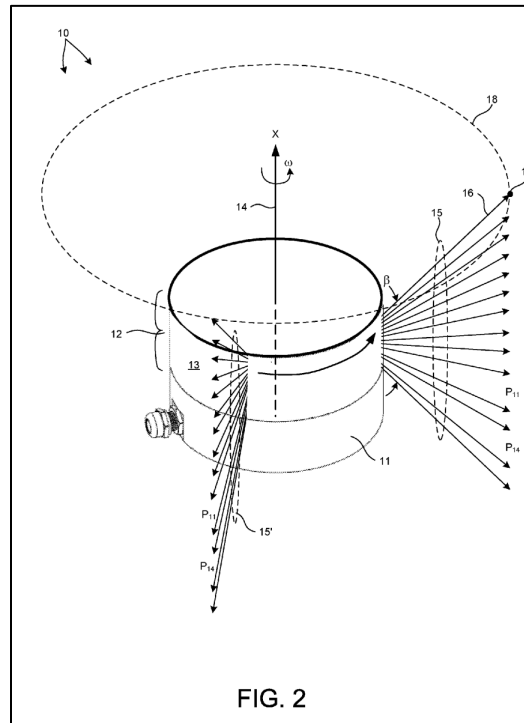
one application of LiDAR systems is in “autonomous vehicle[s],” where “an array of multiple laser emitters and detectors” is used “to generate image information over a broad field of view” with “a minimum of delay between the actions happening in the real world and the imaging of those actions.” *Id.*, 1:64-2:14.

105. Hall identifies several problems with conventional LiDAR systems. First, in LiDAR systems that “employ a single laser emitter/detector combination,” only a two-dimensional point cloud can be captured. *Id.*, 1:34-41. When a 3-D point cloud is necessary, a single emitter may still be used by “alter[ing]” the “light path of a single laser emitter/detector combination ... to achieve a broader field of view.” *Id.*, 1:55-57. But “[t]he number of pixels such devices can generate per unit time is inherently limited” because a single laser is limited in how often it can emit a pulse—thus, the resulting images will either be lower resolution, or will take much more time to scan. *Id.*, 1:57-60. In applications where a broad field of view is needed, and it “is necessary to have a minimum of delay between the actions happening in the real world and the imaging of those actions” (*e.g.*, autonomous vehicle applications, where objects in the path of the vehicle must be detected in real time), Hall explains that systems have been developed that “include[] an array of multiple laser emitters and detectors.” *Id.*, 1:64-2:14.

106. While the array of emitters and detectors allows for better and faster imaging, it presents a different set of problems. First, the beams of light emitted by

the emitters will frequently suffer from “significant sources of measurement noise” when they return to the detectors, which is “exacerbated as measurement ranges are extended.” *Id.*, 2:28-31. One solution is to improve the signal to noise ratio by increasing the laser pulse intensity, *id.*, 2:31-33, but that comes at the cost of “increases in energy consumption and heat generation,” which are “undesirable,” especially in small LiDAR systems such as those employed for autonomous vehicles. *Id.* 2:39-45. Hall notes that point cloud density (and thus image resolution) can also be improved by “increasing the rate of pulse emission and capture of corresponding signals,” but that too increases power consumption and heat dissipation. *Id.*, 2:34-43. Thus, Hall aims to improve “power management of LIDAR systems ... while maintaining sufficiently high levels of imaging resolution and range.” *Id.*, 2:46-48.

107. To solve these problems, Hall’s system “includes a plurality of pulse illumination sources and corresponding detectors” that are “mounted to a rotating frame of the LIDAR device,” which “rotates with respect to a base frame of the LIDAR device.” *Id.*, 2:54-56, 2:59-62. Hall’s “pulse illumination sources are varied to reduce total energy consumption and heat generated by the LIDAR system.” *Id.*, 2:56-58. One example of Hall’s system is shown in Figure 2, reproduced below:

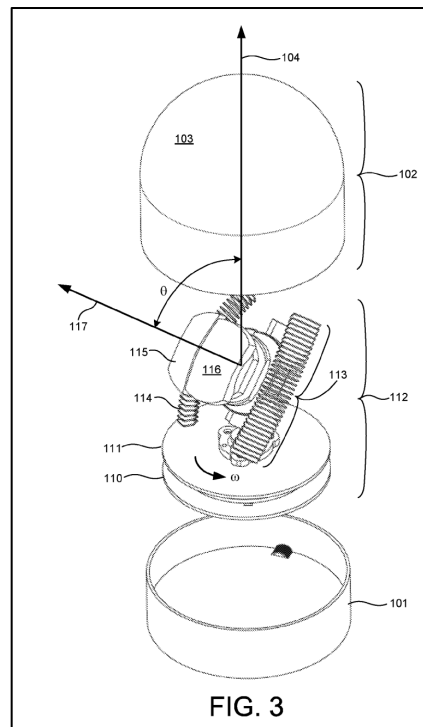


*Id.*, Fig. 2.

108. The example in Figure 2 includes a “lower housing 11 and an upper housing 12 that includes a cylindrical shell element 13 constructed from a material that is transparent to infrared light.” *Id.*, 5:41-49. “[A] plurality of beams of light 15 are emitted from the 3-D LIDAR system 10 through cylindrical shell element 13,” and “[e]ach beam of light is projected outward into the surrounding environment in a plurality of different directions.” *Id.*, 5:20-56.

109. Inside the housing of Hall’s LiDAR system is a “light emission/collection engine” with “an array of light emitting elements 114 and an array of light detecting elements 113.” *Id.*, 6:31-33. The light emission/collection engine is connected to a “rotating electronics board 111” and “rotates about central

axis 104.” *Id.*, 6:10-30. Light emitted from the emitters “passes through a series of illumination optics 115 that collimate the emitted light” before it is emitted into the environment. *Id.*, 6:33-38. After emission, the light is “reflected from objects in the environment” and “collected by collection optics 116 ... where it is focused onto each detecting element of the array of detecting elements 113.” *Id.*, 6:41-47. The light emission/collection engine is shown in Figure 3, reproduced below:

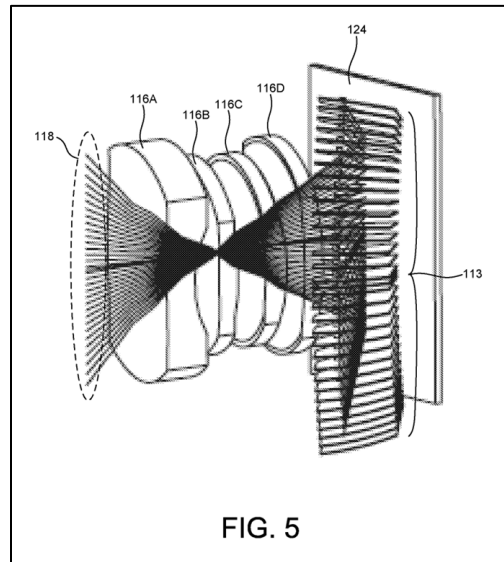


*Id.*, Figs. 3.

110. Although Figure 3 shows the light emission/collection engine in the context of a different embodiment, where the housing includes a domed cap, it would have been obvious to POSITA that the same engine is or can be used in the example of Figure 2. For example, Hall explains that both “3-D LIDAR system 10 depicted

in FIG.2, and system 100, depicted in FIG.1, include[] a plurality of pulsed illumination sources each emitting a pulsed beam of illumination light.” *Id.*, 7:40-44. Hall further explains that its LiDAR systems include both “a pulsed illumination system 130” and “a light detection system 150,” which together “comprise a LIDAR measurement channel.” *Id.*, 7:53-57. This is consistent with the light emission/detection engine shown in Figure 3. In any event, nothing would prohibit a POSITA from using the light emission/detection system shown in Figure 3 (and described in the accompanying text) in the exemplary system of Figure 2, and, indeed, Hall does not teach a different implementation of the illumination and detection systems for use in the example of Figure 2.

111. Hall also describes the optical elements within the light emission/detect engine in more detail. For example, Hall explains that the collection optics (element 116 in Figure 3) “include four lens elements 116A-D arranged to focus collected light 118 on to each of the array of detect elements 113,” as shown in Figure 5, reproduced below:



*Id.*, Fig. 5, 7:7-13. “[O]ne or more of the optical elements of collection optics 116” may be “constructed from one or more materials that absorb light outside of a predetermined wavelength range that includes the wavelengths of light emitted by each of the array of light emitting elements 114.” *Id.*, 7:13-27.

**E. U.S. Patent Pub. No. 2013/0300840 (“Borowski”)**

112. Borowski is titled *3D Landscape Real-Time Imager and Corresponding Imaging Methods*. Ex. 1009. Borowski was published on November 14, 2013.

113. Borowski “relates to a 3D landscape real-time imager” that includes “at least one illuminating part ... designed to scan at least a portion of the landscape at a given range and having an ultra-short laser pulse source emitting at least one wavelength,” “an optical rotating block, with a vertical axis of rotation, and controlled such that given packets of pulses are shaped in a pattern of rotating beams sent toward the said at least partial landscape,” and “at least one receiving part

[having] a set of SPAD detector arrays, each arranged along a vertical direction and rotating at a given speed in synchronism with the optical rotating block of the illuminating part” so that “the detection data of the SPAD detector arrays [is] combined to acquire 3D imaging data of the said at least partial landscape.” *Id.*, Abstract. Borowski explains that one application for such 3D landscape imagers is in LiDAR systems. *Id.*, [0003].

114. Borowski explains that existing 3D imagers are limited in their ability to achieve high resolution, fast acquisition speed, and long measurement ranges. For example, 3D imagers that have a “very high depth accuracy” are “mostly limited in their characteristics of speed of acquisition and measurement distance. *Id.*, [0002]. This is because there is a “risk of confusion of pulses if multiple pulses are on the way between transmitter and receiver at one time,” and “high repetition rate pulses ... may cause partial reflections of pulses” in optical elements. *Id.* Both of these scenarios would introduce noise into the measurements. Borowski notes that “[t]he measurement distance of such devices is [also] limited by the low energy of the pulses they use to maintain eye safety.” *Id.* Thus, because of their low speed and limited range, “[s]uch techniques are not suitable for obtaining fast landscape imaging,” which “should be able to scan the surroundings in nearly all directions.” *Id.* On the other hand, devices such as “long distance rangefinders” and “airborne lidars” are unable to generate images at “high resolution, at all ranges,” and typically

take a long “time to acquire a complete frame of the scene ... especially when the scanned scene is a complete landscape.” *Id.*

115. Borowski thus recognizes that “there is a need for a 3D landscape real-time imager having enhanced speed, distance and resolution capabilities.” *Id.*, [0003]. Borowski addresses the typical trade-off between resolution, speed, and range by, among other things, using “a set of SPAD (single photon avalanche diode) detector arrays” with “a means for combining data acquired with the SPAD detector arrays ... to obtain 3D images” of a landscape. *Id.*, [0007]; *see also id.*, [0078]-[0083] (describing the receiver implementation in more detail). “The reflected photons are efficiently detected on linear arrays of ultrafast SPAD sensors.” *Id.*, [0022]. Borowski’s SPAD arrays “are capable of detecting single photons at very high speed thanks to an avalanching process that provides significant carrier amplification” (*i.e.*, the avalanche process I describe in Section VI.C.2 above). *Id.*, [0035]. The “combination of the 3D data of all SPAD detector arrays generates a complete image of the landscape around the 3D real-time landscape imager’s available field of view.” *Id.*, [0043].

116. As I discuss in Section VI.C.2 above, a well-known problem with SPADs is that they need to be “quenched” after avalanche, during which time additional incoming photons cannot be detected. Borowski acknowledges and addresses this issue by providing “clusters of several SPAD detector cells” organized

into a “macro-cell” with a signal processor that “multiplex[es] and average[es] the detected events of the SPAD detector cells.” *Id.*, [0053]. In this way, each macro-cell “acts as the equivalent of a single ‘perfect’ SPAD having no recovery time.” *Id.*; *see also id.*, [0171] (describing how “the data acquired on each SPAD detector cell are filtered and averaged in a group of SPAD detector cells, clustered in a macro-cell”).

**F. U.S. Patent No. 10,473,766 (“Spector”)**

117. Spector is titled *Light detection and ranging (LiDAR) system and method*. Ex. 1005. It was filed on June 27, 2017 and claims priority to Provisional Application No. 62/470,706, filed on March 13, 2017. *Id.*; Ex. 1010 (provisional application).

118. Spector relates to “a LiDAR system” that “creates a two-dimensional array of light spots.” Ex. 1005, Abstract; Ex. 1010 at 12 (describing “spots” created using a “lens array”). “The spots traverse the scene in the first dimensional direction and in the second dimensional direction without substantially overlapping points in the scene already scanned by other spots in the array.” Ex. 1005, Abstract; Ex. 1010 at 12 (“Projection” figure showing non-overlapping light spots), 13 (“isolated spots are illuminated” and a “small stage can be used to move the projected spots”).

119. The “receiver optics,” include “an array of optical detection sites” with “a one-to-one correspondence between light spots in the two dimensional array and

the optical detection sites.” Ex. 1005, 1:48-51; Ex. 1010 at 13 (each light spot has a “matching aperture” at the receiver), 19 (apertures at the receiver are “[s]ymmetric” with emitted light spots). The one-to-one correspondence is effected using a “mask” that “defin[es] a plurality of transparent apertures arranged according to the two dimensional array [of light spots],” which “limit[] the visibility by each optical detection site to a single corresponding light spot.” Ex. 1005, 2:1-6; Ex. 1010, 12 (describing “aperture[s] ... used to select imaged light at locations that correspond to the projected light”), 19 (light spots and aperture array have the “[s]ame pattern”). Spector’s receiver optics are shown on the right side of Figure 1, reproduced and annotated below 1:

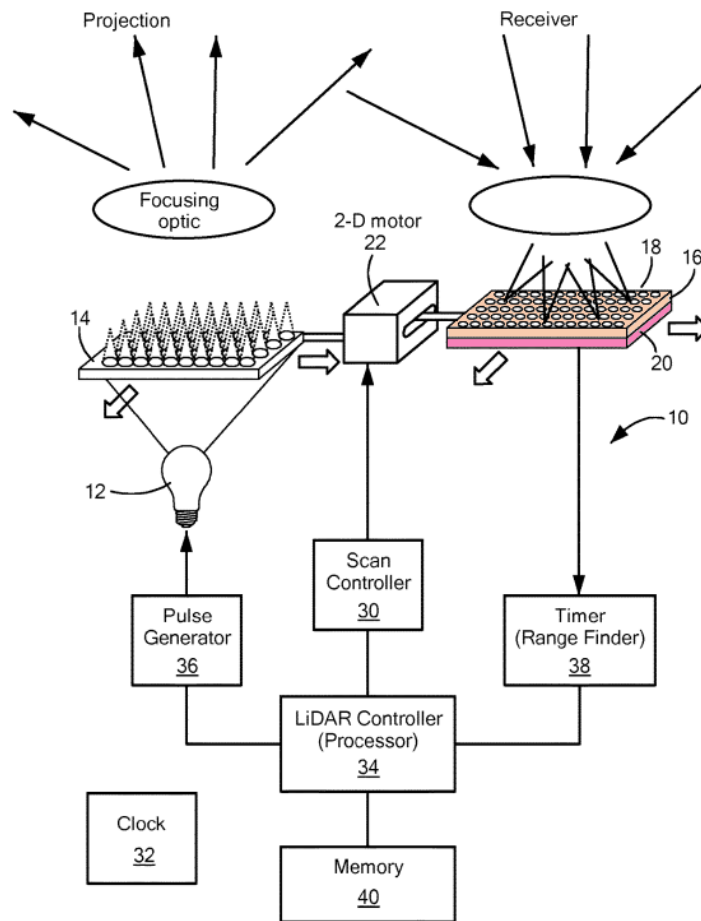


**FIG. 1**

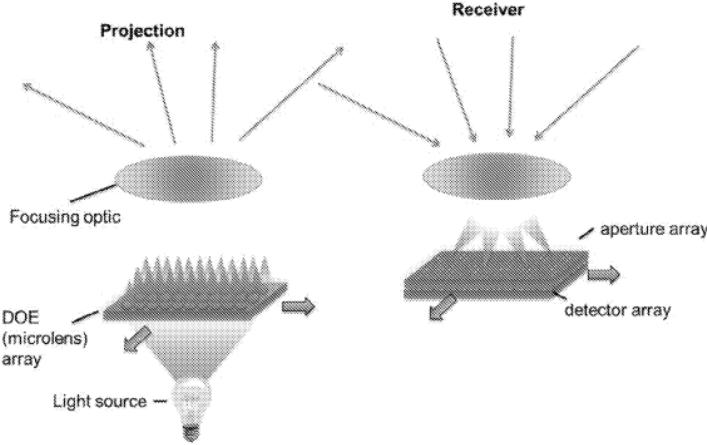
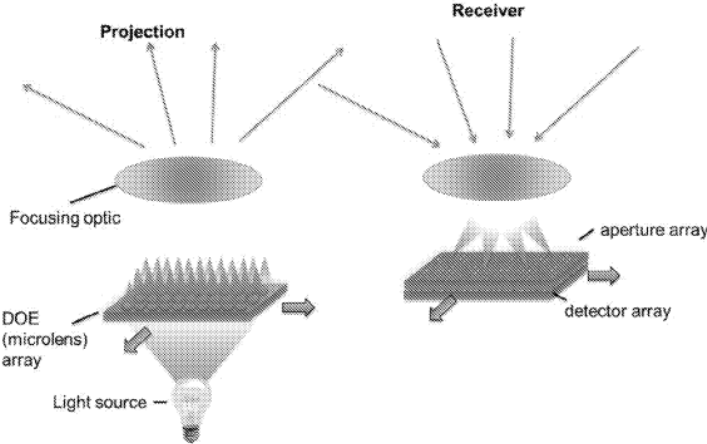
Ex. 1005, Fig. 1 (annotated); *see also* Ex. 1010 at 12, 19 (similar figures).

