

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HESAI TECHNOLOGY CO., LTD.
Petitioner

v.

OUSTER, INC.
Patent Owner

U.S. Patent No. 11,422,236
Inter Partes Review No. 2023-01458

**DECLARATION OF LAMBERTUS HESSELINK, PH.D.
EXHIBIT 1003**

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EXHIBIT LIST

No.	Short Name	Exhibit
1001	'236 Patent	U.S. Patent No. 11,422,236 to Pacala <i>et al.</i>
1002	'236 Prosecution History	Prosecution history for U.S. Patent No. 11,422,236
1003	Hesselink Declaration	Declaration of Prof. Lambertus Hesselink, Ph.D.
1004	Hall	U.S. Patent No. 7,969,558 to Hall
1005	Borowski	U.S. Patent Pub. No. 2013/0300840 to Borowski
1006	Lipson	U.S. Patent No. 9,831,630 to Lipson
1007	Hipp	U.S. Patent No. 7,787,105 to Hipp
1008	Tan	U.S. Patent No. 7,544,945 to Tan <i>et al.</i>
1009	Albert	U.S. Patent Pub. No. 2016/0327639 to Albert <i>et al.</i>
1010	Grzesik	U.S. Patent No. 9,911,774 to Grzesik
1011	Hipp-747	U.S. Patent No. 6,747,747 to Hipp
1012	NIST	<i>Performance Analysis of Next-Generation LADAR for Manufacturing, Construction, and Mobility</i> , National Institute of Standards and Technology (2004)
1013	HDL-64	User Manual and Technical Drawings for Velodyne HDL-64E
1014	DGC	<i>Report to Congress: DARPA Prize Authority</i> (2006)
1015	Team DAD	Hall <i>et al.</i> , <i>Team DAD Technical Paper</i> , DARPA Grand Challenge (2005)

No.	Short Name	Exhibit
1016	McManamon	McManamon, <i>Field Guide to LiDAR</i> , SPIE Field Guides, Vol. FG36 (2015)
1017	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)
1018	Matsubara	Matsubara <i>et al.</i> , <i>Development of Next Generation LiDAR</i> , R&D Review of Toyota CRDL (2012)
1019	Pennecot-117	U.S. Patent Pub. No. 2015/0055117 to Pennecot <i>et al.</i>
1020	ITC Complaint	Complaint in ITC Inv. No. 337-TA-1363
1021	Delaware Complaint	Complaint in <i>Ouster, Inc. v. Hesai Group et al.</i> , No. 23-cv-00406 (D. Del.)
1022	Stay Order	Order Granting Stay in <i>Ouster, Inc. v. Hesai Group et al.</i> , No. 23-cv-00406 (D. Del.)
1023	Preliminary Constructions	Preliminary Claim Constructions in ITC Action
1024	Niclass	Niclass <i>et al.</i> , <i>A Single Photon Avalanche Diode Array Fabricated in Deep-Submicron CMOS Technology</i> , (2006)
1025	Grage	U.S. Patent No. 5,210,586 to Grage
1026	Osram	Osram Datasheet
1027	Rodrigo	U.S. Patent Pub. No. 2016/0084945 to Rodrigo
1028	Lorenzoni	U.S. Patent No. 9,964,437 to Lorenzoni
1029	Weimer	U.S. Patent No. 8,736,818 to Weimer

Declaration of Prof. Lambertus Hesselink, Ph.D.

No.	Short Name	Exhibit
1030	Retterath	U.S. Patent No. 10,203,399 to Retterath
1031	Matsui	Certified English Translation of PCT Patent Pub. No. WO2017/110573 to Matsui
1032	Matsui Priority	Certified English Translation of Japanese Patent Application No. 2015-251136 to Matsui
1033	Imai	U.S. Patent No. 10,114,110 to Imai
1034	Higashi	Certified English Translation of Japanese Patent Publication No. 2015-78953
1035	Matsui-JP	PCT Patent Pub. No. WO2017/110573 to Matsui
1036	Matsui Priority-JP	Japanese Patent Application No. 2015-251136 to Matsui
1037	Higashi-JP	Japanese Patent Publication No. 2015-78953
1038	Droz	U.S. Patent No. 8,742,325 to Droz
1039	Jarosinski	U.S. Patent Pub. No. 2018/0045816 to Jarosinski et al.
1040	Pennecot	U.S. Patent No. 9,651,658 to Pennecot <i>et al.</i>
1041	Hesselink CV	Curriculum Vitae of Dr. Lambertus Hesselink, Ph.D.
1042	ITC Order	Order No. 10 in ITC Inv. No. 337-TA-1363
1043	Higashi Patent	Certified English Translation of Japanese Patent No. JP6314418B2 to Higashi
1044	Higashi Patent-JP	JP Patent No. JP6314418B2 to Higashi

CHALLENGED CLAIMS

Claim 1	
1(a)	An optical system for collecting distance information, the optical system comprising:
1(b)	an optical imaging transmit module comprising a bulk transmitting optic and an illumination source comprising a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical emitter in the plurality of optical emitters can project light at a nominal wavelength through the bulk transmitting optic and into a field ahead of the optical system;
1(c)	an optical imaging receive module comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and
1(d)	an actuator operable to rotate the optical imaging receive module about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the optical imaging receive module is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system;
1(e)	wherein the optical system generates, for each of a plurality of arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system.
Claim 2	
2	The optical system of claim 1 further comprising an optical filter disposed in front of each pixel in the plurality of pixels and operable to allow a set of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the set of wavelengths of light from reaching the plurality of pixels.

Claim 7	
7	The optical system of claim 1 wherein the circular paths traversed by pixels from the second set of pixels in the second column are interleaved with the circular paths traversed by pixels from the first set of pixels in the first column.
Claim 8	
8	The optical system of claim 1 wherein the optical imaging receive module further comprises a plurality of apertures and a stop region disposed between adjacent apertures in the plurality of apertures, wherein the plurality of apertures includes a first aperture and a second aperture horizontally and vertically offset from the first aperture, the first set of pixels includes a first pixel disposed in a first optical path that extends through the first aperture and the second set of pixels includes a second pixel disposed in a second optical path that extends through the second aperture.
Claim 9	
9	The optical system of claim 1 wherein the optical system implements time of flight techniques to determine distances from the optical system to external surfaces in the field.
Claim 23	
23(a)	An optical system for collecting distance information, the optical system comprising:
23(b)	an optical imaging transmit module comprising a bulk transmitting optic and an illumination source comprising a plurality of optical emitters arranged behind the bulk transmitting optic, wherein the plurality of optical emitters project a plurality of beams of light at an operating wavelength through the bulk transmitting optic and into a field ahead of the optical system;
23(c)	an optical imaging receive module comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and

23(d)	an actuator operable to rotate the optical imaging receive module about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the optical imaging receive module is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system;
23(e)	wherein the optical system generates, for each of a plurality of arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system.
Claim 24	
24	The optical system of claim 23 wherein the optical system further comprises an optical bandpass filter disposed between the bulk transmitting optic and the plurality of pixels and having a center wavelength matched to the operating wavelength of the plurality of optical emitters.
Claim 25	
25	The optical system of claim 23 wherein the optical imaging receive module further comprises a plurality of apertures and a stop region disposed between adjacent apertures in the plurality of apertures, wherein the plurality of apertures includes a first aperture and a second aperture horizontally and vertically offset from the first aperture, the first set of pixels includes a first pixel disposed in a first optical path that extends through the first aperture and the second set of pixels includes a second pixel disposed in a second optical path that extends through the second aperture.
Claim 26	
26	The optical system of claim 23 wherein the illumination source comprises a plurality of vertical cavity surface emitting lasers (VCSELs).
Claim 27	
27	The optical system of claim 26 wherein the optical system implements time of flight techniques to determine distances from the optical system to external surfaces in the field.

I. INTRODUCTION

1. My name is Dr. Lambertus Hesselink. I have been retained by Petitioner Hesai Technology Co., Ltd. (“Hesai”) to provide expert opinions with respect to U.S. Patent No. 11,422,236 (the “‘236 Patent”), which I understand is assigned to Patent Owner Ouster, Inc. (“Ouster”).

2. I am being compensated at my standard consulting rate of \$645 per hour for my time, 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 EX1041. Here, I provide a summary of my background and qualifications.

4. I am currently a Professor of Electrical Engineering in the Department of Electrical Engineering at Stanford University, and by courtesy in the Departments of Applied Physics and Aeronautics and Astronautics.

5. In 1970 I received a Bachelor of Science degree in Mechanical Engineering from the Twente Institute of Technology in Enschede, Netherlands, and a Bachelor of Science degree in Applied Physics from the same institution in 1971. The following year, I received my Master of Science degree in Mechanical Engineering from California Institute of Technology. In 1974, I obtained an Applied Mechanics engineering degree from the Twente Institute of Technology, and then I subsequently continued my studies at the California Institute of Technology and, in 1977, earned my doctorate degree in Applied Mechanics and Physics/Applied Physics.

6. My expertise is in ultra-high density optical data storage, and optical information systems generally, as well as optical communication components, nano photonics, optics and optical systems, and optical interconnects. I have been awarded several scientific awards from scientific and professional societies, including the Fulbright Scholarship, Stheeman Price Award, DARPA Award, Best Paper Awards from the Institute of Electrical and Electronics Engineers (IEEE) and OSA, Fellow of the Optical Society of America (OSA), the Society of Photo-Optical Instrumentation Engineers (SPIE), and the National Information Solutions Cooperative (NISC), among others. In addition to being an assistant, associate, or full Professor performing research in these fields for over 30 years, I am a member of the Royal Dutch Academy of Arts and Sciences, have been the keynote or

invited speaker in over 290 scientific meetings and the organizer of over 70 scientific meetings, have authored more than 500 papers in scientific journals, have written over 15 book chapters on optics, data analysis and visualization, optical storage, and image processing, and have been the editor of several scientific publications, including *Applied Optics*, *Applied Scientific Research*, and *IEEE Transaction on Visualization*.

7. I have had an intimate knowledge of the technology in the area of optical systems since at least 1978. As an undergraduate student in Applied Physics, while working as an intern at the Optical Industries in Delft, The Netherlands, I was first exposed to LiDAR through work on the development of a ND-Yag laser for distance measurements. Since then, I have used LiDAR and laser distance measurement technology in my research throughout the years. I have taught courses at the California Institute of Technology and Stanford University on optical systems design, modern optics, optical signal processing and digital image processing, among others, for over 30 years, covering specific topics that include the design and operation of LiDAR systems and their underlying optical components.

8. In addition to my academic experience, I have extensive corporate and consulting experience. I have founded three high-technology companies, I have been Chief Technology Officer in the Branded Products division of Western

Digital, I have been a member of the Scientific Advisory Board of the United States Air Force, and I was a member of one of the two NASA Ad Hoc Advisory Committees tasked with repairing the Hubble Space Telescope just after its launch. With a broad knowledge of optics, optical systems and devices, optical storage systems, a solid grounding in LiDAR and its underlying technologies and components, and experience with the patent and trade secret process, I believe that I am qualified to provide an accurate assessment of the technical issues addressed in this declaration. In particular, as noted in Section VII below, my opinion is that a POSITA as of August 24, 2016 would have had an undergraduate degree in mechanical or electrical engineering or physics and two to three years of experience in LiDAR design. The following factors support my opinion. I met and exceeded those requirements as of August 2016.

III. LEGAL UNDERSTANDING

9. 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

10. 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.

11. 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

12. 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

13. 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.

14. 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.

15. 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.

16. 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.

17. 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.

18. 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.

IV. SUMMARY OF INVALIDITY GROUNDS

19. For purposes of this declaration, I have been asked to analyze claims 1-2, and 7-27 of the '236 Patent in view of the prior art. In my opinion, the challenged claims are obvious based on the following grounds:

Ground	Claims	References
1A	1, 7, 9-10, 23	Hall, Borowski
1B	2, 15, 24	Hall, Borowski, Lipson
1C	8, 25	Hall, Borowski, Hipp
1D	26, 27	Hall, Borowski, Tan
1E	11-13, 16-17, 22	Hall, Borowski, Weimer
1F	14, 19-21	Hall, Borowski, Hipp, Weimer
1G	18	Hall, Borowski, Weimer, Lipson
2A	1, 7, 9-13, 16-17, 22-23, 26-27	Matsui, Imai
2B	1-2, 7, 9-13, 15-18, 22-24, 26-27	Matsui, Imai, Higashi
2C	8, 14, 19-21, 25	Matsui, Imai, Hipp
2D	8, 14, 19-21, 25	Matsui, Imai, Higashi, Hipp

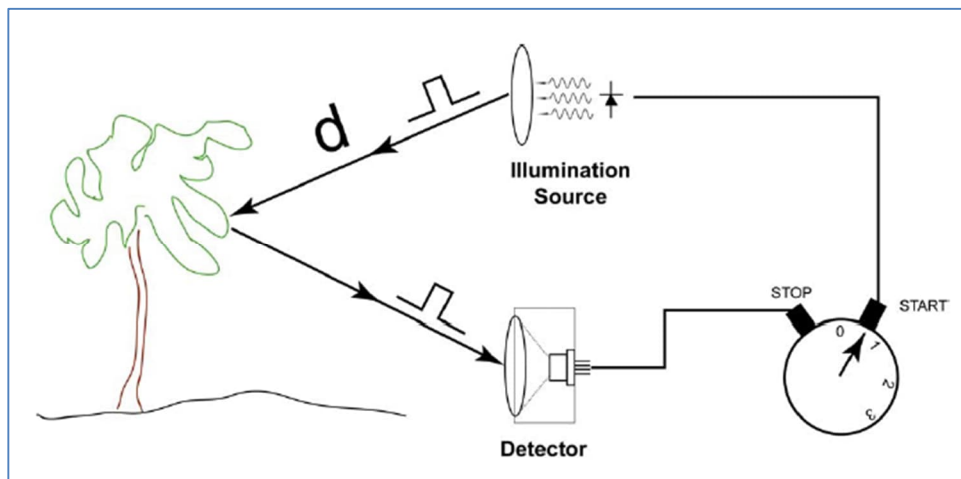
V. TECHNOLOGY BACKGROUND

20. In this section, I provide an overview of technical concepts and design principles underlying the ‘236 Patent.

A. LiDAR and Time-of-Flight

21. The concept of using lasers to detect objects and measure distance dates back to the 1960s. Just as sound waves had been used for distance measurements in RADAR (“Radio Detection and Ranging”), the proliferation of laser technology allowed light to be used for the same purpose. Hence the names LiDAR (“Light Detection and Ranging”) and LaDAR (“Laser Detection and Ranging”).