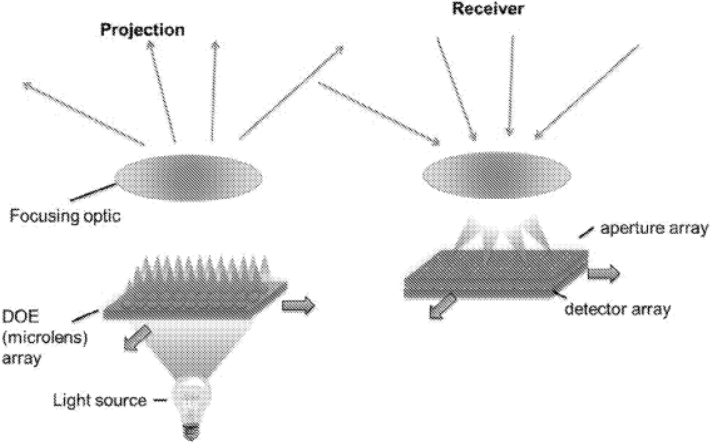
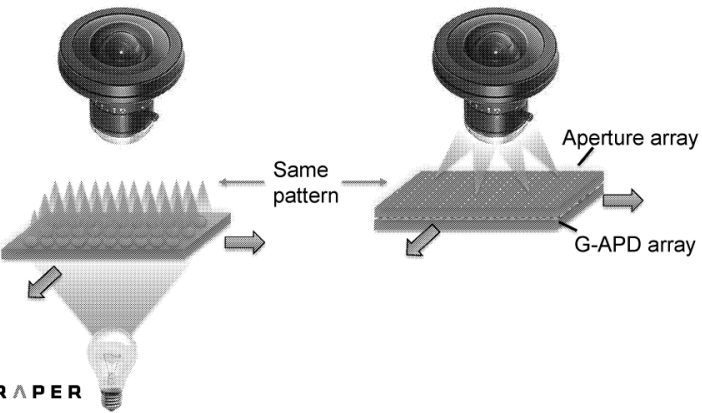
120. Spector identifies advantages to using an array of light spots with corresponding apertures and detection sites at the receiver. Among other things, each aperture “limits visibility by each optical detection site to a single corresponding light spot.” Ex. 1005, 3:59-61; Ex. 1010 at 12 (“an aperture is used to select imaged light at locations that correspond to the projected light”). This allows Spector’s system to reduce “cross-talk and multipath signal ... advantageously.” Ex. 1005, 6:12-15; Ex. 1010 at 12 (invention “minimizes cross-

talk and background”), 13 (“Because the spots are isolated, cross-talk and multipath signal are reduced. The aperture on the receiver further reduces cross-talk and background.”). In addition, because multiple light spots and multiple optical detection sites can be used in parallel, “a much smaller scanning motion is required, thereby permitting the use of smaller and/or simpler and less expensive scanning mechanisms.” Ex. 1005, 6:15-18; Ex. 1010 at 13 (“A much smaller scanning motion is required.”).

121. I note that the claims of Spector (Ex. 1005) are supported by the description of Provisional Application No. 62/470,706 (Ex. 1010). For example, each element of claims 1 and 3 of Spector (Ex. 1005) is described in Provisional Application No. 62/470,706 (Ex. 1010):

| <b>Spector (Ex. 1005)</b>                                   | <b>Provisional Application No.<br/>62/470,706 (Spector Provisional) (Ex. 1010)</b>         |
|-------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| 1. A light detection and ranging (LiDAR) system comprising: | Spector Provisional teaches that the “target application is LiDAR system.” Ex. 1010 at 12. |
| a light source;                                             | Spector Provisional shows a light source at the “Projection” side of the system:           |

| Spector (Ex. 1005)                                                                                                                                                                                                                                                                 | Provisional Application No. 62/470,706 (Spector Provisional) (Ex. 1010)                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                    |  <p>Ex. 1010 at 12.</p>                                                                                                                                                                                                                                                                                                                   |
| <p>an arrayed micro-optic configured to receive light from the light source so as to produce and project a two dimensional array of light spots on a scene, wherein the two dimensions of the array includes a first dimensional direction and a second dimensional direction;</p> | <p>Spector Provisional teaches that a “lens array” (<i>e.g.</i>, a “DOE (microlens) array”) can be used to create “[s]pots ... in the imaging plane of the projector lens,” which “are projected out onto the scene.” Ex. 1010 at 12. The microlens array creates light spots in two dimensions, as shown below:</p>  <p><i>Id.</i></p> |
| <p>receiver optics having an array of optical detection sites configured so as to be suitable for establishing a one-to-one correspondence between</p>                                                                                                                             | <p>Spector Provisional teaches that the “receive side functions much like the projector” and uses “an aperture ... to select imaged light at locations that correspond to the projected light.” Ex. 1010 at 12</p>                                                                                                                                                                                                          |

| Spector (Ex. 1005)                                                                                  | Provisional Application No.<br>62/470,706 (Spector Provisional) (Ex. 1010)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>light spots in the two dimensional array and optical detection sites in the receiver optics;</p> | <p>The apertures correspond to optical detection sites, as shown in the figure below (<i>i.e.</i>, the “detector array”), and each light spot has a “matching aperture,” and, by extension, a corresponding optical detection site. <i>Id.</i> at 13.</p>  <p><i>Id.</i> at 12.</p> <p>Spector Provisional similarly teaches that the “[a]perture array on receiver” is “[s]ymmetric with focused spots on emitter.” <i>Id.</i> at 19. This is reflected in a figure similar to the one above.</p>  <p><i>Id.</i></p> |
| <p>a scanner configured to physically oscillate the arrayed micro-optic and</p>                     | <p>Spector Provisional teaches that “[m]easurements are made while these spots are scanned to fill the area in the scene.” Ex. 1010 at 12. “The scanning can be</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

| Spector (Ex. 1005)                                                                                                                                                                                                              | Provisional Application No.<br>62/470,706 (Spector Provisional) (Ex. 1010)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>the receiver optics synchronously to scan:<br/>(a) the two dimensional array of light spots and<br/>(b) the receiver optics so as to maintain the one-to-one correspondence; and</p>                                         | <p>done by moving the diffractive optic (or other device) creating the spots, [or] by moving the lens.” <i>Id.</i> For example, “[a] small stage can be used to move the projected spots on the projector and the aperture on the receiver.” <i>Id.</i> at 13. “One example method would be to scan a lens array using a miniature x-y stage driven by a voice coil.” <i>Id.</i> at 12. “The same scanning method and optics can be used [for the receive side].” <i>Id.</i> As noted above, “[a]t the receiver a matching aperture is also scanned.” <i>Id.</i> at 13; <i>see also id.</i> at 19 (describing the receiver and detector scanning as “[s]ynchronized”).</p> <p>One such scanning mechanism is shown in the figure below.</p> <div data-bbox="641 1001 1128 1423" data-label="Image"> <p style="text-align: center;">Flexure Stage<br/>(voice-coil driven)</p> </div> <p><i>Id.</i> at 21.</p> |
| <p>a scan controller operable to cause the scanner to move the array of light spots back and forth so as to complete a scan of the scene wherein the spots traverse the scene in the first dimensional direction and in the</p> | <p>As noted above, Spector Provisional teaches that “[m]easurements are made while these spots are scanned to fill the area in the scene.” Ex. 1010 at 12. “The scanning can be done by moving the diffractive optic (or other device) creating the spots, by moving the lens.” <i>Id.</i> “A small stage can be used to move the projected spots on the projector and the aperture on the receiver.” <i>Id.</i> at 13. “One example method would be to scan a lens array using a miniature x-y stage driven by a voice coil.” <i>Id.</i></p>                                                                                                                                                                                                                                                                                                                                                                |

| <b>Spector (Ex. 1005)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>Provisional Application No.<br/>62/470,706 (Spector Provisional) (Ex. 1010)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>second dimensional direction no more than 150% of the distance between adjacent spots in the first dimensional direction and in the second dimensional direction, respectively.</p>                                                                                                                                                                                                                                                                        | <p>Spector Provisional also teaches that the scanning distance is within 150% of the distance between adjacent spots, because the scanner only needs to traverse the distance between adjacent spots (<i>i.e.</i>, 100%, which is no more than 150%): “The scanning range is minimal, as only the distance between the spots needs to be covered.” <i>Id.</i> at 12. “A much smaller scanning motion is required. To fill the scene, the illumination and detector aperture only have to be scanned the distance between illumination spots.” <i>Id.</i> at 13.</p> |
| <p>3. The LiDAR system according to claim 1 wherein the scan controller is operable to cause the scanner to move the array of light spots back and forth so as to complete a scan of the scene wherein the spots traverse the scene in the first dimensional direction and in the second dimensional direction no more than the distance between adjacent spots in the first dimensional direction and in the second dimensional direction, respectively.</p> | <p>As noted above, Spector Provisional teaches that the scanner only has to traverse the “the distance between illumination spots.” Ex. 1010 at 13.</p>                                                                                                                                                                                                                                                                                                                                                                                                             |

## **XI. OBVIOUSNESS ANALYSIS FOR THE CHALLENGED CLAIMS**

122. In this section, I provide an analysis of how the prior art renders obvious claims 21 and 23-34 of the ‘405 Patent. I have organized my analysis into the following grounds:

| <b>Grounds</b> | <b>Claims</b>         | <b>Statutory Basis</b> | <b>Prior Art</b>                            |
|----------------|-----------------------|------------------------|---------------------------------------------|
| 1              | 21, 23, 26-31, and 34 | §103                   | Pacala in view of Droz                      |
| 2              | 24-25 and 32-33       | §103                   | Pacala in view of Droz and Villeneuve       |
| 3              | 21 and 23-33          | §103                   | Hall in view of Borowski and Spector        |
| 4              | 34                    | §103                   | Hall in view of Borowski, Spector, and Droz |

123. For each ground, I address motivation to combine and reasonable expectation of success, and then analyze the teachings of the prior art on an element-by-element basis.

### **A. Ground 1: Pacala and Droz Render Obvious Claims 21, 23, 26-31, and 34**

124. For the reasons set forth in detail below, and based on my review of the ‘405 Patent, file history, and the prior art references cited in my analysis, a POSITA would have readily understood that the combined teachings of Pacala and Droz provide all elements of claims 21, 23, 26-31, and 34.

125. Pacala describes the basic elements of a LiDAR device, such as the external housing with a window, a rotating platform on which a LiDAR sensor is

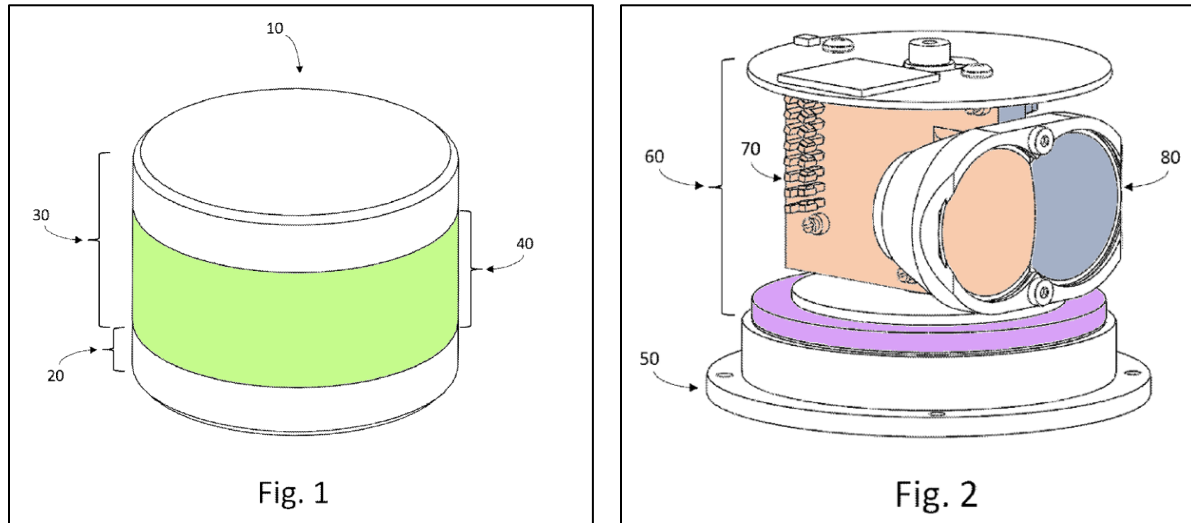
mounted, and basic components used in LiDAR sensors, such as bulk transmitter and receiver optics, emitters, and photosensors. Pacala also describes using SPADs for the photosensors. Pacala does not describe the detailed implementation of the receiver optics and photosensors, and it would have been obvious to incorporate optical filters and waveguide arrays based on the teachings of Droz. Droz explains that optical filters mitigate the effect of stray light, and that waveguide arrays mitigate the effect of cross-talk between neighboring detector arrays. Droz also teaches that these improvements are particularly beneficial when using sensitive detectors such as SPADs. A POSITA would have been motivated to combine the teachings of Pacala and Droz to achieve the known benefits of optical filters and waveguides in a LiDAR system with SPADs, namely, reduction of noise and interference from stray light and cross-talk.

### **1. Predictable Combination of Pacala and Droz**

126. Based upon my review of the references and my knowledge and experience in this field, it is clear that a POSITA would have been motivated to combine the teachings of Pacala and Droz. This is particularly the case in view of the relatively late time frame leading up to May 2017 (the filing date of the provisional application).

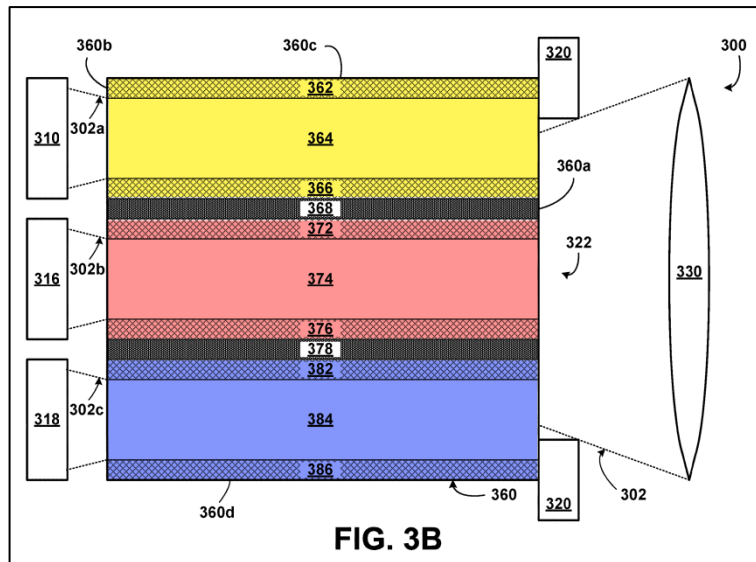
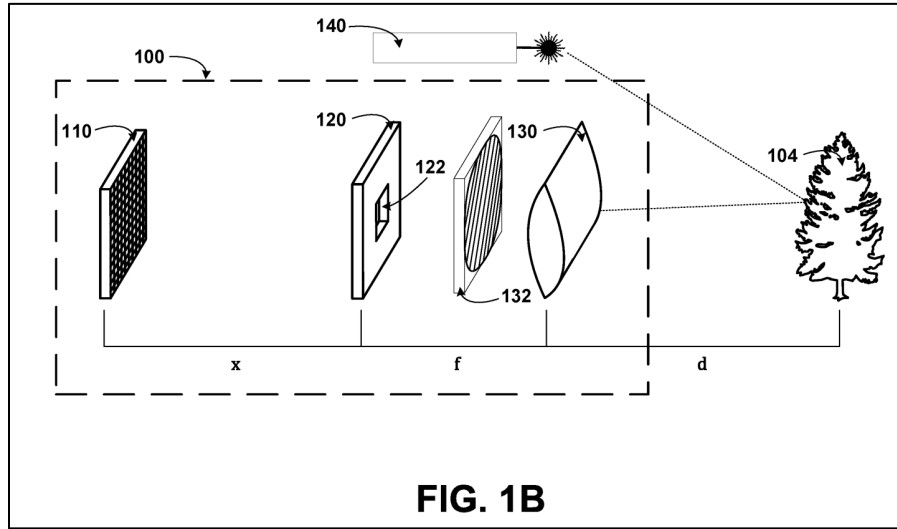
127. As I explain above, Pacala describes a LiDAR system with an external housing including a “static base,” “static head assembly,” and “window” that is

optically transparent. Ex. 1004, [0012], Fig. 1. Pacala further describes a “spinning turret” mounted atop the static base, which contains “optoelectronic components” (e.g., “optical transmitters and receivers”) and “collimation and focusing lenses.” *Id.*, [0013], Fig. 2.



Ex. 1004, Figs. 1-2 (annotated).

Pacala teaches that the optical receivers may be “a detector array (e.g., Single-Photon Avalanche Diode [SPAD] array).” *Id.*, [0014]. Droz, like Pacala, proposes using an “array of SPADs ... connected in parallel to one another” for each photosensor, explaining that this “improve[s] the sensitivity of the system.” Ex. 1006, 3:63-67. Droz then provides straightforward suggestions for mitigating the impact of noise and interference on SPADs. For example, Droz describes using optical filters to prevent stray light from arriving at the detectors, and waveguides to minimize cross-talk. *Id.*, 3:22-35, 4:12-23, 4:40-43, 7:51-64, Figs. 1B, 3B.



Ex. 1006, Figs. 1B, 3B (annotated).

128. In the resulting combination, each pixel in Pacala's detector array (e.g., Ex. 1004, [0014], Fig. 2) would have been implemented based on Droz's suggestions of incorporating optical filters to reduce stray light (e.g., Ex. 1006, 7:51-64, Fig. 1B) and incorporating waveguides to reduce cross-talk (e.g., Ex. 1006, 3:22-35, 4:12-23, Fig. 3B). A light-absorbing material would be included between adjacent

waveguides to further prevent light from one waveguide to leak into a neighboring waveguide, as taught by Droz. *Id.*, 4:40-43. In this manner, the input of each waveguide would also define an aperture to further reduce the effect of stray light. *Id.*, 9:27-30, 16:17-21.

129. As I explain below, based on my review of Pacala and Droz, and my knowledge and experience in the field, a POSITA would have understood that Droz's suggestions would have been predictably applied to the LiDAR system of Pacala to incorporate optical filters and waveguides for the reduction of stray light and cross-talk.