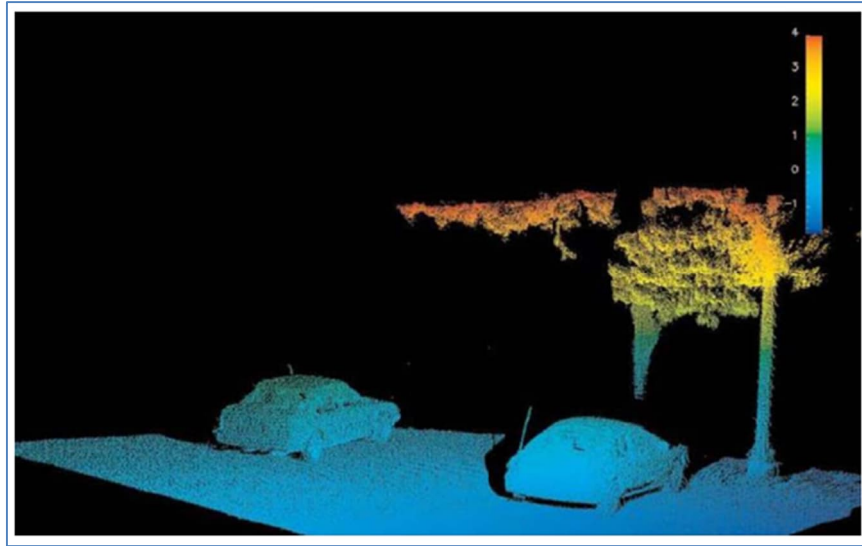
22. The core components of a LiDAR system are photon emitters (*e.g.*, lasers), photon detectors (*e.g.*, photodiodes), circuitry to fire the emitters and process signals generated by the detectors, and optical components (*e.g.*, lenses and mirrors) to route photons from the emitters, to the surrounding environment, back to the detectors. Distance from the LiDAR device to an object struck by an emitted photon is measured by determining the time between emission and detection, dividing by two (to account for the fact that the photon made a round trip to the detected object), and multiplying by the speed of light. For example, if the emission-detection interval 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 principle, known as “time-of-flight,” is illustrated in the simplified diagram below:



EX1012, 2.3.¹

¹ I note that this is a simplified diagram that assumes equal path lengths from and to the source and detector, respectively.

23. When multiple distance measurements are processed and combined, the result is a three-dimensional map of the surrounding environment, also known as a “point cloud”:



EX1012, Fig. 6.3.

B. LiDAR Design Principles

24. Many modern LiDAR devices—including those disclosed in Hall and Matsui as set forth in the invalidity Grounds below—are used for autonomous or self-driving vehicles. In these applications, the vehicle and its sensors—like LiDAR—are designed for mimicking the human brain and a person’s ability to drive a vehicle. The vehicle and its sensors, therefore, must be capable of sensing the environment in a timely manner with limited resources. As the LiDAR platform (the sensing and processing system) is located on a moving vehicle platform, powered by on-board computing and energy systems, resources are

scarce. Additionally, the environment surrounding the vehicle is complex including stationary objects and infrastructure, dynamic traffic conditions, moving vehicles, pedestrians, animals, bicycles, motorcycles and recently electric bikes and scooters. To make the challenge even greater, the weather is variable, visibility varies from clear to obscuration caused by rain, sleet, and snow, while the sun is periodically illuminating the environment to be sensed. Acquiring, storing, and processing this flood of data was a known challenge in the field dating back at least a decade before the priority date of the '236 Patent.

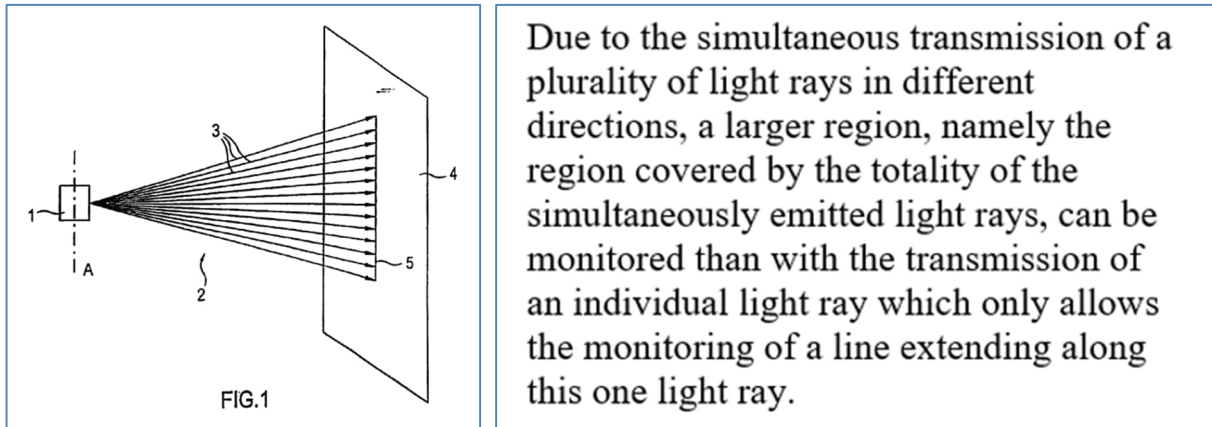
25. A POSITA would have been aware of these challenges and would naturally focus on energy efficiency and minimizing the energy drain of on-board sensing and computing resources, while enabling high-resolution detection in complex environments. For example, laser distance measurements provide better quality data with larger laser power. However, eye safety requirements limit the power that may be emitted from a LiDAR system to avoid causing vision damage. Therefore, the laser intensity, *i.e.*, the number of emitted photons per pulse is limited. As light reflected from objects scatters, absorbs, and redirects photons, a limited fraction of the emitted photons will be detected by the receivers further limiting signal quality. A POSITA would therefore naturally focus on staying up to date with developments in the field that would provide benefits in achieving solutions to this challenge. For example, designers of efficient sensor systems

would naturally pay attention to detector technologies as they evolve, because the higher the detection efficiency, the better the quality of the detected signals, in turn providing better data for autonomous vehicles. As an example (discussed further below), a POSITA would look to the most sensitive detectors available (*e.g.*, well-known single photon avalanche detectors) for creating point clouds with as high a resolution as possible under the most diverse weather conditions the vehicle may encounter would significantly benefit the safety and driving capability of self-driving vehicles. Other examples include techniques for the position and alignment of emitters and detectors in the LiDAR system, and the use of common optical design elements like lenses, apertures, and filters to efficiently emit and detect light, generate a high-resolution point cloud, and maintain a compact device size with low power consumption and low cost. These design principles are discussed below and in connection with the invalidity Grounds herein.