130. As a first reason, a POSITA would have been motivated to combine Pacala and Droz to implement each pixel within Pacala as an array of SPADs (to the extent that Pacala's SPAD arrays are not on a per-pixel basis). A POSITA would have readily recognized that doing so would improve the sensitivity of the system, and thereby improve its detection capability. Ex. 1029 at 8. Based on my knowledge and experience in the field, a POSITA would have recognized from both Pacala's and Droz's teachings that multi-SPAD pixels advantageously increased the likelihood the pixel would more accurately detect photons, especially when one or more of the individual SPADs was subject to quenching and reset. Ex. 1004, [0007]; Ex. 1006, 1:10-23, 3:63-67, 11:2-10. For example, Pacala teaches that conventional LiDAR devices "can miss low intensity pulses." Ex. 1004, [0007]. Droz expressly

teaches that SPADs have “high sensitivities,” which was already well known in the art by May 2017. Ex. 1006, 10:63-65; Ex. 1029 at 8. But Droz also recognizes that “[o]nce a SPAD absorbs a single photon,” it “cannot detect additional photons until the SPAD is quenched.” Ex. 1006, 11:2-10. Droz thus teaches to use a plurality of interconnected SPADs to represent a pixel in order to “improve the sensitivity of the system.” Ex. 1006, 3:63-67. Indeed, others in the field also recognized that interconnecting multiple SPADs allows the combined SPADs to act as a single “perfect” SPAD with no recovery time. Ex. 1009, [0053], [0171], [0192].

131. As a second reason, a POSITA would have been motivated to combine Pacala and Droz to incorporate optical filters between Pacala’s receiver optics and detectors, based on Droz’s suggestion, to reduce the effect of stray light on the system. Droz expressly teaches that by adding optical filters to “selectively transmit light within a predefined wavelength range”—i.e., the wavelength range of the light emitted by the emitters—the system advantageously “reduce[s] ambient light or background light from adversely affecting measurements.” Ex. 1006, 7:51-64. A POSITA would particularly be motivated to incorporate optical filters into Pacala’s system because Pacala’s system uses SPAD arrays, and Droz teaches that a “reduction in light intensity” is “particularly beneficial” in those circumstances because “reducing the light power incident on any individual light detector (*e.g.*, any one SPAD) allows the SPAD to “remain unsaturated,” which results in “increased

accuracy.” *Id.*, 10:63-11:15. Droz teaches that the optical filter may be “located in various positions” to achieve these benefits, including between a lens and an aperture, between an aperture and a detector, combined with the detector array, covering each individual light detector in the array, combined with an aperture, or on the surface of the lens. *Id.*, 7:65-8:11. A POSITA would have understood that the precise location of the optical filter is a design choice, and that any of these options would achieve the benefits described by Droz.

132. As a third reason, a POSITA would have been motivated to combine Pacala and Droz to incorporate waveguides, based on Droz’s suggestion, to improve light detection in several different ways. First, Droz teaches that using waveguides increases “the number of light detectors able to fit into a detection area,” thus allowing for more SPADs within the SPAD array, which, in turn, may increase resolution and/or the sensitivity and detection quality (as discussed above). *Ex.* 1006, 3:34-67. This is because the detection area is smallest where the light is most focused, and the waveguide adds distance between the focal point and the detection area. *Id.*, 3:41-43. The waveguide array also facilitates detecting multiple pixels “separately and simultaneously” to increase imaging speed. *Id.*, 13:34-37. Second, Droz teaches that waveguides prevent cross-talk by “limit[ing] the divergence of a portion of the light guided,” so that light is directed to the array corresponding to that waveguide, and are not detected at neighboring arrays. *Id.*, 4:12-23. Droz also

teaches that cross-talk can be further mitigated by including an absorbing layer between adjacent waveguides. *Id.*, 4:40-48, 14:47-60.

133. As a fourth reason, a POSITA would have found it obvious to combine Pacala and Droz because doing so would have been—certainly by the timeframe leading up to May 2017—merely the application of a known technique to a known system ready for improvement to yield predictable results. Pacala describes a known LiDAR system including standard components of a rotating LiDAR device, such as a housing, rotating sensor, and emitters and detectors (including SPADs). Droz describes known improvements to LiDAR technology for improving its detection capabilities, including the use of multi-SPAD detectors, optical filters, and waveguides to increase sensitivity while mitigating the effect of stray light and cross-talk. Both Pacala and Droz are analogous and similarly relate to LiDAR systems, and, in my view, a POSITA would have recognized that applying Droz’s suggestion to Pacala’s system would have led to predictable results of enhancing the sensitivity and detection capability of the resulting LiDAR device—all while maintaining Pacala’s purpose/functionality as a LiDAR unit. In my view, a POSITA would have had a reasonable expectation of success in making the proposed modifications based on the similarity of the LiDAR systems in Pacala and Droz. Here, Pacala does not require any particular implementation of its detectors (beyond noting that they may include arrays of SPADs). Droz plainly suggests configurations that improve the

detection capabilities using techniques known in the prior art before May 2017, and that a POSITA could have implemented in Pacala's system using basic electrical engineering techniques and principles.

## **2. Claim 21**

134. Based on my review of Pacala and Droz, and my knowledge and experience in the field, a POSITA would have found it obvious that Droz's suggestions, predictably combined with the teachings of Pacala, provide all elements of claim 21. I explain in detail below how each element of claim 21 is disclosed by the combination of Pacala and Droz.

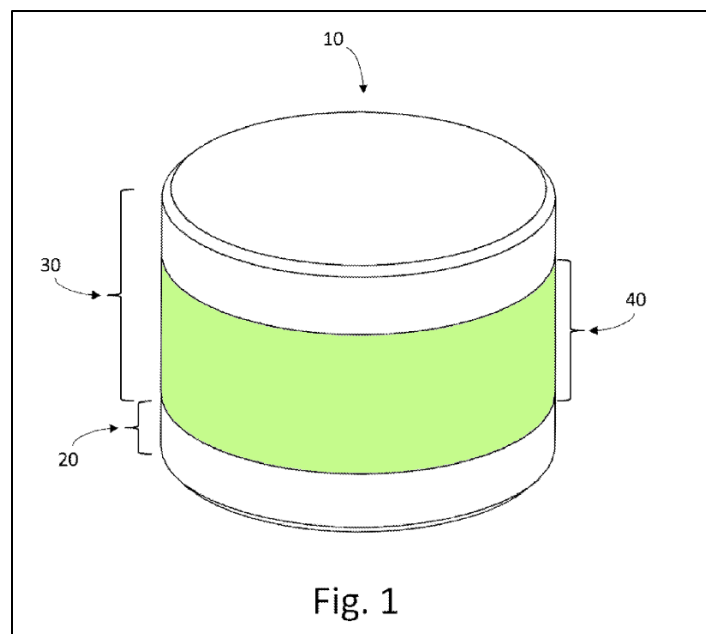
*a) Element 21(a): An optical system for performing distance measurements, the optical system comprising:*

135. The Pacala-Droz combination provides the recited system of element 21(a). Pacala teaches a "lidar-based apparatus and method." Ex. 1004, Abstract. Pacala also teaches that a "lidar sensor ... can measure the distance to a target or objects in a landscape." *Id.*, [0004].

136. Also, in the Pacala-Droz combination, Droz teaches "a light detection and ranging (LIDAR) device [that] includes a LIDAR transmitter that illuminates a scene" and "a LIDAR receiver that receives light scattered by one or more objects within the scene." Ex. 1006, 1:60-64.

- b) *Element 21(b): a stationary housing having a base, a top and an optically transparent window disposed between the base and the top and extending fully around a periphery of the stationary housing;*

137. The Pacala-Droz combination provides element 21(b). The disclosed LiDAR sensor includes a “static base 20 and a static head assembly 30 that includes a window 40 that is transparent at the wavelength of the laser used in each transmitter,” as illustrated in Figure 1:



Ex. 1004, Fig. 1 (annotated), [0012]. In the annotated in Figure 1, the window 40 is highlighted in green, and is plainly disposed between the static base 20 and the top of the static head assembly 30.

138. Pacala does not expressly say that the window extends fully around the periphery of the housing, but it would have been obvious to POSITA that this would be the case. Since Pacala teaches that the housing is stationary, and the emitters and

detectors rotate on a platform internal to the housing (*e.g.*, *id.*, [0012]-[0013]), the window would need to extend fully around the periphery of the housing, or the sensor would necessarily have a blind spot in the region not covered by the window (because light could not be emitted or received in that region. In addition, other prior art from the same inventors confirms that Pacala's window extends fully around the periphery of the housing. For example, U.S. Patent Publication No. 2016/0047901 ("Pacala-2016"), another Quanergy patent which also named Mr. Pacala as the lead inventor, includes an identical figure showing a housing with a window. Ex. 1013, [0014], Fig. 1. Pacala-2016 confirms that the system has "no moving external parts and an internal spinning turret," and, in at least one embodiment, the field of view of the system is "360 degrees." This can only be the case if the window extends fully around the housing, for the reasons I note above.

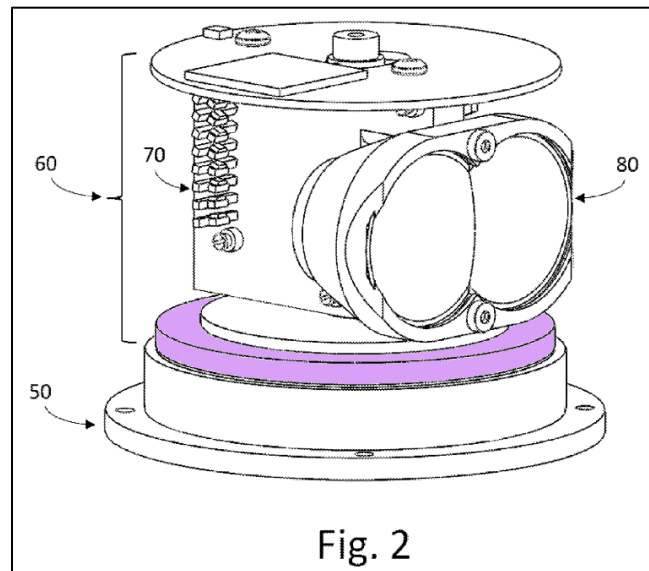
*c) Element 21(c): a light ranging device disposed within the housing and comprising:*

139. The Pacala-Droz combination provides element 21(c). Pacala's system includes "light detection and ranging sensor." Ex. 1004, [0004]. The sensor includes a "a spinning turret," "optoelectronic components," and "collimation and focusing lenses," which are standard components of a light ranging device. *Id.*, [0013]. These light ranging components (as shown in Figure 2) correspond to the

“internal view” of the sensor, and are contained within the housing (as shown in Figure 1), which is the “external view” of the system. *Id.*, [0012]-[0013], Figs. 1, 2.

*d) Element 21(d): a platform*

140. The Pacala-Droz combination provides element 21(d). As noted above, Pacala’s LiDAR sensor includes a spinning turret 60 that contains “optoelectronic components 70 ..., collimation and focusing lenses 80 and distributed electronics.” Ex. 1004, [0013]. Figure 2 shows that the LiDAR sensor containing the optical, electronic, and optoelectronic components sits atop a platform, annotated in purple below:

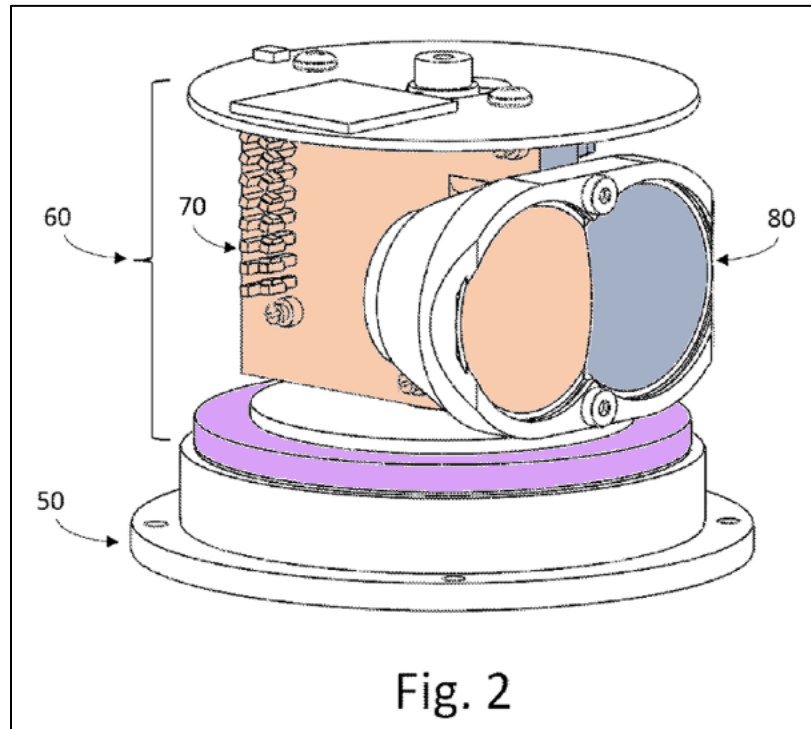


Ex. 1004, Fig. 2 (annotated).

141. Pacala-2016 also corroborates that Pacala's internal LiDAR components are mounted to a rotating platform. For example, Pacala-2016 also describes a LiDAR device with an internal "spinning turret," and in a claimed embodiment, describes the LiDAR sensor as "rigidly mounted" to "a rotating platform." Ex. 1013, [0017], cl. 11.

*e) Element 21(e): a light transmission module coupled to the platform and comprising a bulk transmitter optic and a plurality of optical emitters, each optical emitter in the plurality of optical emitters configured to generate and transmit pulses of radiation through the bulk transmitter optic and through the optically transparent window into a field external to the optical system*

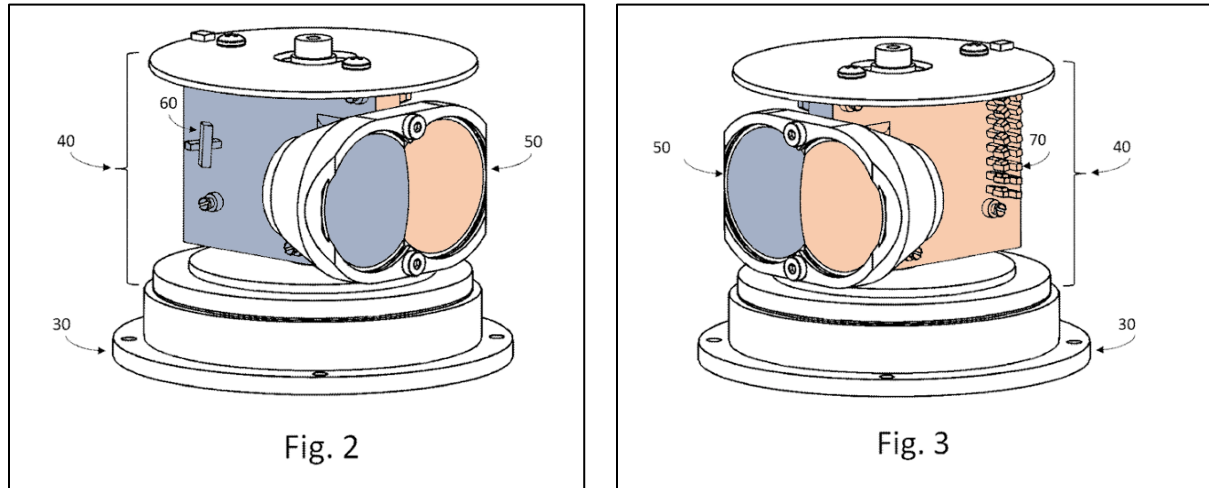
142. The Pacala-Droz combination provides element 21(e). Pacala's spinning turret 60 contains "optoelectronic components 70 (including optical transmitters and receivers), collimation and focusing lenses 80 and distributed electronics." Ex. 1004, [0013]. These components are coupled to the platform at the base of the sensor, as shown in Figure 2, and as corroborated by Pacala-2016 (discussed in the preceding section):



Ex. 1004, Fig. 2 (annotated).

143. In the above image, Pacala’s LiDAR sensor has been annotated to show a light transmission module (blue) and a light sensing module (orange). Pacala does not expressly describe separate transmission and sensing modules, but it would be clear to POSITA that Pacala’s optoelectronic components and lenses form discrete modules for light transmission and light detection. This type of configuration, with transmitters and transmitter optics in one region of the device, and detectors and detector optics in another region of the device, is typical in many LiDAR systems. It is also confirmed by a third Quanergy reference, which also names Mr. Pacala as the lead inventor. Specifically, U.S. Patent No. 10,036,803 (“Pacala-803”) includes separate figures showing the “emitting side” and “receiving side” of a similar

LiDAR device, as shown below (Figure 2 is the emitting side and Figure 3 is the receiving side):



Ex. 1014, Figs. 2, 3 (annotated), 3:19-27. In addition, each of the two lenses (labeled 50 in the two figures above, and labeled 80 in Figure 2 of Pacala) is positioned on one of the two sides of the turret, so that each lens has an optical path to either the emitters or the receivers, but not both. Finally, one of skilled in the art would know that of the “collimation and focusing lenses” described in Pacala (Ex. 1004, [0013]), a collimation lens would be used to collimate outgoing light from emitters, whereas a focusing lens would be used to collect and focus incoming light to the receivers, and thus these lenses would correspond to a light transmission and light sensing module, respectively.

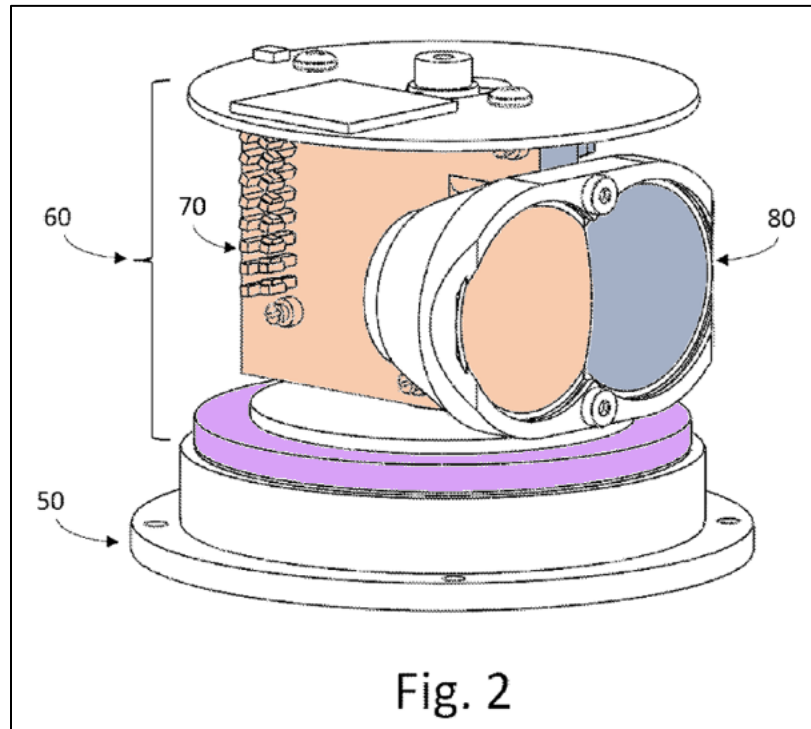
144. Pacala also provides a bulk transmitter optic. As noted above, a POSITA would have known that Pacala’s collimation lens and focusing lenses are two different lenses, and would have known that the collimation lens would be used

for light transmission, and the focusing lens would be used for light sensing. This comports with the '405 Patent, which states that the bulk transmitter optic can be a “lens” that “outputs a collimated beam.” Ex. 1001, 30:20-22, 31:15-16.