1. Multi-Beam Systems

26. Early LiDAR devices focused on military applications, such as range finders to determine the precise distance to a target. These systems were relatively simple in design and often employed a single laser to allow for one-dimensional distance measurement to a specific point, or two-dimensional measurement in a plane. EX1004, 1:32-39. As the technology progressed, those in the field recognized that a more detailed map of the environment could be achieved by

using multiple emitter-detector pairs and moving or rotating the device to scan a larger 3D region. U.S. Patent No. 6,747,747 (“Hipp-747”), for example, teaches a LiDAR system that improves point cloud density and coverage by using a plurality of emitters spaced apart in a fanned arrangement:



EX1011, Fig. 1, 1:66-2:5.

27. Hipp-747 also recognized that 3D point cloud coverage could be improved by rotating the emitters and detectors through a wide horizontal field of view, such as a 360-degree sweep. *Id.* at 4:1-11.

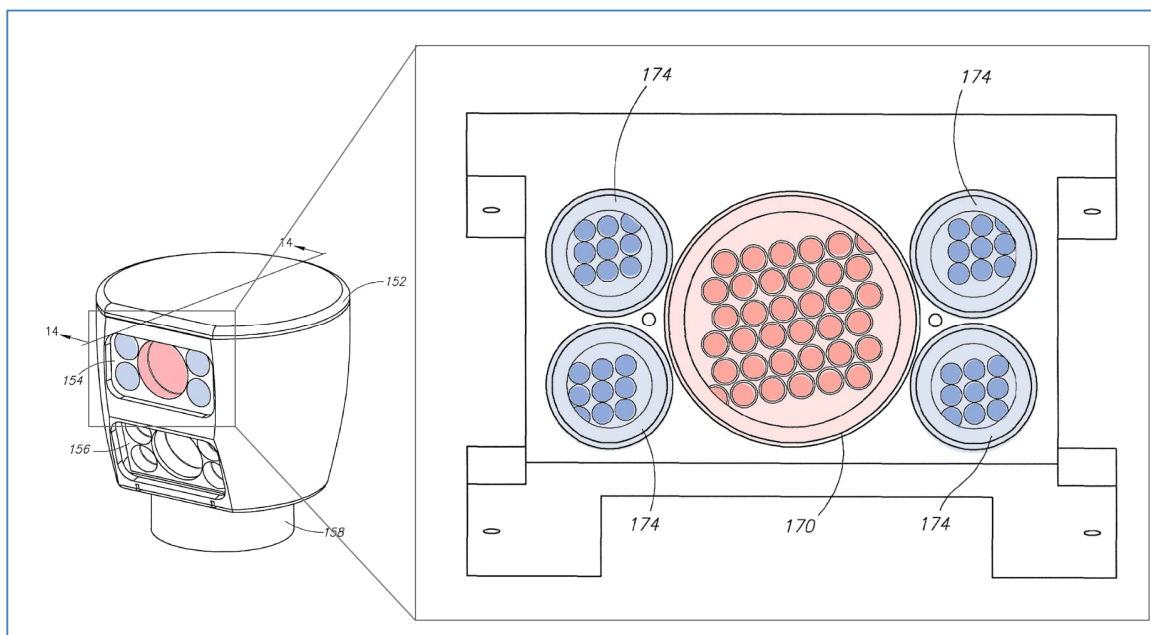
28. In 2005, a company called Velodyne Acoustics implemented these same techniques in a LiDAR device for autonomous-vehicle navigation. EX1015, 1-2. The device came about in connection with the 2005 DARPA Grand Challenge, a government-sponsored event to incentivize development of autonomous-vehicle technology. EX1014. The Velodyne team—known as Team DAD—designed the device with sixty-four emitter-detector pairs mounted on a platform that rotated around a fixed base via a built-in DC motor. EX1015, 8-9.

The rotational mount allowed the device to achieve a 360-degree horizontal field-of-view, and angular spacing of the emitter-detector pairs allowed it to achieve a 20-degree vertical field of view. *Id.* This permitted the device to produce a “very high-density profile map of the surrounding environment,” which on-board software processed to make autonomous navigation decisions. *Id.*

29. Velodyne commercialized its first LiDAR device as the HDL-64E. EX1013. Velodyne also filed patents describing the features of its LiDAR device, including U.S. Patent No. 7,969,558 (“Hall”), which was filed in 2007 and is relied on in the invalidity Grounds below. EX1004. The Hall device reflects several design features that became common among modern LiDAR devices. First, the use of sixty-four emitter-detector pairs allowed the device to capture approximately one million data points per second and therefore produce a high-resolution point cloud. EX1004, 4:9-11. Second, the use of a DC motor to rotate the emitter-detector pairs allowed the device to achieve a 360-degree *horizontal* field-of-view, which means data points were collected around the entire device or around the vehicle on which it was mounted. *Id.*, 4:11-13. Third, careful positioning of the emitter-detector pairs allowed the device to achieve a wide *vertical* field-of-view of 26.8°, which means data points were collected downward in the area immediately surrounding the device, but also upward through the horizon to identify objects in the distance. *Id.*, 4:3-5.

2. Emitter and Detector Arrays

30. To achieve these design goals while maintaining a suitable device size, Hall positioned the emitters and detectors in two-dimensional *arrays*. EX1004, Fig. 22. As shown in Figure 22 (which is reproduced below in the right hand image), the emitter arrays (blue) are positioned behind a lens in cavities 174, while the detector arrays (red) are positioned behind a lens in cavity 170:



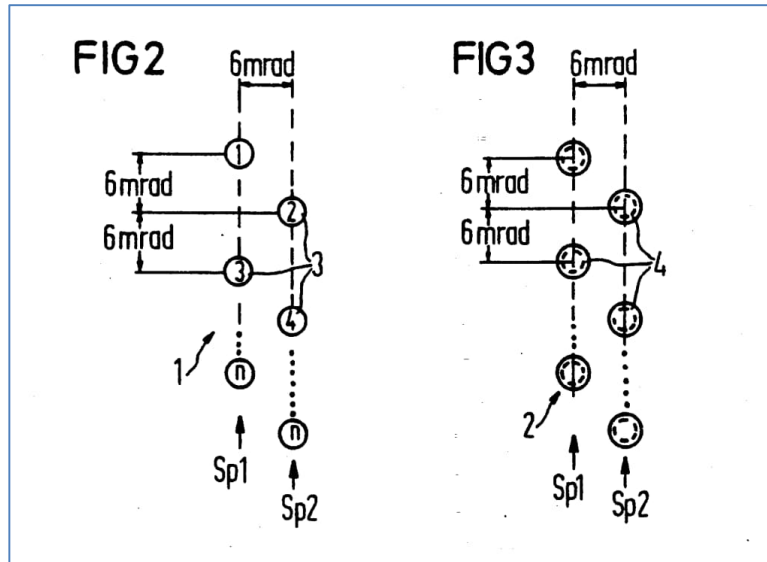
Id., Figs. 13, 22.²

31. By organizing the emitters and detectors in multi-column arrays (rather than a single column), the overall height and profile of the device is reduced. At the same time, the device captures a wider horizontal “snapshot” for a given rotational position at a given point in time. Hall also teaches that the

² Images like this have been annotated with color and/or text for illustrative purposes. Unless I note otherwise, the annotations were added.