145. Pacala also provides a plurality of optical emitters that generate and transmit pulses of radiation through the bulk transmitter optic and window into an external field. Pacala’s LiDAR sensor includes “optical transmitters” (referenced in the plural) that “irradiat[e] [a] target or landscape with light, using pulses.” Ex. 1004, [0004], [0013]. As discussed above, a POSITA would have known, and Pacala-803 confirms, that Pacala’s optical transmitters are positioned behind the collimation lens, and thus emitted light would necessarily pass through the lens as it is transmitted into an external field. Similarly, because the LiDAR sensor is internal to the housing, all emitted and received light must pass through the window.

- f) Element 21(f): a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field, and an optical filter disposed between the bulk receiver optic and the plurality of photosensors and configured to allow a band of radiation, including an operating wavelength of the plurality of optical emitters, to pass through the filter to the plurality of photosensors while blocking radiation outside the band from reaching the plurality of photosensors*

146. The Pacala-Droz combination provides element 21(f). As noted above for elements 21(d) and 21(e), Pacala's spinning turret 60 contains "optoelectronic components 70 (including optical transmitters and receivers), collimation and focusing lenses 80 and distributed electronics." Ex. 1004, [0013]. These components are coupled to the platform at the base of the sensor, as shown in Figure 2, and as corroborated by Pacala-2016 (discussed in the preceding section):



Ex. 1004, Fig. 2 (annotated), [0013].

147. Also as discussed above for element 21(e), Pacala describes separate light transmission and light sensing modules, as confirmed by Pacala-803. As also noted above, a POSITA would have known that Pacala’s collimation lens would be used for light transmission, and the focusing lens would be used for light sensing. Pacala’s focusing lens thus provides a bulk receiver optic. This comports with the ‘405 Patent, which states that “light rays” are “focused by bulk receiver optic 202.”

Ex. 1001, 30:20-22, 31:15-16.

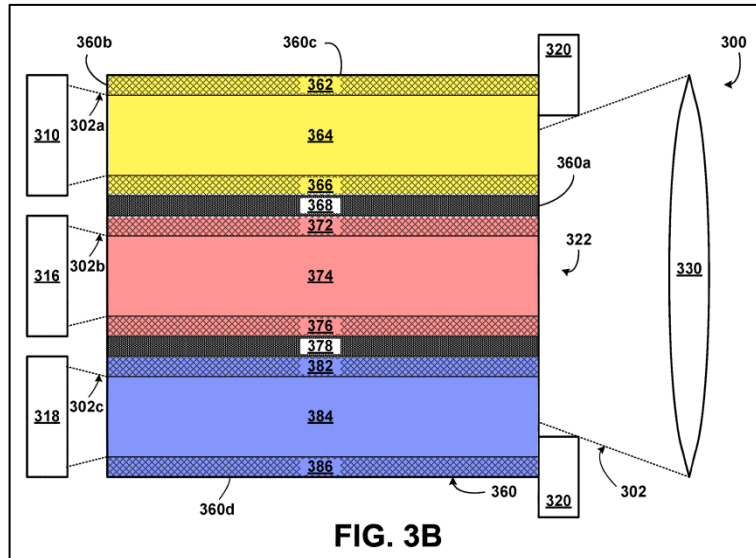
148. Pacala also provides a plurality of photosensors that detect photons emitted from the emitters and received through the bulk receiver optic after being reflected from surfaces within the field. Pacala’s LiDAR sensor includes “optical

... receivers” that detect photons that “travel to [a] target or landscape and return after reflection.” Ex. 1004, [0004], [0013]. As discussed above, a POSITA would have known, and Pacala-803 confirms, that Pacala’s optical receivers are positioned behind the focusing lens, and thus reflected light would necessarily pass through the lens before it is received at the photosensors.

149. In the Pacala-Droz combination, Pacala’s LiDAR system is implemented based on Droz’s suggestions to use a waveguide array with waveguides separated by a light absorbing material, and an optical filter between the focusing lens and optical receivers. *See* Section XI.A.1; Ex. 1006, 3:22-35, 4:12-23, 4:40-43, 7:51-64, 9:27-30, 16:17-21, Fig. 1B, Fig. 3B. As detailed in Section XI.A.1, a POSITA would have been motivated to incorporate optical filters and waveguides as disclosed in Droz into Pacala’s light sensing module.

150. Droz’s waveguide array in the Pacala-Droz combination provides an aperture layer. Each waveguide defines an aperture that only allows light intended for an associated detector array, while blocking light intended for neighboring arrays. Specifically, each waveguide includes an optically transparent core layer (364, 374, and 384 in Figure 3B)—which allows light to pass through—surrounded by cladding layers (362, 366, 372, 376, 382, and 386) that reflect light that reaches the edge of the core layer in order to guide it along the path defined by the

waveguide. Ex. 1006, 13:27-54. Figure 3B, reproduced below, provides an example of a waveguide array that includes three wave guides (yellow, red, and blue):



*Id.*, Fig. 3B (annotated).

151. Each waveguide defines an aperture, such that waveguide array provides an aperture layer with a plurality of apertures. For example, for a given waveguide, light is received on the input side (side 360a) and guided toward an output side (side 360b). *Id.*, 14:4-17. A detector array (310, 316, or 318 in Figure 3B) is “positioned adjacent to the output end” of the waveguide “to intercept and detect” the light. *Id.*, 14:11-17. Droz expressly teaches that “each respective input end of the waveguides in array 360 may correspond to a respective aperture of system 300.” *Id.*, 16:18-21. In addition, Droz’s absorbing layers (368 and 378) provide a stop region between the apertures, by preventing light from passing

through where the absorbing layers are placed (including between adjacent waveguides). *Id.*, 13:39-43, 14:47-60.

152. As discussed above, Droz also provides an optical filter between the receiver lens and detector arrays. *Id.*, 7:50-8:10. Droz teaches that the optical filter “may be located in various positions relative to [light detector] array 110,” including, among others, between the lens and the apertures, between an aperture and a detector, combined with the detector array, covering each individual light detector in the array, combined with an aperture, or on the surface of the lens. *Id.*, 7:65-8:10. As discussed above, Droz’s optical filter is “configured to selectively transmit light within a predefined wavelength range” and “may be configured to divert light of particular wavelengths away from the array 110,” such as light “that is not of the wavelength range emitted by emitter 140.” *Id.*, 7:51-61. In other words, Droz’s optical filter can be used to filter out light of wavelengths not corresponding to the emitters in the LiDAR system.

g) *Element 21(g): a motor disposed within the housing and operatively coupled to spin the platform and the light ranging device within the housing*

153. The Pacala-Droz combination provides element 21(g). Pacala’s static base “contains a motor.” Ex. 1004, [0013]. Since Pacala’s LiDAR sensor is on a spinning turret mounted on the platform (as discussed in Section XI.A.2(d)), and the

base itself is static, a POSITA would have understood that the motor is coupled to and used to rotate the platform in order to rotate the spinning turret.

*h) Element 21(h): wherein: each photosensor in the plurality of photosensors comprises a plurality of single photon avalanche diodes (SPADs);*

154. The Pacala-Droz combination provides element 21(h). As noted above, Pacala expressly teaches that its optical receivers may be “a detector array,” including a SPAD array. Ex. 1004, [0014]. Because of the recovery time associated with individual SPADs, a POSITA would have understood that a single SPAD should not be used to represent a pixel,<sup>5</sup> and that each pixel in Pacala’s system would thus correspond to a plurality of SPADs. This is also confirmed by Pacala-803, which describes “single-photon avalanche diode (SPAD) arrays” as a type of photodetector (contrasted with avalanche photodiodes and PIN diodes, which are not described as an “array”). Ex. 1014, 2:51-57, 4:22-25.

155. In the Pacala-Droz combination, Droz also teaches using light detector arrays to represent “an image pixel.” Ex. 1006, 13:1-3, 14:37-40; *see also id.*, 4:9-11 (“[E]ach array of light detectors can be connected in parallel to provide a combined output that represents a single image pixel of the scene.”). Droz also expressly explains that each light detector array “may include a plurality of light

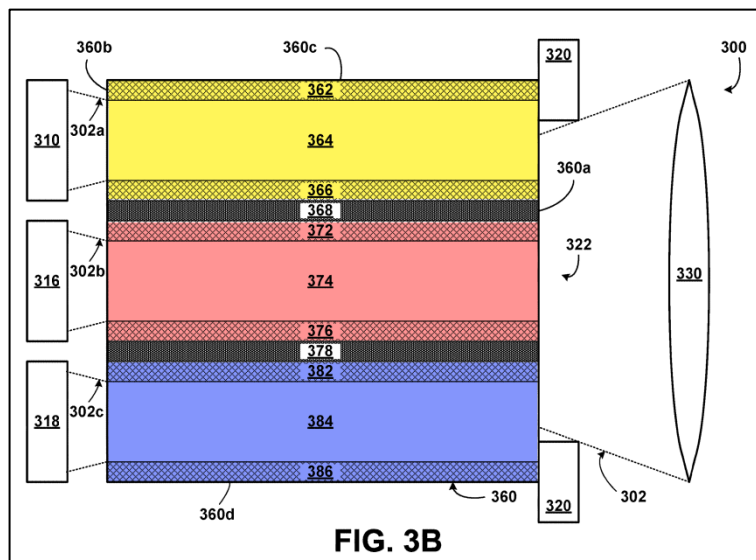
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<sup>5</sup> The ‘405 Patent equates the term “photosensor” with “pixel.” Ex. 1001, 11:39-43

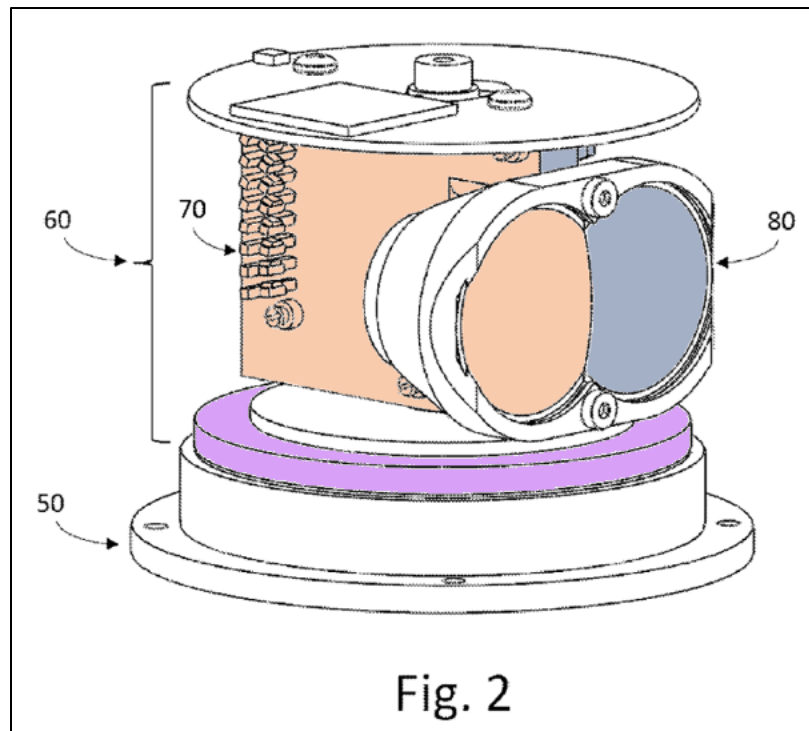
detectors,” including a plurality of SPADs. *Id.*, 13:3-6, 5:28-29, 18:55-57. As detailed in Section XI.A.1, to the extent Pacala does not already teach using arrays of SPADs for each photosensor, a POSITA would have been motivated to do so based on Droz’s teachings.

- i) *Element 21(i): the plurality of apertures comprises at least first, second, third and fourth apertures*

156. The Pacala-Droz combination provides element 21(i). As discussed in Section XI.A.2(f) above, in the Pacala-Droz combination, Pacala’s LiDAR system incorporates waveguides—with each input end defining an aperture—for each photosensor, based on Droz’s suggestion. Droz teaches that the waveguide array includes multiple waveguides (and thus multiple apertures)—for example, three waveguides/apertures in Figure 3B:



Ex. 1006, Fig. 3B (annotated), 13:48-54. But Droz is clear that the waveguide array “may include fewer or more than the three waveguides shown,” and is not limited to three waveguides. *Id.*, 16:54-55. In particular, since each waveguide corresponds to a SPAD array/photosensor, and Pacala’s system includes more than four detectors (as shown in Figure 2, below), the Pacala-Droz combination would include at least for waveguides/apertures.

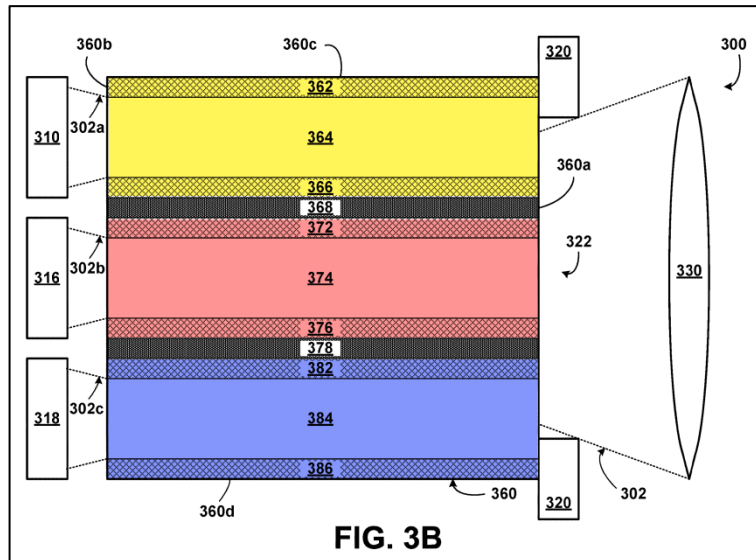


Ex. 1004, Fig. 2 (annotated).

- j) Elements 21(j): the plurality of photosensors comprises at least first, second, third and fourth photosensors; and the light sensing module includes a first optical path to the first photosensor through the first aperture, a second optical path to the second photosensor through the second aperture, a third optical path to the third photosensor through the third aperture, and a fourth optical path to the fourth photosensor through the fourth aperture.*

157. The Pacala-Droz combination provides element 21(j). As discussed in Section XI.A.2(i), Pacala's system includes more than four photosensors, and thus the Pacala-Droz combination would include more than four waveguides/apertures (one for each photosensor).

158. Each waveguide/aperture defines an optical path between the corresponding aperture (the input end of the waveguide) and the SPAD array associated with that waveguide. Each waveguides guides light to a different light detector array. For example, in Figure 3B (below), the waveguide defined by core layer 364 guides light to detector array 310; the waveguide defined by core layer 374 guides light to detector array 316; and the waveguide defined by core layer 384 guides light to detector array 318.



Ex. 1006, Fig. 3B (annotated), 14:4-17. The absorbing layer between the waveguides (368 and 378) also ensure that light will not leak between adjacent waveguides, so that there is a unique optical path between a waveguide/aperture and its associated detector array (but not between the waveguide/aperture and other detector arrays). Ex. 1006, 14:47-60. In the Pacala-Droz combination, that means that each of the more than four waveguides/apertures will define a separate optical path with its associated SPAD array.

3. **Claim 23: The optical system for performing distance measurements according to claim 21 wherein the system generates distance data based on times between transmission of pulses of light from the plurality of optical emitters and detection of photons from the pulses of light by the plurality of photosensors.**

159. The Pacala-Droz combination provides the additional element of claim 23. Pacala teaches that LiDAR sensors “measure the distance to a target or objects

in a landscape” by “irradiating the target or landscape with light, using pulses ... from a laser” (i.e., transmitting pulses of light from emitters) and “measuring the time it takes photons to travel to said target or landscape and return after reflection to a receiver in the lidar module” (i.e., using the time between transmission and detection to measure distance). Ex. 1004, [0004]. Indeed, that is the basic function of a LiDAR sensor.

#### **4. Claim 26**

160. Based on my review of Pacala and Droz, and my knowledge and experience in the field, a POSITA would have found it obvious that Droz’s suggestions, predictably combined with the teachings of Pacala, provide all elements of claim 26. I explain in detail below how each limitation of claim 26 is disclosed by the combination of Pacala and Droz.

##### *a) Elements 26(a)-26(e)*

161. Elements 26(a)-26(e) of claim 26 are word-for-word identical to elements 21(a)-21(e) of claim 21. The Pacala-Droz combination provides these elements for the same reasons I discuss above with respect to the corresponding elements of claim 21, in Sections XI.A.2(a)-(e).

- b) *Element 26(f): a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field, and one or more optical filters disposed between the bulk receiver optic and the plurality of photosensors, each of the one or more optical filters configured to allow a set of wavelengths of radiation, including an operating wavelength of the plurality of optical emitters, to pass through the one or more optical filters while blocking radiation outside that set*

162. The Pacala-Droz combination provides element 26(f). I note that element 26(f) largely mirrors element 21(f) of claim 21, and so for the overlapping limitations, is provided by the Pacala-Droz combination for the same reasons I discuss above with respect to element 21(f), in Section XI.A.2(f).

163. The only substantive difference between element 21(f) and element 26(f) is that element 21(f) requires “an optical filter” configured to allow a “band of radiation” to pass through the filter while “blocking radiation outside the band,” whereas element 26(f) requires “*one or more* optical filters” that allow a “*set of wavelengths* of radiation” to pass through the filters while “blocking radiation outside that *set*.” As noted above, in the Pacala-Droz combination, Droz’s optical filters would be incorporated into Pacala’s system to mitigate the effects of stray light.

164. I understand that as a matter of claim construction law, the indefinite articles “a” and “an” are presumed to mean “one or more,” so there is not necessarily a substantive difference between the elements. However, Droz does also expressly teach multiple optical filters. For example, Droz teaches that “each of the light detectors in array 110 may individually be covered by a separate optical filter.” Ex. 1006, 8:4-6. In that scenario, the Pacala-Droz combination would include more than one optical filter between the lens (bulk receiver optic) and the SPAD arrays (the photosensors). In addition, as I note above in Section XI.A.1, the location of the optical filter is a design choice, and the number of filters needed depends at least in part on the location where it is placed. For example, if the optical filter is at or close to the lens, a single filter may suffice for all of the SPAD arrays; whereas if the filter is provided between the apertures/waveguides and the SPAD arrays, because each aperture/waveguide defines a separate path, multiple optical filters may be needed (one for each aperture/waveguide).

165. With respect to the light that is filtered, Droz teaches that the optical filter “can be configured to selectively transmit light within a predefined wavelength range,” such as “a visible wavelength range, an infrared wavelength range, or any other wavelength range,” each of which defines a set of wavelengths. *Id.*, 7:51-57.

*c) Elements 26(g)-26(j)*

166. Elements 26(g)-26(j) of claim 26 are word-for-word identical to elements 21(g)-21(j) of claim 21. The Pacala-Droz combination provides these elements for the same reasons I discuss above with respect to the corresponding elements of claim 21, in Sections XI.A.2(g)-(j).

**5. Claim 27: The optical system for performing distance measurements set forth in claim 26 wherein the one or more optical filters comprise a bandpass filter.**

167. The Pacala-Droz combination provides the additional element of claim 27. Droz expressly teaches that its optical filters (which are incorporated into Pacala's system in the Pacala-Droz combination) may be a "bandpass optical filter." Ex. 1006, 9:18-19.

**6. Claim 28: The optical system for performing distance measurements set forth in claim 26 wherein the one or more optical filters comprise a plurality of optical filters.**

168. The Pacala-Droz combination provides the additional element of claim 28. As discussed above for element 26(f), Droz expressly teaches a plurality of optical filters. For example, "each of the light detectors in array 110 may individually be covered by a separate optical filter." Ex. 1006, 8:4-6. In this example, there are multiple optical filters between the bulk receiver optic/lens and each photosensor/detector array, but there is also a plurality of optical filters for each photosensor/detector array (one for each SPAD in the array).

**7. Claim 29: The optical system for performing distance measurements set forth in claim 28 wherein each of the plurality of optical filters is supported by an optically transparent substrate.**

169. The Pacala-Droz combination provides the additional element of claim 29. As noted above, Droz teaches that its optical filters “may be located in various positions,” one of which is a “surface screen” on the light detector array or a “surface screen” on the lens. Ex. 1006, 7:65-8:10. If the optical filter is disposed on a “surface screen,” a POSITA would understand that to mean it is attached to and supported by that screen. In addition, the surface of the lens or detector array must be a *transparent* substrate because light must pass through it in order to be received at and detected by the underlying SPADs.

**8. Claim 30: The optical system for performing distance measurements set forth in claim 29 wherein the plurality of optical filters are disposed in the first optical path.**

170. The Pacala-Droz combination provides the additional element of claim 30. As discussed above, one option of implementing Droz’s optical filters—which is one of several options that are ultimately a design choice left to the individual designer—is such that “each of the light detectors in array 110 [is] individually [] covered by a separate optical filter.” Ex. 1006, 8:4-6. In this scenario, the optical filter would be positioned between the input of the waveguide (the aperture) and its corresponding detector array and associated SPADs. Because each aperture and SPAD array defines an optical path (*see* Section XI.A.2(j) for element 21(j)), the

result is that the plurality of optical filters for each SPAD array will be in the optical path defined by that SPAD array and waveguide/aperture.

9. **Claim 31: The optical system for performing distance measurements according to claim 26 wherein the system generates distance data based on times between transmission of pulses of light from the plurality of optical emitters and detection of photons from the pulses of light by the plurality of photosensors.**

171. The additional element of claim 31 is word-for-word identical to the additional element of claim 23. The Pacala-Droz combination provides this element for the same reasons I discuss above with respect to claim 23, in Section XI.A.3.

10. **Claim 34: The optical system for performing distance measurements according to claim 26 wherein the one or more optical filters comprises a first optical filter disposed in the first optical path between the first photosensor and the first aperture, a second optical filter disposed in the second optical path between the second photosensor and the second aperture, a third optical filter disposed in the third optical path between the third photosensor and the third aperture, and a fourth optical filter disposed in the fourth optical path between the fourth photosensor and the fourth aperture.**

172. The Pacala-Droz combination provides the additional element of claim 34. As discussed above, two options of implementing Droz's optical filters—which are among several options that are ultimately a design choice left to the individual designer—include that the optical filter is “combined with [the] aperture,” or that “each of the light detectors in array 110 [is] individually [] covered by a separate optical filter.” Ex. 1006, 8:4-6. In both of these examples, each optical path (between

waveguide/aperture and SPAD array) would have at least one optical filter positioned in that path: one filter per optical path when combined with the aperture, and multiple filters per optical path when each SPAD in the array is covered by a separate filter.

**B. Ground 2: Pacala, Droz, and Villeneuve Render Obvious Claims 24-25 and 32-33**

173. As I discussed above in Ground 1, Pacala and Droz render obvious claims 21, 23, 26-31, and 34. *See* Sections XI.A.1-10. The additional elements of dependent claims 24-25 and 32-33 are provided by the predictable combination of Pacala in view of Droz and Villeneuve. Here, Villeneuve describes a LiDAR system, like Pacala and Droz, but further teaches how to align and correlate the emitters and detectors to optimize detection over a range of distances, by configuring the field of view of the light source/emitter and the field of view of the receiver/detector to be coincident and substantially the same size and shape, over a range of distances.

174. As I explained above in Section X.C, Villeneuve describes a LiDAR system with multiple “sensor heads” that scan “pulses of light across a field of regard.” Ex. 1007, 14:12-17, 15:6-13, 16:57-65. Each light source has an associated field of view, FOV<sub>L</sub>, and each receiver has an associated field of view, FOV<sub>R</sub>. *Id.*, 55:37-55. Villeneuve teaches that the FOV<sub>L</sub> and FOV<sub>R</sub> may be “approximately

equal” in size and shape, and “may be substantially coincident with one another.”  
*Id.*, 56:31-33, 57:4-7.

**1. Predictable Combination of Pacala, Droz, and Villeneuve**

175. Based upon my review of the references and my knowledge and experience in this field, it is clear that a POSITA would have been motivated to combine the teachings of Pacala, Droz, and Villeneuve. Multiple reasons would have prompted a POSITA to implement Villeneuve’s well-understood suggestions (including to substantially match the fields of view of light sources and detectors) with the Pacala-Droz combination (previously articulated above).

176. As a first reason, a POSITA would have been motivated to match the fields of view of the emitters and detectors in the Pacala-Droz combination to so that the fields of view are substantially the same size and shape, and substantially coincident. A POSITA would have understood that a receiver in a LiDAR system will only detect light within its field of view, and so if an emitter and corresponding detector do not have matching fields of view, objects may not be accurately detected. This is confirmed by Villeneuve, which teaches that “any light outside the receiver field of view may not be received or detected.” Ex. 1007, 55:46-47. Villeneuve explains that by properly matching the fields of view of the light sources and receivers, the light from a particular light source will be detected by its corresponding receiver across a range of distances, up to a maximum range. *Id.*,

57:31-59. Further, by May 2017 it was well known that large fields of view for a detector increase the signal to noise ratio because more stray light may be received, and that for optimal performance the detector's field of view should be substantially the same size as the spot of light emitted by the light source. Ex. 1024, 1:53-59, 3:1-12, 4:56.

177. As a second reason, a POSITA would have found it obvious to combine Pacala, Droz, and Villeneuve because doing so would have been—certainly by the timeframe leading up to May 2017—merely the application of known techniques to a known system ready for improvement to yield predictable results. This is explained with respect to the Pacala-Droz combination above in Section XI.A.1. Villeneuve further describes known techniques (e.g., matching light source and receiver fields of view) in LiDAR design for improving the detection capabilities of conventional LiDAR devices, such as the LiDAR device in the Pacala-Droz combination. Villeneuve also describes how its teachings may be applied to systems that include multiple emitters and detectors (for example, a system with multiple sensor heads) or to systems with multiple photodetectors are associated with to a single emitter (e.g., the SPAD arrays in the Pacala-Droz combination). Ex. 1007, 14:12-21, 15:6-13, 16:57-65 (all describing multiple sensor heads), 59:55-60:15 (describing use of SPADs), 65:5-21 (describing detector arrays). Indeed, Villeneuve provides specific teachings for matching emitter and detector fields of view,

identifying various options for the angular extents (sizes), which a POSITA would be able to implement by appropriately sizing waveguides/apertures in the Pacala-Droz combination. Further, because both Pacala and Droz do not require any specific emitter implementation, a POSITA would be free to incorporate the teachings of Villeneuve to implement emitters that are aligned with the SPAD arrays in the Pacala-Droz combination.

2. **Claim 24: The optical system for performing distance measurements according to claim 21 wherein the plurality of optical emitters are arranged to form a plurality of emitter channels having non-overlapping fields of view, and the plurality of photosensors are arranged to form a plurality of receiver channels having non-overlapping the fields of view and having a one-to-one relationship with the plurality of emitter channels such that the field of view for each receiver channel is coincident with the field of view of a corresponding emitter channel.**

178. The Pacala-Droz-Villeneuve combination provides the additional elements of claim 24. In the Pacala-Droz-Villeneuve combination, Pacala's transmitters and receivers (incorporating Droz's apertures/waveguides and SPAD arrays) are implemented based on Villeneuve's suggestion to use light source/receiver pairs, as in Villeneuve's "sensor heads," each including a light source and a corresponding receiver. Ex. 1007, 14:12-21, 15:6-13, 16:57-65. Each emitter and detector/SPAD array would thus define a separate channel, with a one-to-one relationship between emitters and detector/SPAD arrays. Villeneuve's

teachings would further be incorporated to make the field of view of each emitter and the field of view of each receiver “approximately equal,” so that they are “substantially coincident” and “have an angular overlap of approximately 100,” as shown for example in Figure 34, reproduced below, where the fields of view “have an angular overlap of approximately 90%”:

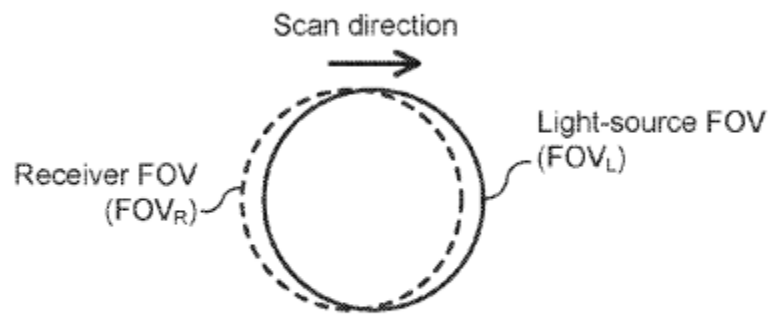


**Figure 34**

*Id.*, 55:41-47, 56:10-15, 56:31-33, 57:4-9.

179. Importantly, Droz’s apertures/waveguides cause each detector channel in the Pacala-Droz-Villeneuve combination to have a non-overlapping field of view, as the apertures/waveguides define a field of view distinct from neighboring apertures/waveguides. As a result, when the emitters in the Pacala-Droz-Villeneuve combination are configured, based on Villeneuve’s teachings, to be substantially coincident with the detectors, the emitters will also have non-overlapping fields of view.

3. **Claim 25: The optical system for performing distance measurements according to claim 21 wherein the plurality of emitters are configured to project a plurality of illuminating beams in the field external to the optical system according to an illumination pattern that substantially matches, in size and geometry across a range of distances from the system, a plurality of non-overlapping fields of view of the plurality of photosensors.**

180. The Pacala-Droz-Villeneuve combination provides the additional elements of claim 25. As discussed above for claim 24, the Pacala-Droz-Villeneuve combination includes a plurality of transmitter/detector pairs, such that each transmitter has a one-to-one relationship with a detector/SPAD array. Further, because the SPAD arrays have non-overlapping fields of view (defined by the apertures/waveguides), the corresponding emitters will also have non-overlapping fields of view. *See* Section XI.B.2.

181. As also noted above, Villeneuve describes using multiple “sensor heads,” each with a light source and a corresponding receiver (consistent with the multiple transmitters and detectors in the Pacala-Droz combination). Ex. 1007, 14:12-21, 15:6-13, 16:57-65. Each non-overlapping transmitter/light source would thus send an illumination beam along its field of view, which would substantially match (in size and geometry) the field of view of the corresponding detector/SPAD array, as shown in Figure 34:

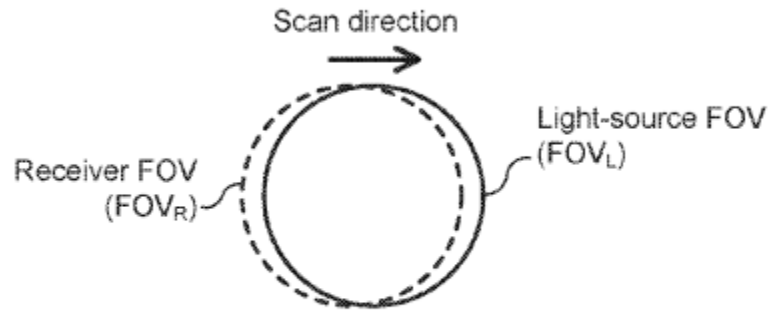


**Figure 34**

*Id.*, Fig. 34, 55:41-47, 56:10-15, 56:31-33, 57:4-9. By implementing the transmitters and detectors according to Villeneuve's suggestion, the fields of view of the transmitters and detectors will be matched over a range of distances, from a close target to a maximum operating range. *Id.*, 57:31-59.

#### **4. Claims 32-33**

182. The additional elements of claims 32 and 33 are word-for-word identical to the additional elements of claims 24 and 25, respectively. The Pacala-Droz-Villeneuve combination provides these elements for the same reasons I discuss above with respect to claims 24 and 25, in Sections XI.B.2-3.

#### **C. Ground 3: Hall, Borowski, and Spector Render Obvious Claims 21 and 23-33**

183. For the reasons set forth in detail below, and based on my review of the '405 Patent, file history, and the prior art references cited in my analysis, a POSITA

would have readily understood that the combined teachings of Hall, Borowski, and Spector provide all elements of claims 21 and 23-33.

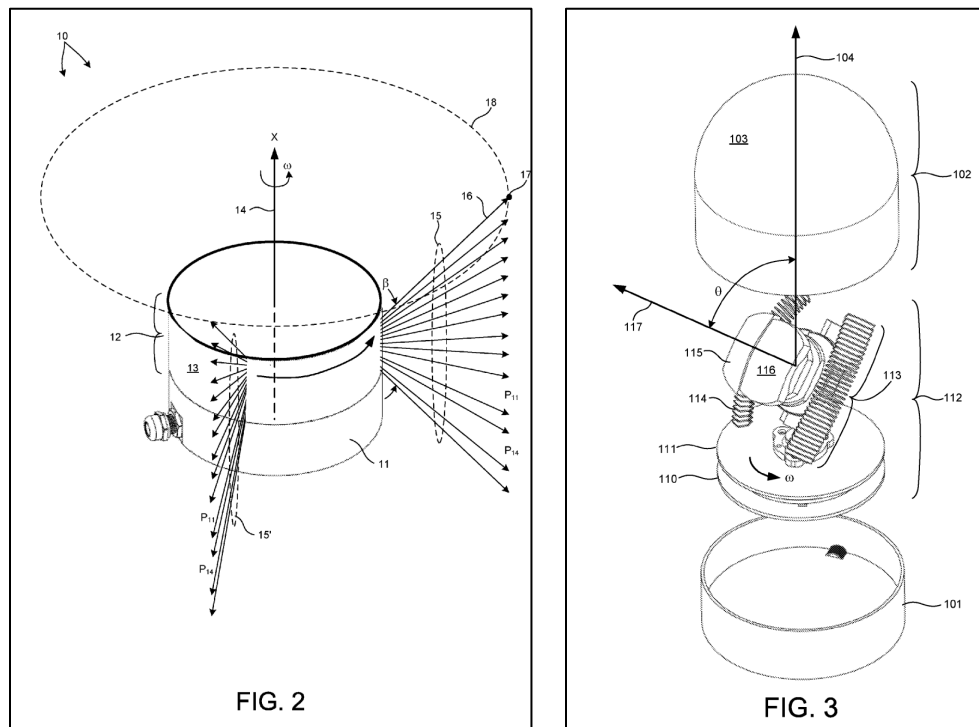
184. Hall describes the basic elements of a LiDAR device, such as a housing with a cylindrical, transparent window, a rotating electronics board on which a light emission/collection engine is mounted, and basic components used in LiDAR sensors, such as transmission and collection optics, optical filters, light emitting elements, and light detecting elements. Hall does not describe the use of SPAD arrays or aperture arrays, and it would have been obvious to incorporate these elements based on the teachings of Borowski and Spector, respectively. Borowski takes advantage of the known benefits of SPADs, and teaches to configure them in arrays in order to overcome the well-known problem of SPAD recovery time. Spector teaches the use of aperture arrays with an array of detector elements to minimize cross-talk and multipath signal (i.e., noise and interference). A POSITA would have been motivated to combine the teachings of Hall, Borowski, and Spector to achieve the known benefits of SPAD arrays and aperture arrays in a LiDAR system, namely, increased sensitivity to reflected light while reducing noise and interference from stray light and cross-talk.

**1. Predictable Combination of Hall, Borowski, and Spector**

185. Based upon my review of the references and my knowledge and experience in this field, it is clear that a POSITA would have been motivated to

combine the teachings of Hall, Borowski, and Spector. This is particularly the case in view of the relatively late time frame leading up to May 2017 (the filing date of the provisional application).

186. As I explain above, Hall describes a LiDAR system with a “lower housing,” “upper housing,” and transparent “cylindrical shell element.” Ex. 1008, 5:41-49, Fig. 2. Hall also describes a “light emission/collection engine” with “an array of light emitting elements 114 and an array of light detecting elements 114,” which is mounted on a “rotating electronics board.” *Id.*, 6:10-33, Fig. 3.



Ex. 1008, Figs. 2, 3.