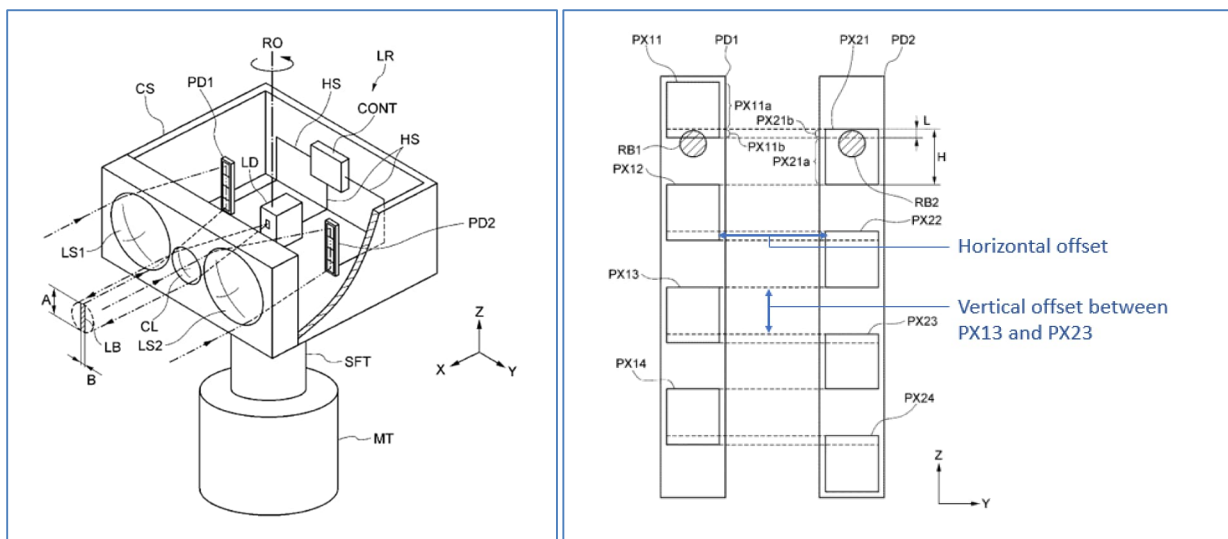
emitters and detectors are offset from the emitters and detectors in an adjacent column. This allows the device to achieve a higher resolution—*i.e.*, an angular spacing of $1/3^\circ$, for a total vertical field-of-view over 20° —than it could if the emitters and detectors were arranged in a linear fashion. *Id.*, 8:14-17.

32. Other devices incorporated the same design principles. For example, an early aerial LiDAR sensor disclosed in U.S. Patent No. 5,210,586 (“Grage”) teaches detectors arranged in columns that are horizontally and vertically offset from one another by a defined pitch to generate a “mesh network-like scan pattern” with a desired resolution. EX1025, 7:54-8:7 (“the semiconductor laser diodes 3 in FIG. 2 and the receiving detectors 4 in FIG. 3 are respectively arranged in at least two columns Sp1 and Sp2 that are parallel to one another, whereby the spacing of the semiconductor laser diodes 3 or, respectively, of the receiving detectors 4 within the columns Sp1 or, respectively, Sp2 is equal to the mesh size, *i.e.* equal to 12 mrad in the present example. The spacing of the columns Sp1 and Sp2 from one another is equal to half the mesh size, *i.e.* 6 mrad.”):



Id., Figs. 2-3.

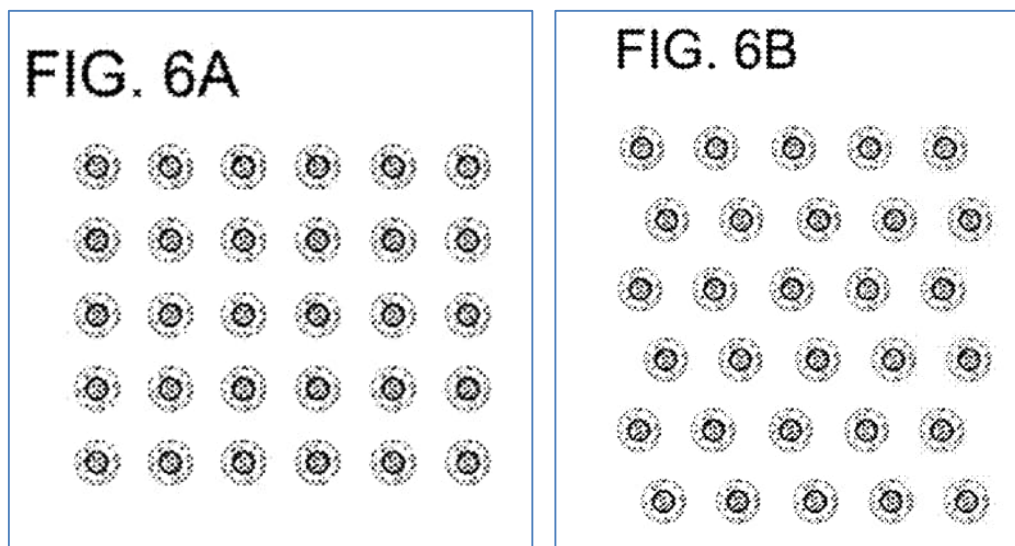
33. WIPO Publication No. 2017/110573 (“Matsui”)—which I discuss in Grounds 2A-2D below—teaches a rotating LiDAR device with pixels arranged in columns (PD1, PD2), where the pixels in the first column (PX11, PX12, etc.) are horizontally and vertically offset from pixels in the second column (PX21, PX22, etc.):



EX1031, Fig. 2; [0016], [0037].