Emitted light “passes through a series of illumination optics 115 that collimate the emitted light,” and light “reflected from objects in the environment” is “collected by

collection optics 116 ... where it is focused onto each detecting element of the array of detecting elements 113.” *Id.*, 6:33-47. The collection optics may include multiple lens elements, one or more of which may be a filter that absorbs light outside of the wavelengths of the light emitting elements. *Id.*, 7:7-27. Borowski, like Hall, describes a LiDAR system, but offers the straightforward suggestion of using SPAD arrays for the detectors in order to address the typical trade-off between resolution, speed, and range. Ex. 1009, [0003], [0007], [0078]-[0083]. Using Borowski’s teachings, each pixel is represented by a “macro-cell” of multiple SPADs, which collectively function a “a single ‘perfect’ SPAD having no recovery time.” *Id.*, [0053], [0171]. Spector also describes a LIDAR system, but is more focused on reducing noise from cross-talk. Spector explains that this can be achieved using the straightforward technique of adding a layer of apertures at the receiver in a “one-to-‘one’” correspondence with an arrayed micro-optic generating light spots. Ex. 1005, 2:1-12, 3:28-41, 6:12-15, Figs. 4A-4B; Ex. 1010 at 12-13, 15, 17.

187. In the resulting combination, Hall’s light detecting elements (e.g., Ex. 1008, Fig. 3, element 113) would have been implemented based on Borowski’s suggestion of using SPAD arrays to represent individual pixels (e.g., Ex. 1009, [0003], [0007], [0078]-[0083]), and Spector’s suggestion to add an arrayed micro-optic and aperture layer to minimize cross-talk (e.g., Ex. 1005, 6:12-15; Ex. 1010 at 12.). Spector’s teachings would also result in a one-to-one relationship between each

of Hall's light emitting elements and a corresponding light detecting element, which further reduces cross-talk and multipath signal. Ex. 1005, 2:7-12, 6:12-15; Ex. 1010 at 12, 13.

188. As I explain below, based on my review of Hall, Borowski, and Spector, and my knowledge and experience in the field, a POSITA would have understood that Borowski's and Spector's suggestions would have been predictably applied to the LiDAR system of Hall to incorporate SPAD arrays and aperture arrays, and implement a one-to-one correspondence between light emitting elements and light detecting elements.

189. As a first reason, a POSITA would have been motivated to combine Hall and Borowski to implement each light detecting element in Hall as an array of SPADs, based on Borowski's suggestion. For example, Borowski refers to a related patent application, filed the same day by the same applicant, which describes the advantages of using SPADs as detectors. Ex. 1009, [0035]-[0036]. That application, published as U.S. Patent Publication No. 2013/0300838 ("Borowski-838"), identifies multiple advantages of SPADs, including the fact that they are "ultra-sensitive" and "can be easily fabricated." Ex. 1025, [0014]. Indeed, these and other benefits of SPADs were well known in the art long before the '405 Patent. Ex. 1028, 4 (describing SPADs as having "extraordinary" sensitivity for LiDAR applications); Ex. 1029, 8 ("SPADs have a very high sensitivity, with the ability to detect single

photons, and they can be easily incorporated into an array since their operating voltage is low.”). However, the SPAD arrays of Borowski and Borowski-838 are uniquely advantageous because they overcome many of the problems encountered in the prior art, including the large recovery time associated with individual SPADs. Ex. 1025, [0019]-[0027] (describing problems in the prior art), [0315] (describing how arrays of SPADs are “equivalent to a perfect i.e., recovery-free, single SPAD”); Ex. 1009, [0053] (explaining how a SPAD “macro-cell ... acts as the equivalent of a single ‘perfect’ SPAD having no recovery time.”).

190. Borowski’s SPAD arrays also directly address a problem identified by Hall. Hall notes the existing LiDAR devices rely on “increasing laser pulse intensity” to increase measurement range, and that better “power management” is needed that “maintain[s] sufficiently high levels of imaging resolution and range.” Ex. 1008, 2:27-48. Borowski teaches that its SPAD arrays can provide detection at lower light intensities because SPADs “provide[] significant carrier amplification.” Ex. 1009, [0035]. A POSITA would have thus been motivated to incorporate SPAD arrays into Hall’s LiDAR sensor both because of the independent benefits of SPADs and SPAD arrays, and because they solve a specific problem identified by Hall.

191. As a second reason, a POSITA would have been motivated to combine Hall and Spector to incorporate an arrayed micro-optic at Hall’s light emission module, and an aperture array at Hall’s light detection module, as suggested by

Spector. Hall acknowledges that cross-talk may be a problem in systems with multiple emitters, but proposes avoiding cross-talk by staggering the interrogation from different emitters, or only allowing emitters that are sufficiently spaced apart to emit light at the same time, which limits the speed at which detection can be performed. Ex. 1008, 9:13-25. Spector's arrayed micro-optic and aperture layer operate together to "project a two dimensional array of light spots on a scene" and "establish[] ... individual optical detection sites." Ex. 1005, 3:54-61; Ex. 1010 at 12 ("describing "[s]pots" created by "a lens array," and "an aperture [] used to select imaged light at locations that correspond to the projected light"). Spector's implementation avoids the delays and spatial separation used by Hall, while still reducing cross-talk. Ex. 1005, 6:12-15; Ex. 1010 at 13 ("Because the spots are isolated, cross-talk and multipath signal are reduced. The aperture on the receiver further reduces cross-talk and background." Spector also describes additional advantages associated with its arrayed micro-optic and aperture array, such as enabling "smaller and/or simpler and less expensive scanning mechanisms" because only the distance between adjacent light spots needs to be scanned. Ex. 1005, 6:15-20; Ex. 1010 at 13 ("A much smaller scanning motion is required.").

192. As a third reason, a POSITA would have found it obvious to combine Hall, Borowski, and Spector because doing so would have been—certainly by the timeframe leading up to May 2017—merely the application of a known technique to

a known system ready for improvement to yield predictable results. Hall describes a known LiDAR system including standard components of a rotating LiDAR device, such as a housing, rotating sensor, filters, and emitters and detectors. Borowski describes known improvements to LiDAR technology, using multi-SPAD detectors to increase sensitivity and accuracy. Spector describes known improvements to similar devices using arrayed micro-optics and aperture arrays to reduce cross-talk and reduce scanning complexity. Hall, Borowski, and Spector are also analogous and similarly relate to LiDAR systems, and, in my view, a POSITA would have recognized that applying Borowski's and Spector's suggestions to Hall's system would have led to predictable results of enhancing the sensitivity and detection capability of the resulting LiDAR device—all while maintaining Hall's purpose/functionality as a LiDAR unit. In my view, a POSITA would have had a reasonable expectation of success in making the proposed modifications based on the similarity of the LiDAR systems in Hall, Borowski, and Spector. Here, Hall does not specify the type of detectors used, nor does it require a particular configuration of emitters or detectors. Borowski plainly suggests configurations that improve detector sensitivity and accuracy (multi-SPAD detectors), and Spector suggests configurations to improve scanning speed and reduce noise from cross-talk (arrayed micro-optics and aperture arrays), both using techniques known in the prior

art before May 2017. A POSITA could have implemented these improvements in Hall's system using basic electrical engineering techniques and principles.

193. In particular, as noted above, SPADs and SPAD arrays were well known and widely studied in the LiDAR field long before the priority date of the '405 Patent. Ex. 1028, 4; Ex. 1029, 8.

194. In particular, as noted above, SPAD (Geiger-mode) arrays and their benefits were well known and widely studied in the LiDAR field more than a decade before the priority date of the '405 Patent. In 2003, researchers at the MIT Lincoln Lab studied a "compact 3D imaging laser radar system using Geiger-mode APD arrays." Ex. 1028. The research focused on a Gen-III device for rugged and compact LiDAR applications. *Id.*, 2. Marino explains that "Because the Gen-III and similar systems rely upon the photon-counting ability of the Lincoln Geiger-mode APD/CMOS arrays, the sensitivity of these systems is extraordinary." *Id.*, 4. Marino further explains that future development of SPAD arrays in 3D LiDAR would continue, and that scaling the technology would be "relatively straightforward." *Id.*, 5.

195. Development and use of SPAD sensors for LiDAR and time-of-flight applications continued as predicted. In 2012, researchers at Toyota studied SPAD technology for automotive LiDAR. Ex. 1029. The report notes: "SPADs have a very high sensitivity, with the ability to detect single photons, and they can be easily

incorporated into an array since their operating voltage is low.” *Id.*, 8. These features allowed Toyota to incorporate SPAD pixels into a long-range LiDAR sensor. *Id.*, 7-8, 11

## 2. Claim 21

196. Based on my review of Hall, Borowski, and Spector, and my knowledge and experience in the field, a POSITA would have found it obvious that Borowski’s and Spector’s suggestions, predictably combined with the teachings of Hall, provide all elements of claim 21. I explain in detail below how each element of claim 21 is disclosed by the combination of Hall, Borowski, and Spector.

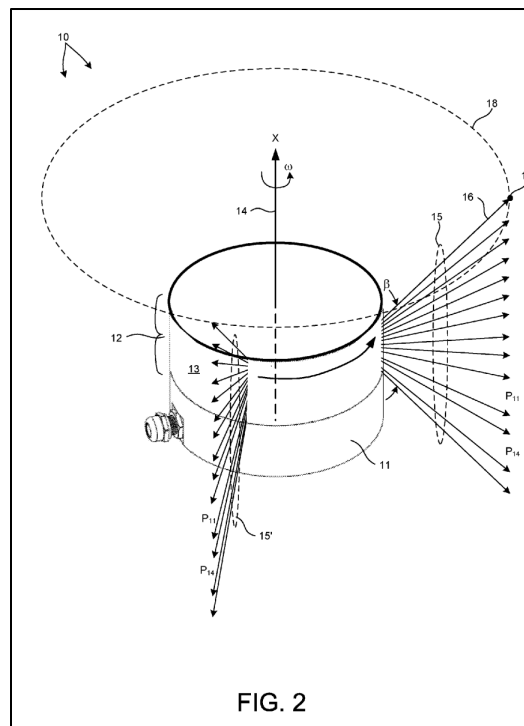
*a) Element 21(a): An optical system for performing distance measurements, the optical system comprising:*

197. The Hall-Borowski-Spector combination provides the recited system of element 21(a). Hall teaches a “LIDAR based 3-D point cloud measuring system.” Ex. 1008, 1:16-17. Hall also teaches that a LiDAR sensor “employ[s] pulses of light to measure distance to an object.” *Id.*, 1:21-23.

198. Also, in the Hall-Borowski-Spector combination, Borowski and Spector both teach LiDAR devices and application for collecting three-dimensional images of a scene. Ex. 1009, [0002]-[0003]; Ex. 1005, 1:18-21; Ex. 1010 at 12.

- b) *Element 21(b): a stationary housing having a base, a top and an optically transparent window disposed between the base and the top and extending fully around a periphery of the stationary housing;*

199. The Hall-Borowski-Spector combination provides element 21(b). The disclosed LiDAR sensor includes a “lower housing 11 and an upper housing 12 that includes a cylindrical shell element 13 constructed from a material that is transparent to infrared light,” as illustrated in Figure 2:



Ex. 1008, Fig. 2, 5:41-47. The cylindrical shell element acts as a window, and a POSITA would understand that if it is cylindrical in shape, then it extends around the full periphery of the housing. As shown in Figure 2, the window is also positioned between the top of the upper housing 11 and the lower housing 12.

200. Hall does not expressly describe its housing as stationary, but a POSITA would understand that the housing is stationary because rotation is accomplished via a separate rotating electronics board that rotates relative to a stationary electronics board, which is “mounted in a fixed position with respect to [the] lower housing.” *Id.*, 6:16-30, 6:48-7:6.

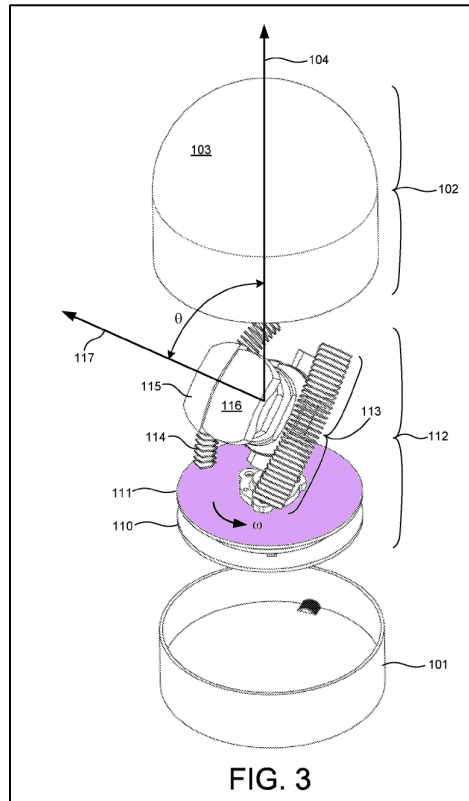
*c) Element 21(c): a light ranging device disposed within the housing and comprising:*

201. The Hall-Borowski-Spector combination provides element 21(c). Hall’s system is a light ranging device because it “perform[s] three dimensional LIDAR measurements” to detect “objects ... in the three dimensional environment.” Ex. 1008, 2:52-54, 3:20-41. As discussed in more detail below, the elements of the light ranging device are contained within Hall’s housing, e.g., a “light emission/collection engine” with light emitting elements, light detecting elements, and optical and electronic components, which are collectively mounted to a rotating electronics board. Ex. 1008, 6:10-7:6.

*d) Element 21(d): a platform*

202. The Hall-Borowski-Spector combination provides element 21(d). As noted above, Hall’s light emission/collection engine is “fixedly positioned” on and “mechanically and electrically coupled to” a “rotating electronics board 111,” which “rotates about central axis 104.” Ex. 1008, 6:27-30, 6:48-7:6. The rotating electronics board (annotated in purple below) provides a platform for the light

emission/collection engine. The rotating electronics board is in turn “disposed above stationary electronics board 110,” which is “mounted in a fixed position with respect to lower housing 101.” The configuration is shown in Figure 3, reproduced and annotated below:



Ex. 1008, Fig. 3 (annotated).

203. As I note above, Figure 3 shows the light emission/collection engine in the context of an alternative embodiment where the housing includes a domed cap, but it would have been obvious to POSITA that the same engine is or can be used in the example of Figure 2. For example, Hall explains that both “3-D LIDAR system 10 depicted in FIG.2, and system 100, depicted in FIG.1, include[] a plurality of

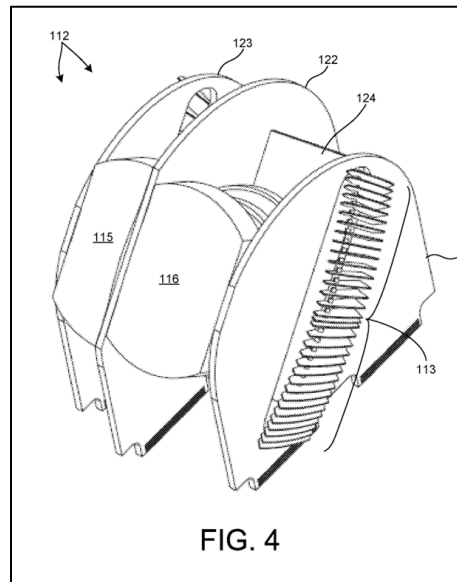
pulsed illumination sources each emitting a pulsed beam of illumination light.” *Id.*, 7:40-44. Hall further explains that its LiDAR systems include both “a pulsed illumination system 130” and “a light detection system 150,” which together “comprise a LIDAR measurement channel.” *Id.*, 7:53-57. This is consistent with the light emission/detection engine shown in Figure 3. In any event, nothing would prohibit or discourage a POSITA from using the light emission/detection system shown in Figure 3 (and described in the accompanying text) in the exemplary system of Figure 2, and, indeed, Hall does not teach a different implementation of the illumination and detection systems for use in the example of Figure 2.

- e) *Element 21(e): a light transmission module coupled to the platform and comprising a bulk transmitter optic and a plurality of optical emitters, each optical emitter in the plurality of optical emitters configured to generate and transmit pulses of radiation through the bulk transmitter optic and through the optically transparent window into a field external to the optical system*

204. The Hall-Borowski-Spector combination provides element 21(e). Hall’s light emission/collection engine is “mechanically and electrically coupled to rotating electronics board 111.” Ex. 1008, 6:27-30, 6:48-7:6. The light emission/collection engine includes a bulk transmitter optic, in the form of “a series of illumination optics 115” that “collimate the emitted light into an array of beams” that are emitted through the window of the housing and out into the scene. *Id.*, 6:31-

38. It also includes a plurality of optical emitters, in the form of “an array of light emitting elements 114.”

205. Notably, the light emitting elements and illumination optics occupy a distinct module within the light emission/collection engine, and are separate from the light detecting elements and collection optics. For example, an intermediate electronics board 122, shown in Figure 4 (reproduced below) may “spatially and optically separate[] the illumination optics 115 and the collection optics 116 to avoid contamination of the collected light with illumination light.”

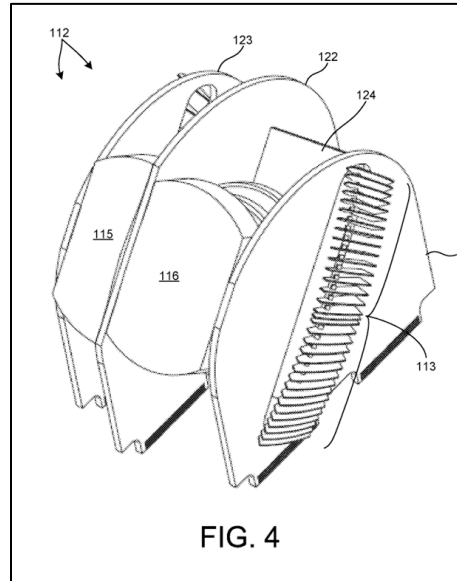


*Id.*, Fig. 4, 6:48-7:6.

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- f) Element 21(f): a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field, and an optical filter disposed between the bulk receiver optic and the plurality of photosensors and configured to allow a band of radiation, including an operating wavelength of the plurality of optical emitters, to pass through the filter to the plurality of photosensors while blocking radiation outside the band from reaching the plurality of photosensors*

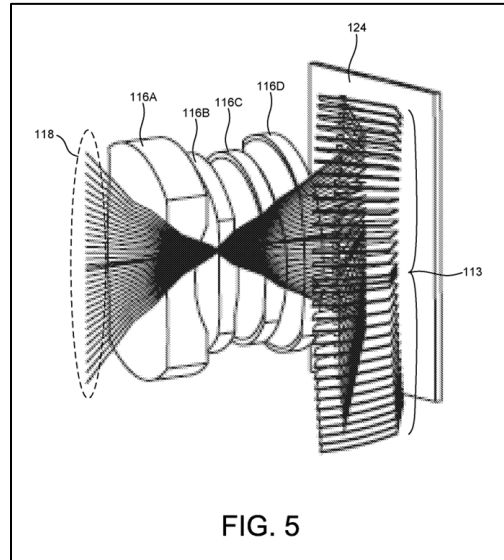
206. The Hall-Borowski-Spector combination provides element 21(f). As noted above for elements 21(d) and 21(e), Hall's rotating electronics board mounts the light emission/collection engine, which includes an intermediate electronics board that separates the light emitting elements and illumination optics from the light detecting elements and collection optics, thereby forming a light transmission module and a light sensing module.



*Id.*, Fig. 4, 6:27-30, 6:48-7:6.

207. The light sensing module provides a bulk receiver optic in the form of “collection optics 116,” which collect reflected light and focus it onto an “array of detecting elements 113.” *Id.*, 6:41-47. The array of detecting elements includes a plurality of photosensors (i.e., each detecting element).

208. Hall also provides an optical filter as part of or connected to the collection optics. For example, Hall teaches that collection optics 116 may “include four lens elements 116A-D arranged to focus collected light 118 onto each of the array of detecting elements 113,” as shown in Figure 5, reproduced below:



*Id.*, Fig. 5, 7:7-10. “[O]ne or more of the optical elements of collection optics 116” may be an optical filter, “constructed from one or more materials that absorb light outside of a predetermined wavelength range that includes the wavelengths of light emitted by each of the array of light emitting elements.” *Id.*, 7:13-27. A wavelength range is, by definition, a band of radiation, which, in the case of Hall, includes the operating wavelength of the light emitting elements, consistent with the claim element.

209. Because any of the lens elements 116A-D may be an optical filter, in most configurations the optical filter will be between the bulk receiver optic (one or more of the focusing optical elements in collection optics 116) and the array of detectors 113. For example, if lens element 116A is a focusing lens, and lens elements 116B-116D are optical filters, all three optical filters will be located between the bulk receiver optic (116A) and the plurality of photosensors (113).

210. In the Hall-Borowski-Spector combination, Hall's LiDAR system is implemented based on Spector's suggestion to use an aperture array to reduce cross-talk at the light detecting elements. *See* Section XI.C.1; Ex. 1005, 2:1-6, 3:28-41, 6:12-15, Figs. 4A-4B; Ex. 1010 at 12-13, 15, 17. As detailed in Section XI.C.1, a POSITA would have been motivated to incorporate an aperture layer as disclosed in Spector into Hall's light emission/collection engine.

211. Spector describes a LiDAR system that, among other things, includes at the receiver "a mask defining a plurality of transparent apertures arranged according to the two dimensional array [of optical detection sites]." Ex. 1005, 2:1-6; Ex. 1010 at 12 ("an aperture is used to select imaged light at locations that correspond to the projected light" and showing an "aperture array"). The aperture array "establish[es] the individual optical detection sites" because [t]he plurality of transparent apertures limits visibility by each optical detection site to a single corresponding light spot in the two dimensional array." Ex. 1005, 3:54-61; Ex. 1010 at 12. Spector's aperture layer 18 (in orange below) and detector array 20 (in red below) are shown in Figure 1, reproduced and annotated below:

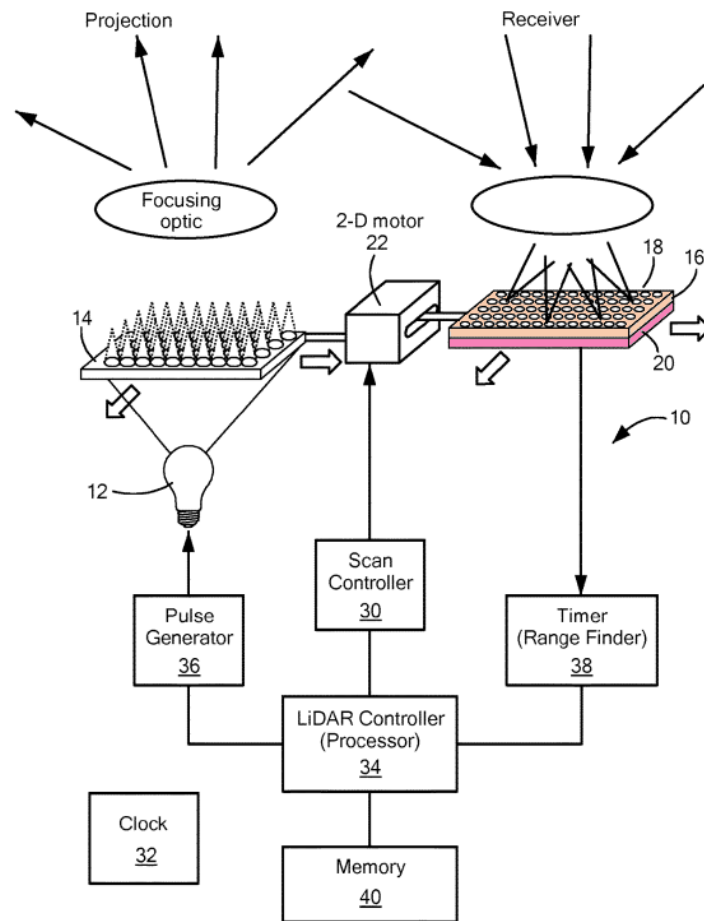


**FIG. 1**

Ex. 1005, Fig. 1 (annotated); *see also* Ex. 1010 at 12, 19 (showing similar figures of Spector's system with an aperture array and detector array), 20 (showing aperture array in more detail).

212. I note that a mask is a well known type of structure that only allows light to pass through in specific patterns, and otherwise blocks light. It would be clear to a POSITA that Spector is referring to such a mask for its aperture layer because Spector teaches that the mask defines “a plurality of transparent apertures,” which “limit[] visibility by each optical detection site.” Ex. 1010, 2:1-6; Ex. 1010

at 13 (“At the receiver a matching aperture is also scanned, so that only the illuminated spots are visible to the detector.”), 20 (showing aperture array). In other words, light only passes through the transparent apertures in Spector’s mask/aperture array, and is otherwise blocked. Thus, the portion of the aperture array outside of the transparent apertures acts as a stop region according to the claim.

g) *Element 21(g): a motor disposed within the housing and operatively coupled to spin the platform and the light ranging device within the housing*

213. The Hall-Borowski-Spector combination provides element 21(g). As noted above, Hall’s light emission/collection engine is mounted on a rotating electronics board, which is disposed above a stationary electronics board mounted to the lower housing. Ex. 1008, 6:16-30. Hall does not expressly say that a motor is used to spin the rotating electronics board, but because the housing itself is stationary, it would be clear to a POSITA that a motor or similar structure is included to effect the rotation of the rotating electronics board.

214. Other Velodyne patents corroborate that Hall would have used a motor to rotate the rotating electronics board. For example, U.S. Patent No. RE46,672 (“Hall-672”) is a Velodyne patent relating to an older Velodyne LiDAR system, which also names David Hall as the inventor. Ex. 1015. Hall-672 expressly states that a “rotary motor,” such as a “brushed or brushless motor ... controls the rotation of the emitters/detectors.” *Id.*, 2:9-10, 5:5-7. A POSITA would understand that the

same type of motor can be, and most likely is, used in Hall's system, since Hall does not specify the means of rotating the rotating electronics board, and does not claim to have invented a new rotation mechanism. Indeed, since LiDAR sensors only require simple rotation around a central axis, any standard rotary motor is sufficient.

*h) Element 21(h): wherein: each photosensor in the plurality of photosensors comprises a plurality of single photon avalanche diodes (SPADs);*

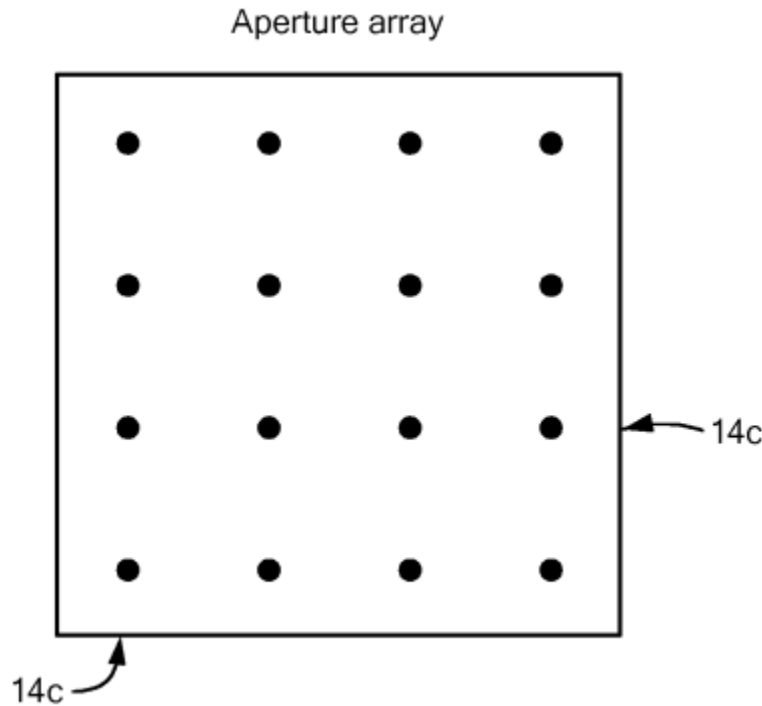
215. The Hall-Borowski-Spector combination provides element 21(h). As I discuss in Section XI.C.1 above, in the Hall-Borowski-Spector combination, Hall's LiDAR system is implemented based on Borowski's suggestion to use arrays of SPADs for the light detecting elements. *See* Section XI.C.1; Ex. 1009, [0003], [0007], [0078]-[0083]. As detailed in Section XI.C.1, a POSITA would have been motivated to incorporate SPAD arrays as disclosed in Borowski's into Hall's light emission/collection engine, particularly as Hall does not specify or require any particular type of light detecting element, and Borowski identifies plain and well-known advantages to using SPAD arrays.

216. Borowski's SPAD arrays, as incorporated into Hall's LiDAR system, include a plurality of SPADs for each photosensor. For example, Borowski explains that the "receiving part" of its LiDAR device includes a "plurality of SPAD detector arrays," each of which "comprises a plurality of SPAD detector cells." Ex. 1009, [0078], [0171]. Neighboring SPAD detector cells are arranged in clusters, referred

to as a “macro-cell,” and the outputs of the SPADs within a macro-cell are “multiplex[ed] and average[ed]” so that the plurality of SPADs within the macro-cell collectively “act[s] as the equivalent of a single ‘perfect’ SPAD having no recovery time.” *Id.*, [0053], [0171], [0192].

*i) Element 21(i): the plurality of apertures comprises at least first, second, third and fourth apertures*

217. The Hall-Borowski-Spector combination provides element 21(i). As discussed in Section XI.C.2(f) above, in the Hall-Borowski-Spector combination, Hall’s LiDAR system incorporates Spector’s aperture array based on Spector’s suggestion, in order to reduce cross-talk and improve detection. In one example, illustrated in Figure 4A and reproduced below, an aperture array may include a 4x4 grid of apertures, so that there are sixteen apertures in total.



Ex. 1005, Fig. 4A; *see also* Ex. 1010 at 20 (showing similar aperture array).

218. In the specification, Figure 4A is described as an aperture array that may be used on the emitter side of Spector's system. However, a POSITA would understand that the same type of aperture array may be used at the receiver, particularly since Spector refers to both as an "aperture array" and does not describe a different implementation or configuration for the aperture array at the receiver. Indeed, several other figures in Spector show the aperture array at a lower level of detail, but still containing the same general structure, ranging in size anywhere from a 4x4 grid of apertures (e.g., in Figure 5A) to a 5x14 grid of apertures (e.g., in Figure 1).

- j) Elements 21(j): the plurality of photosensors comprises at least first, second, third and fourth photosensors; and the light sensing module includes a first optical path to the first photosensor through the first aperture, a second optical path to the second photosensor through the second aperture, a third optical path to the third photosensor through the third aperture, and a fourth optical path to the fourth photosensor through the fourth aperture.*

219. The Hall-Borowski-Spector combination provides element 21(j). As discussed in Section XI.C.2(i), in the combined system, Hall's LiDAR light emission/collection engine incorporates an aperture array as suggested by Spector, which, as discussed above, includes anywhere between sixteen and thirty apertures. Ex. 1005, Figs. 1, 4A, 5A-5B; Ex. 1010 at 20. Even if Spector's aperture array is modified to fit the number of light detecting elements present in Hall's base system, Hall's light emission/collection engine shows roughly 30 light detecting elements (e.g., light detecting elements 113 in Figure 4). Ex. 1008, Fig. 4. Each light detecting element has a corresponding aperture, because Hall teaches that the apertures are "arranged according to the two-dimensional array" of detectors. Ex. 1005, 3:57-59; Ex. 1010 at 13 (each light spot has a "matching aperture" that ensures only the "illuminated spot[]" is visible to the associated detector).

220. Each aperture defines an optical path by "limiting visibility by each optical detection site to a single corresponding light spot." Ex. 1005, 2:4-6; Ex.

1010 at 12 (“[A]n aperture is used to select imaged light at locations that correspond to the projected light.”). That is, each aperture creates a narrow optical path that is designed to pass through only the light spot directed to that aperture, and block other sources of light. Because the Hall-Borowski-Spector combination includes at least four light detecting elements and at least four corresponding apertures, there will be at least four optical paths, one between each aperture and its corresponding detector.

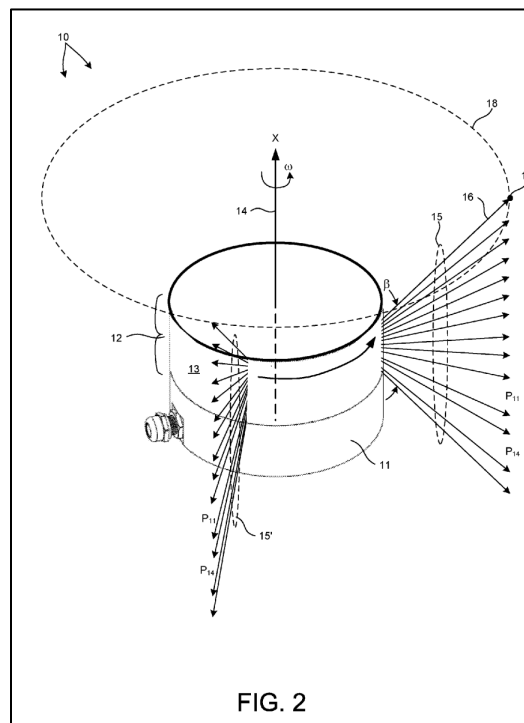
**3. Claim 23: The optical system for performing distance measurements according to claim 21 wherein the system generates distance data based on times between transmission of pulses of light from the plurality of optical emitters and detection of photons from the pulses of light by the plurality of photosensors.**

221. The Hall-Borowski-Spector combination provides the additional element of claim 23. Hall teaches that LiDAR sensors “employ pulses of light to measure distance to an object based on the time of flight (TOF) of each pulse of light.” Ex. 1008, 1:21-23. Time of flight is a basic concept in LiDAR technology, which measures the time between the transmission of a pulse of light and the detection of reflected light in order to calculate distance, and Hall applies a similar definition, i.e., “the time elapsed between emission of the pulse of light and detection of the returned pulse of light.” *Id.*, 1:26-28. Determining distance based on time of flight is a basic function of a LiDAR sensor.

**4. Claim 24: The optical system for performing distance measurements according to claim 21 wherein the plurality**

**of optical emitters are arranged to form a plurality of emitter channels having non-overlapping fields of view, and the plurality of photosensors are arranged to form a plurality of receiver channels having non-overlapping the fields of view and having a one-to-one relationship with the plurality of emitter channels such that the field of view for each receiver channel is coincident with the field of view of a corresponding emitter channel.**

222. The Hall-Borowski-Spector combination provides the additional elements of claim 24. Hall's system already uses a set of non-overlapping emitters, each of which has a corresponding detector that, together with its emitter, defines a measurement channel. For example, Hall's light emitting elements are configured to emit beams of light "in a plurality of different directions," as shown in Figure 2, where each beam 16 is emitted at a different angle and along a different path:

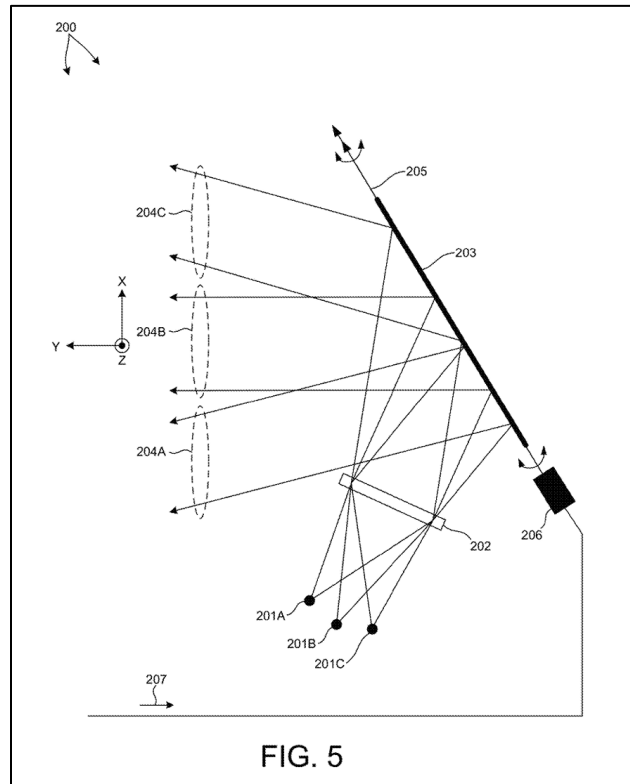


*Id.*, Fig. 2, 5:50-56. Each light emitting element also corresponds to a “LIDAR measurement channel.” *Id.*, 7:53-57. Hall explains that “each beam of light is projected onto a plane ... at a plurality of different locations spaced apart from one another.”<sup>6</sup> *Id.*, 5:28-31.