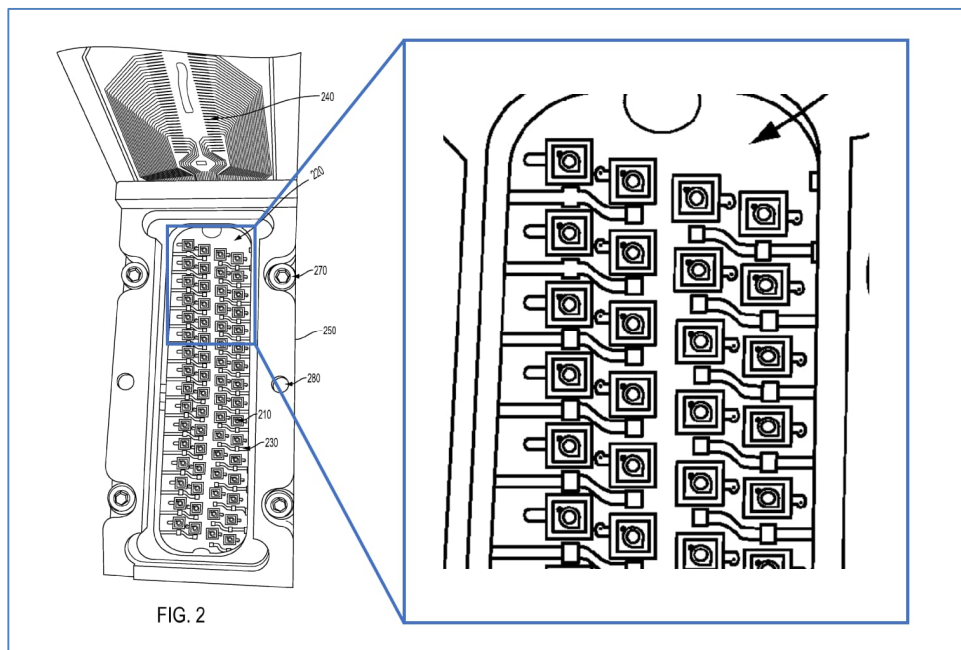
34. Matsui explains that the offset pixels “achieve high resolution and reduce detection failure” by eliminating “non-detection regions” of the device. *Id.*, [0029]-[0030].

35. U.S. Patent 9,911,774 (“Grzesik”) teaches an array of Geiger-mode avalanche photodiodes for LiDAR applications and explains that an “aperiodic” arrangement of the detectors helps to reduce cross-talk interferences. EX1010, 1:21-67, 7:17-28, 7:35-52, 8:20-33. Figure 6A illustrates a periodic arrangement, where the pixels and apertures in each column are not offset; Figure 6B illustrates an aperiodic arrangement where pixels and apertures in the first column are horizontally and vertically offset from pixels in the second column:



Id., Figs. 6A-B

36. The aperiodic position of photodiodes and corresponding apertures reduces “translational symmetry” and thereby minimizes cross-talk. *Id.*, 7:17-28, 7:35-52, 8:20-33 (“This demonstrates that there can be achieved a condition of reduced translational symmetry.... [T]he placement of entire columns of photodiodes can be shifted relative to adjacent or other columns in the array.”). And a similar design is shown in U.S. Patent No. 8,742,325 (“Droz”), which teaches a rotating LiDAR device with an array of detectors “arranged in four staggered parallel rows”:



EX1038, Fig. 2, 3:59-4:5.

3. Alignment

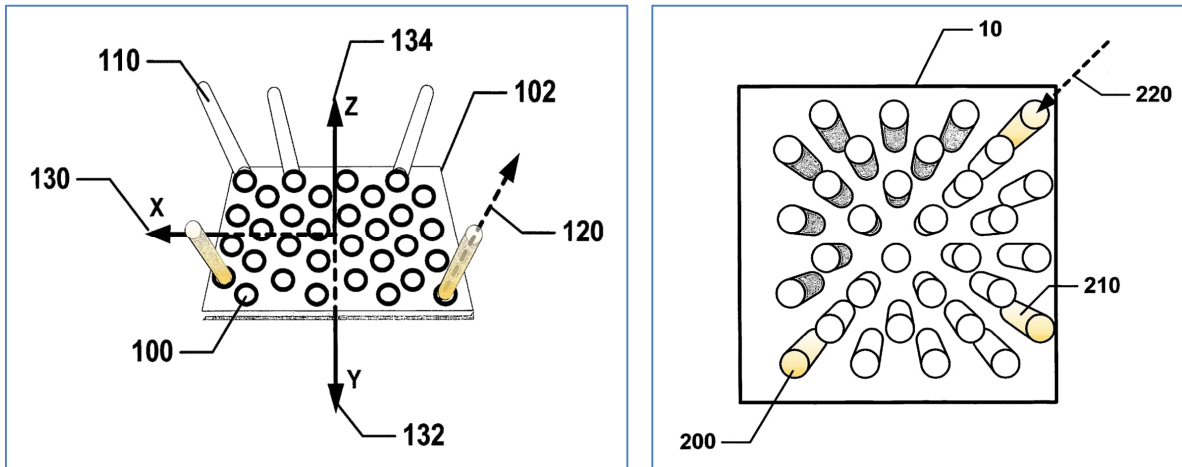
37. Multi-beam LiDAR devices also realized the importance of precise alignment between each emitter and its corresponding detector. As discussed

above, the time-of-flight calculation is based on the round-trip time for a photon to leave the emitter and reach the detector. The “clock” starts when the emitter is fired and stops when the photons are detected. Thus, it is important that a given detector receives photons from its corresponding emitter; if the detector generates a signal based on stray photons, then the “clock” might stop prematurely and the time-of-flight calculation will be incorrect.

38. A known technique to avoid that result was to align each emitter-detector pair to have a coincident field-of-view. For example, U.S. Patent No. 8,736,818 (“Weimer”) teaches a LiDAR device with angularly-spaced emitter-detector arrays. EX1029, 3:1-12. Weimer explains that “[l]arge fields of view per detector are not desirable because a wide field of view results in the acceptance of more background light than a narrower field of view, reducing the signal to noise ratio.” *Id.*, 1:53-56. Thus, “the goal for good daytime performance has been to have the laser spot size only slightly smaller than the receiver’s instantaneous field of view.” *Id.*, 1:56-59. To achieve that goal, Weimer teaches controlling the spot size of each emitter such that “individual beams [] can be directed to cover an area corresponding to a single pixel of the detector,” which is shown in Figure 3A. *Id.*, 4:56-58.

39. U.S. Patent No. 10,203,399 (“Retterath”) teaches a similar design, where an array of emitters 100 each has a unique and non-overlapping emission

vector 120. EX1030, 7:41-8:40. Retterath further teaches an array of detectors 200, each with a unique detection vector 220:



Id., Figs. 4, 8, 9:58-10:31.