223. Because Hall’s beams are directed to different locations in the field, the fields of view of their corresponding emitters (and associated measurement channels) will not overlap. This is confirmed by a related Velodyne patent, also naming David Hall as an inventor, U.S. Patent No. 10,393,877 (“Hall-877”). Hall-877 describes a LiDAR system with a light emission/collection engine, similar to Hall’s LiDAR system. Ex. 1030, Abstract, 7:28-34. But Hall-877 more clearly explains that “[e]ach light source is associated with a different LIDAR measurement channel,” and that emitted beams “maintain their separate trajectories,” so that “objects in the environment are interrogated by different beams of illumination at different locations.” *Id.*, 8:16-18, 8:30-40. One example is shown in Figure 5, where each light source/emitter projects a non-overlapping beam of light in its field of view (e.g. beams 204A-C):

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<sup>6</sup> This description is provided with respect to the example in Figure 1 with the domed cap, but the same explanation would apply to the beams shown in Figure 2.



*Id.*, Fig. 5. Different examples vary as to whether the light sources project a pattern of beams at different locations in the x-direction, in the z-direction, or in both the x- and z-directions (as illustrated in Figures 5, 6, and 7, respectively, and the corresponding discussion in the specification), but in each example Hall-877 makes clear that the beams (and thus the measurement channels) do not overlap at a given time. *Id.*, 8:12-10:30.

224. Hall also teaches that each “pulsed illumination system” also has an associated “light detection system,” and *together* the “pulsed illumination system” and “light detection system ... comprise a LIDAR measurement channel.” Ex. 1008, 7:53-57. The system may have multiple LIDAR measurement channels, each with

an associated pulsed illumination system and light detection system, which emit beams “in different directions from the LIDAR device during a measurement period.” *Id.*, 8:57-62, 8:65-9:7. Because each emitter/detector pair corresponds to a separate measurement channel, which Hall teaches does not overlap with other measurement channels, Hall’s light detecting elements, like its light emitting elements, will also define a set of channels with non-overlapping fields of view. Because the emitters and detectors share the same measurement channel, the fields of view of the emitter and detector in a particular pair will be the same—i.e., they are coincident.

225. Alternatively, in the Hall-Borowski-Spector combination, Hall’s LiDAR system is implemented based on Spector’s suggestion to incorporate an arrayed micro-optic (at the light emitting elements) and an aperture layer (at the light detecting elements) in a “one-to-one correspondence.” *See* Section XI.C.1; Ex. 1005, 2:1-12, 3:28-41, 6:12-15, Figs. 1, 4A-4B; Ex. 1010 at 12-13, 15, 17. As detailed in Section XI.C.1, a POSITA would have been motivated to incorporate an arrayed micro-optic and aperture layer as disclosed in Spector into Hall’s light emission/collection engine.

226. Spector’s arrayed micro-optic, implemented as part of a light emission module, “project[s] a two-dimensional array of light spots on a scene.” Ex. 1005, 3:1-3; Ex. 1010 at 12 (“spots” of light are “created by methods such as a diffractive

optic, a lens array, or a simple aperture array). Each light spot is “isolated” from other emitted light spots. Ex. 1005, 6:12-15, Figs. 1, 2B, 3B, 4B (showing each light spot as non-overlapping with other light spots); Ex. 1010 at 13 (“isolated spots are illuminated”). When implemented in Hall’s light emission/collection engine, each of Hall’s light emitting elements would project a separate light spot, isolated from any other emitted light spot (i.e., in a separate emitter channel that does not overlap with the field of view of any other emitter channel).

227. Spector’s aperture array performs a similar function at the receiver optics. Each aperture “limits visibility by each optical detection site to a single corresponding light spot,” thereby separating the optical detection sites into distinct receiver channels with fields of view that do not overlap. Ex. 1005, 3:59-61; Ex. 1010 at 12 (“an aperture is used to select imaged light at locations that correspond to the projected light”). Spector also makes clear that each light detecting element/optical detection site has a “one-to-one correspondence” with a light emitting element/light spot. Ex. 1005, 3:34-37, 3:59-61, 5:33-35; Ex. 1010 at 12 (“an aperture is used to select imaged light at locations that correspond to the projected light”), 13 (“a matching aperture is also scanned”). Because each aperture at the detectors matches a corresponding light spot at the emitters, the emitter/detector pairs will have coincident fields of view.

5. **Claim 25: The optical system for performing distance measurements according to claim 21 wherein the plurality of emitters are configured to project a plurality of illuminating beams in the field external to the optical system according to an illumination pattern that substantially matches, in size and geometry across a range of distances from the system, a plurality of non-overlapping fields of view of the plurality of photosensors.**

228. The Hall-Borowski-Spector combination provides the additional elements of claim 25. As discussed above for claim 24, in the Hall-Borowski-Spector combination, Hall's system is implemented, based on Spector's suggestion, using an arrayed micro-optic at the light emitting elements and an aperture array at the light detecting elements. *See* Section XI.C.1; Ex. 1005, 2:1-12, 3:28-41, 6:12-15, Figs. 1, 4A-4B; Ex. 1010 at 12-13, 15, 17.

229. Spector's arrayed micro-optic "project[s] a two-dimensional array of light spots on a scene." Ex. 1005, 1:44-47, 3:1-3; Ex. 1010 at 12 (figure showing two dimensional array of light spots being projected). As noted above, each of Spector's light spots has a "one-to-one correspondence" with an optical detection site. Ex. 1005, 3:34-37, 3:59-61, 5:33-35; Ex. 1010 at 12 ("an aperture is used to select imaged light at locations that correspond to the projected light"), 13 ("a matching aperture is also scanned"). The light spots are also "focused on the individual optical detection sites," and the optical detection sites in turn use the aperture array to "limit[] visibility by each optical detection site to a single

corresponding light spot.” Ex. 1005, 3:38-41, 3:59-61; Ex. 1010 at 12 (apertures “select imaged light at locations that correspond to the projected light”), 13 (“only the illuminated spots are visible to the detector”), 19 (emitters and detectors have “same pattern”). Spector is also clear that the “arrayed micro-optic” and the “receiver optics” will “both point at the same place in the distance.” Ex. 1005, 4:18-21; Ex. 1010 at 19 (“Aperture array” is “[s]ymmetric with focused spots on emitter” and scanning is “[s]ynchronized”). By configuring the arrayed micro-optic and the aperture array in this manner, the field of view of each emitter (and, by extension, the beam/light spot that it emits) will match the size and shape of the field of view of the corresponding receiver. Spector confirms that by configuring the arrayed micro-optic and receiver optics in this manner (*i.e.*, to point at region of interest in the distance), the system will provide the “best performance at all ranges of interest.” Ex. 1005 4:21-27.

## **6. Claim 26**

230. Based on my review of Hall, Borowski, and Spector, and my knowledge and experience in the field, a POSITA would have found it obvious that Borowski’s and Spector’s suggestions, predictably combined with the teachings of Hall, provide all elements of claim 26. I explain in detail below how each element of claim 26 is disclosed by the combination of Hall, Borowski, and Spector.

a) *Elements 26(a)-26(e)*

231. Elements 26(a)-26(e) of claim 26 are word-for-word identical to elements 21(a)-21(e) of claim 21. The Hall-Borowski-Spector combination provides these elements for the same reasons I discuss above with respect to the corresponding elements of claim 21, in Sections XI.C.2(a)-(e).

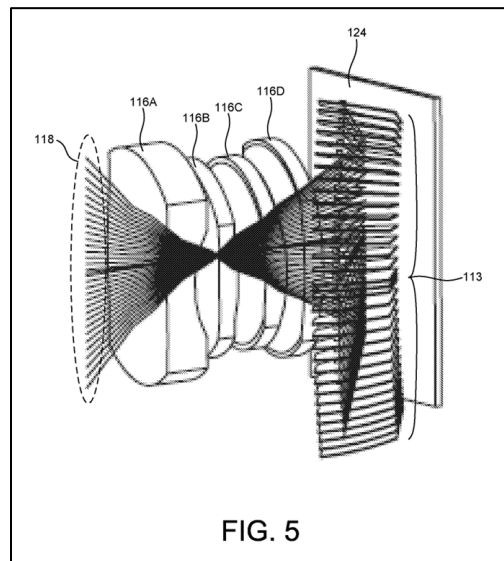
b) *Element 26(f): a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field, and one or more optical filters disposed between the bulk receiver optic and the plurality of photosensors, each of the one or more optical filters configured to allow a set of wavelengths of radiation, including an operating wavelength of the plurality of optical emitters, to pass through the one or more optical filters while blocking radiation outside that set*

232. The Hall-Borowski-Spector combination provides element 26(f). I note that element 26(f) largely mirrors element 21(f) of claim 21, and so for the overlapping limitations, is provided by the Hall-Borowski-Spector combination for the same reasons I discuss above with respect to element 21(f), in Section XI.C.2(f).

233. The only substantive difference between element 21(f) and element 26(f) is that element 21(f) requires “an optical filter” configured to allow a “band of radiation” to pass through the filter while “blocking radiation outside the band,” whereas element 26(f) requires “*one or more* optical filters” that allow a “*set of*

*wavelengths* of radiation” to pass through the filters while “blocking radiation outside that *set*.” As noted above, Hall teaches the use of optical filters to block radiation outside of a band that contains the wavelength used by the emitters.

234. I understand that as a matter of claim construction law, the indefinite articles “a” and “an” are presumed to mean “one or more,” so there is not necessarily a substantive difference between the elements. However, Hall does also expressly teach multiple optical filters. In fact, Hall specifically states that “one *or more* of the optical elements of collection optics 116” may be an optical filter by “construct[ing] [it] from one or more materials that absorb light.” Ex. 1008, 7:13-23. For example, in Figure 5 (reproduced below), lens elements 116B, 116C, and 116D may all be optical filters, each disposed between the bulk receiver element (116A) and the light detecting elements (113):



*Id.*, Fig. 5.

*c) Elements 26(g)-26(j)*

235. Elements 26(g)-26(j) of claim 26 are word-for-word identical to elements 21(g)-21(j) of claim 21. The Hall-Borowski-Spector combination provides these elements for the same reasons I discuss above with respect to the corresponding elements of claim 21, in Sections XI.C.2(g)-(j).

**7. Claim 27: The optical system for performing distance measurements set forth in claim 26 wherein the one or more optical filters comprise a bandpass filter.**

236. The Hall-Borowski-Spector combination provides the additional element of claim 27. Hall teaches that its optical filters will absorb light “outside of a predetermined wavelength range that includes the wavelengths of light emitted by each of the array of light emitting elements.” Ex. 1008, 7:13-19. Light may have wavelengths both shorter and longer than that emitted by the light emitting elements, and thus a range that includes the wavelengths used by the light emitting elements can be defined as a band of wavelengths, with a minimum and maximum. Filtering light outside of that band is, by definition, a bandpass filter. Bandpass filters are well known components that only allow light within a particular set of wavelengths to pass through, and block all other light. A POSITA would have been very familiar with bandpass filters, as they are basic components used in electronics and optoelectronics, and would have known that it would be obvious to use a bandpass filter for one of Hall’s lens elements.

**8. Claim 28: The optical system for performing distance measurements set forth in claim 26 wherein the one or more optical filters comprise a plurality of optical filters.**

237. The Hall-Borowski-Spector combination provides the additional element of claim 28. As I explained above in my discussion of element 26(f), Hall states that “one *or more* of the optical elements of collection optics 116” may be an optical filter. Ex. 1008, 7:13-23. Thus, if lens elements 116B, 116C, and 116D (as shown in Figure 5) are all optical filters, then there is a plurality of optical filters.

**9. Claim 29: The optical system for performing distance measurements set forth in claim 28 wherein each of the plurality of optical filters is supported by an optically transparent substrate.**

238. The Hall-Borowski-Spector combination provides the additional element of claim 29. A substrate is simply a layer underneath a surface or other layer. A POSITA would have understood that each lens element in Hall’s system can serve as a substrate that supports and is connected to an adjacent optical element, particularly since the lens elements are described as being a single assembly, i.e. all part of Hall’s collection optics. Thus, for example, if lens element 116B is constructed as a filter, and lens element 116A and/or 116C are not (i.e. they are transparent), then lens elements 116A and/or 116C can act as a substrate to support lens element 116B. Similarly, if lens element 116D is constructed as a filter, lens element 116C in the above example would act as a substrate to support lens element 116D.

**10. Claim 30: The optical system for performing distance measurements set forth in claim 29 wherein the plurality of optical filters are disposed in the first optical path.**

239. The Hall-Borowski-Spector combination provides the additional element of claim 30. Each lens element 116A-D is part of Hall's collection optics, and light arriving at the receivers first passes through the collection optics. Ex. 1008, 6:41-47 ("Collected light passes through collection optics 116 where it is focused onto each detecting element of the array of detecting elements 113."). Thus, in the combined system, each optical path between the apertures and the light detecting elements, when extended outward from the apertures, will also pass through each of the lens elements. Thus, when multiple lens elements are constructed as filters, the plurality of filters will be disposed in each of the claimed optical paths, including in the first optical path.

**11. Claim 31: The optical system for performing distance measurements according to claim 26 wherein the system generates distance data based on times between transmission of pulses of light from the plurality of optical emitters and detection of photons from the pulses of light by the plurality of photosensors.**

240. The additional element of claim 31 is word-for-word identical to the additional element of claim 23. The Hall-Borowski-Spector combination provides this element for the same reasons I discuss above with respect to claim 23, in Section XI.C.3.

**12. Claims 32-33**

241. The additional elements of claims 32 and 33 are word-for-word identical to the additional elements of claims 24 and 25, respectively. The Hall-Borowski-Spector combination provides these elements for the same reasons I discuss above with respect to claims 24 and 25, in Sections XI.C.4-5.

**D. Ground 4: Hall, Borowski, Spector, and Droz Render Obvious Claim 34**

242. As I discussed above in Ground 3, Hall, Borowski, and Droz render obvious claims 21 and 23-33. *See* Sections XI.C.1-12. The additional elements of dependent claims 34 are provided by the predictable combination of Hall in view of Borowski, Spector, and Droz. Here, Droz describes what would be common knowledge to a POSITA, namely, that optical filters in a LiDAR system used to filter background and stray light may be effectively located in any number of places within the system, so long as received light passes through the filter before it arrives at the detectors. Droz's optical filters are otherwise no different from those used in Hall's system—they are located between the bulk receiver optics and the light detectors and are used to “selectively transmit light within a predefined wavelength range” corresponding to “the wavelength range emitted by [the] emitter,” and to block light outside of that range. Ex. 1006, 7:50-8:10.

**1. Predictable Combination of Hall, Borowski, Spector, and Droz**

243. Based upon my review of the references and my knowledge and experience in this field, it is clear that a POSITA would have been motivated to combine the teachings of Hall, Borowski, Spector, and Droz. There are plain reasons that would have prompted a POSITA to apply Droz's suggestion, allowing for flexibility in the placement of optical filters in a LiDAR system, with the Hall-Borowski-Spector combination (previously articulated above).

244. As a first reason, Droz makes clear that the position of an optical filter within a LiDAR system is a design choice, and that the optical filter "may be located in various positions relative to [a light detector] array." *Id.*, 7:65-8:10. Although Hall's optical filters are located at Hall's light collection optics, Hall does not suggest that such positioning is particularly advantageous compared to other configurations, and a POSITA would understand that the benefits of using an optical filter can be achieved so long as the filter is positioned such that incoming light passes through the filter on its way to the detectors. A POSITA would have been motivated to try other positions based on Droz's suggestion because doing so provides more flexibility in the implementation, and may enable cost savings (by using cheaper components at different positions) or size savings (by positioning the

filter in a position where there is more space available), or may simplify assembly or manufacture of the system.

245. As a second reason, a POSITA would have found it obvious to combine Hall, Borowski, Spector, and Droz because doing so would have been—certainly by the timeframe leading up to May 2017—merely the application of known techniques to a known system ready for improvement to yield predictable results. This is explained with respect to the Hall, Borowski, and Spector combination above in Section XI.C.1. Droz further describes known techniques based on conventional knowledge (i.e., that a filter may be placed in various positions within an optical system) that enables more flexibility in developing and implementing a LiDAR device, such as the LiDAR device in the Hall-Borowski-Spector combination. It would have been trivial for a POSITA to apply Droz’s teachings and reposition the optical filter(s) within Hall’s LiDAR system.

2. **Claim 34: The optical system for performing distance measurements according to claim 26 wherein the one or more optical filters comprises a first optical filter disposed in the first optical path between the first photosensor and the first aperture, a second optical filter disposed in the second optical path between the second photosensor and the second aperture, a third optical filter disposed in the third optical path between the third photosensor and the third aperture, and a fourth optical filter disposed in the fourth**

**optical path between the fourth photosensor and the fourth aperture.**

246. The Hall-Borowski-Spector-Droz combination provides the additional element of claim 34. As discussed above, in Hall's system, the optical filters are implemented as one or more lens elements within Hall's collection optics. Ex. 1008, 7:7-27, Fig. 5. In the combined system, Droz's teachings enable the optical filter to be "located in various positions relative to [the light detector] array." Ex. 1006, 7:65-8:10. As discussed in Section XI.D.1, there are several reasons why a POSITA would be motivated to reposition Hall's optical filter elsewhere within the LiDAR system, including cost, size, and other implementation or manufacturing constraints.

247. Droz suggests a number of different locations where an optical filter may be located, including between the lens and the apertures, between an aperture and a detector, combined with the detector array, covering each individual light detector in the array, combined with an aperture, or on the surface of the lens. *Id.*, 7:65-8:10. Each of these positions would, at a minimum, be obvious to try, as they represent a small number of alternative design choices that are functionally equivalent. When Hall's optical filters are separately installed to cover each individual SPAD within the SPAD arrays of the combined system, each optical path between an aperture and a SPAD array would have a plurality of optical filters (one for each SPAD in the array) in that path.

**E. Secondary Considerations**

248. I am not aware of any evidence regarding secondary considerations of non-obviousness, and Ouster did not identify any such evidence in the patent specification, prosecution history, or related district court and ITC complaints. To the extent Ouster identifies evidence of secondary considerations at a later point in the proceeding, I reserves the right to address it at that time.

**XII. CONCLUSION**

249. For the aforementioned reasons, a POSITA would have recognized that a number of predictable prior art combinations (articulated in the grounds above) would have achieved all elements of claims 21 and 23-34 of the '405 Patent, and that those claims are thus invalid in view of the prior art, for the reasons discussed above.

U.S. Patent No. 11,175,405  
Declaration in Support of Petition for *Inter Partes* Review

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on the information and belief are believed to be true; I declare under penalty of perjury that the foregoing is true and correct, and understand that willful false statements and the like are punishable by fine or imprisonment, or both pursuant to 18 U.S.C. 1001.

Date: September 14, 2023

Respectfully Submitted

*James F. Shanley*

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Dr. James F. Shanley