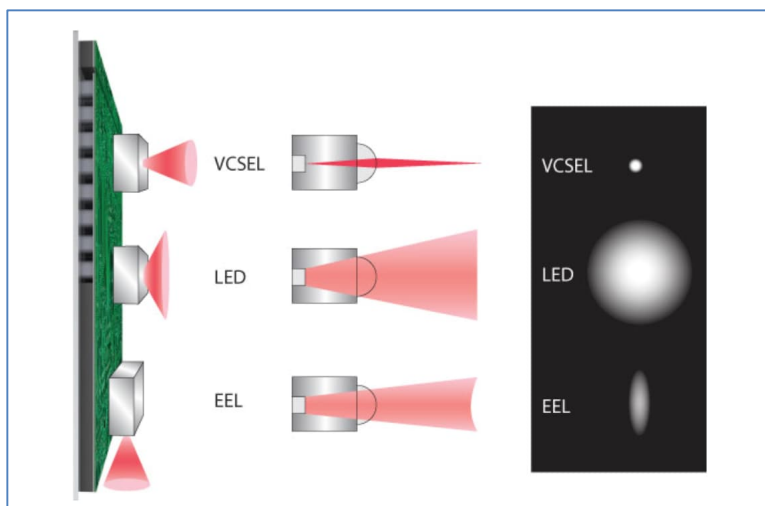
40. Retterath explains that each emission vector 120 is “on-coincident axis” with a corresponding detection vector 220. *Id.*, 6:23-39. The design ensures that the majority of photons received at a given detector are emitted from its corresponding emitter, thus reducing interference among emitter-detector pairs in the array or a nearby LiDAR device. *Id.*, 3:5-9; 9:62-65. To achieve those goals, Retterath teaches a tight beam spot to increase precision and reduce cross-talk, *Id.*, 9:36-44, and an angular waveguide or aperture associated with each detector to ensure it receives light along its intended vector. *Id.*, 10:4-22.

C. Emitters and Detectors

41. In addition to the *arrangement* and *alignment* of emitters and detectors, the *type* of emitters and detectors useful for LiDAR applications was subject to extensive research in the field.

1. VCSEL Arrays

42. Traditional LiDAR devices employed laser diodes, which are semiconductor structures that emit photons when biased with a voltage. EX1016, 67. Edge-emitting lasers (“EEL”) output photons from the side of the device, which produces a wide beam divergence and necessitates the use of optics to collimate the beam and narrow its focus. An alternative is the vertical-cavity surface-emitting laser (“VCSEL”), which is designed to emit photons from a cavity formed in the upper surface of the semiconductor layers. As illustrated below, VCSELs provide a tighter beam divergence than EEL diodes—and light-emitting diodes (“LEDs”)—and thus produce a more precise illumination spot:



43. Those skilled in the art recognized numerous advantages of VCSEL emitters for LiDAR applications. EX1008 (Tan), 4:51-5:21. Examples include: a small angular divergence; emission of light normal to the surface of the semiconductor layers, which allowed VCSEL arrays to emit light perpendicular to a PCB on which they were mounted; tight spacing of VCSEL arrays; high-speed activation on the order of picoseconds; fabrication at multiple wavelengths; an integrated design that allowed for integration of optical elements and improved alignment; and ease of manufacturing. *Id.*

44. These advantages complemented the LiDAR design principles discussed above. For example, references like Hipp and Hall recognized the importance of using multiple emitter-detector pairs to improve resolution of the device. EX1004, EX1008. The tight beam divergence of VCSELs allowed multiple emitters to be spaced closely together, to increase resolution without overlap among their emission patterns. The prior art also recognized the advantage of using arrays to pack emitters and detectors closely together. The ability to mount an array of VCSEL emitters onto a common PCB allowed for that type of design. These benefits made VCSEL emitters an advantageous choice for multi-beam LiDAR devices. *Id.* EX1008, 4:51-5:21; EX1040 (“Pennecot”), 4:55-62.

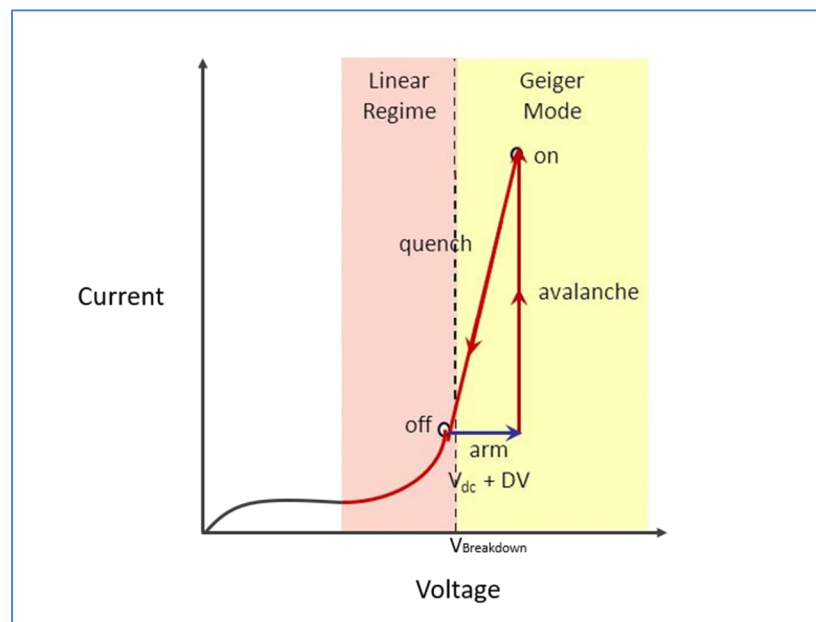
2. SPAD Arrays

45. Regarding detector technology, traditional LiDAR devices employed linear-mode avalanche photodiodes (“APDs”). A photodiode is a semiconductor device that converts photons into electric current. When light is exposed to the surface of the photodiode, it causes current to flow that can be detected as a signal to indicate light has been received.

46. In the 1960s, researchers realized they could use the “avalanche” effect to create a larger gain. The avalanche occurs when photons excite electrons, which are accelerated by the bias voltage to knock other electrons free, and the process accelerates through further electron collisions. For a given number of photons received at the diode, a larger amount of current flows, making the signal easier to detect and analyze. However, when the diode receives too much reverse bias it can break down and produce such a large current that the device becomes thermally unstable and potentially fails. Thus, in traditional linear-mode APDs, the diode is reverse biased towards the breakdown voltage but not over that threshold. The term “linear-mode” refers to the fact that operation of the APD has a linear relationship between the number of photons it detects and the output of the signal it generates.

47. An alternative mode of the APD operation is referred to as Geiger-mode or single-photon avalanche photodiodes (“SPADs”). These devices are

designed to operate above the breakdown voltage to produce a binary output. EX1009, 8 (“SPADs, also known as Geiger-mode avalanche photodiodes, are reverse biased at their characteristic breakdown voltage, thus providing single-photon detection capability.”). In this state, the receipt of a single photon triggers a very strong avalanche effect and resulting signal. The image below helps illustrate the principle of operation:



48. In linear-mode (pink), as the voltage increases up to the breakdown voltage, the current and gain of the resulting signal increase. In Geiger-mode (yellow), the avalanche effect increases significantly, such that receipt of a single photon (on) results in a large current signal. Because the diode is already above the breakdown threshold voltage, however, it does not provide additional values upon receipt of additional photons. To detect another photon, a special circuit is

required—called a “quenching circuit”—to reduce the voltage below breakdown and prevent destruction of the device. After a recovery period, the diode is reset and able to detect another photon.

49. As with VCSELs, those skilled in the art recognized that the unique operation of SPADs would benefit existing LiDAR devices. Early research at the Massachusetts Institute of Technology, for example, identified SPADs as having “extraordinary” sensitivity for LiDAR detection. EX1008, 4. Researchers at Toyota leveraged that same benefit to incorporate SPAD detectors into long-range LiDAR for vehicle-based platforms. EX1009 (Albert), 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.”). And others in the field reported that SPADs allow for high data-rate output, reduced power, compact design, ease of scalability, and integration with CMOS logic. EX1007 (Hipp), [0012]-[0014], [0020]-[0021]; EX1005 (Borowski), 1:19-26, 1:42-52, 3:66-4:4.

50. The same benefits were recognized for time-of-flight devices that used multiple detectors, with each detector including an array of SPADs. For example, Borowski teaches a time-of-flight LiDAR sensor with multiple detectors on a rotating mount. EX1005, [0078]. The multi-SPAD detectors allow for highly efficient and ultrafast detection of photons emitted from corresponding laser arrays. *Id.*, [0022]. The use of multiple SPAD cells in each detector also allows

for an average to be taken, such that the array “acts as the equivalent of a single ‘perfect’ SPAD having no recovery time.” *Id.*, [0053]. Albert recognizes the same principle, teaching a time-of-flight sensor with multiple light receivers, each of which includes an “array comprising single photon avalanche diodes.” EX1007, [0049], [0138]-[0139]. The multi-SPAD receiver allows the SPAD cells to be evaluated together, which avoids the situation where a single-SPAD pixel fails to register a measurement because it is “already saturated.” *Id.*, [0050].

51. The teachings of Borowski and Albert reflect an important characteristic of the array design because each individual cell is subject to a “dead time” during which the voltage is quenched and the SPAD is reset. A single-SPAD pixel will be inoperative during the dead time, whereas a multi-SPAD pixel will allow for detection by some of its SPADs even if others are being actively quenched and reset. Forming each detector/receiver/pixel as a plurality of SPADs ensures that the detector/receiver/pixel processes photon returns even if one or more of its SPADs is subject to quenching or reset. *Id.* Additional literature discussing the known benefits of SPAD arrays includes Niclass et al., *A Single Photon Avalanche Diode Array Fabricated in Deep-Submicron CMOS Technology* (2006), which notes that applications like LiDAR, “where sensitivity and timing accuracy are critical, will significantly benefit from this technology.” EX1024.

* * *

52. In my opinion, the challenged claims of the ‘236 Patent represent obvious combinations of the features and technologies described above.

VI. THE ‘236 PATENT

53. In this section, I provide an overview of the ‘236 Patent, a summary of the prosecution history, and a listing of the challenged claims.

A. Overview

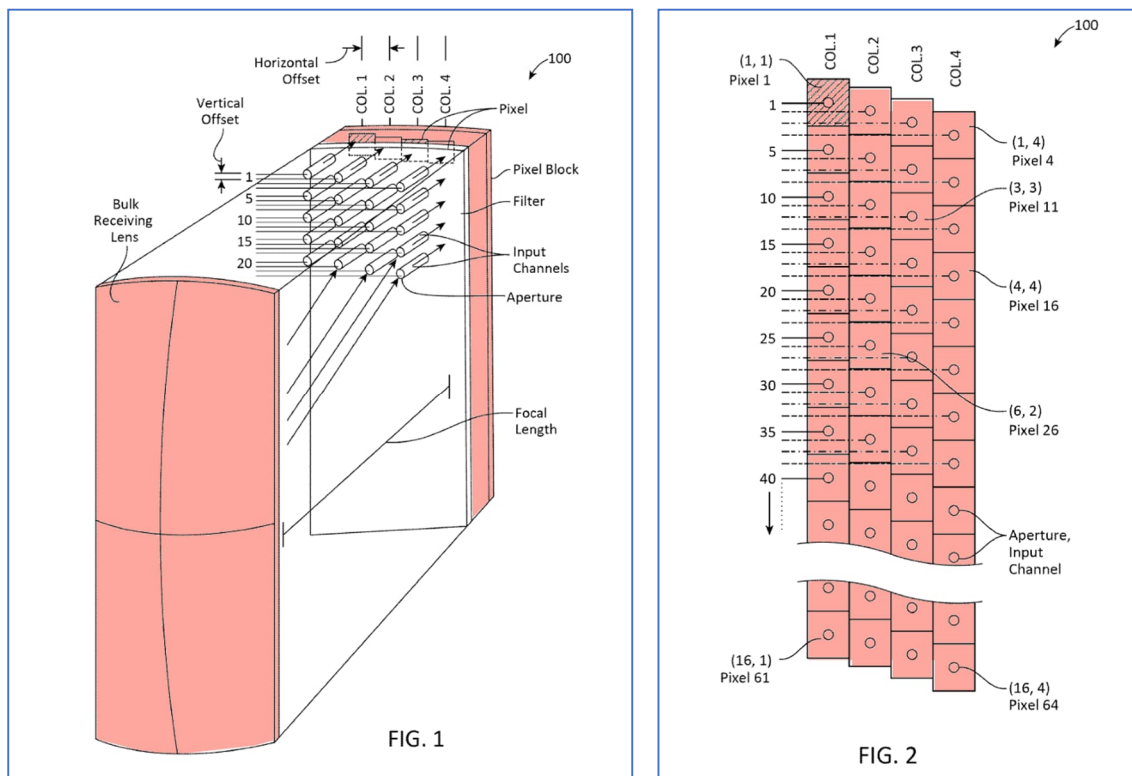
54. The ‘236 Patent is titled *Optical System for Collecting Distance Information Within a Field*. EX1001. Its underlying application was filed on December 15, 2021, as a continuation of Application No. 17/194,068, filed March 5, 2021, which is a continuation of Application No. 15/685,384, filed August 24, 2017. *Id.* I understand the ‘236 Patent is related to Provisional Application No. 62/379,130, filed on August 24, 2016. *Id.* For purposes of my analysis, I have used the provisional application filing date as the effective filing date for the challenged claims. As detailed below, all of the prior art discussed herein was filed, issued, published, or claims priority to a date before August 24, 2016.³

B. Specification

55. The ‘236 Patent is directed to systems or collecting distance information. EX1001, Abstract. Embodiments of the specification describe a LiDAR device with an output circuit that includes a plurality of laser emitters and

³ I reserve the right to challenge any priority claim to the provisional application filing date at a later point in time.

a lens to generate and transmit laser pulses to the surrounding environment. *Id.*, 11:6-14, 11:36-41. The device also includes an input circuit that includes a lens and a plurality of pixels to receive and detect laser pulses reflected from objects in the environment. *Id.*, 4:20-43. The figures of the '236 Patent focus on the input circuit, with Figures 1 and 2 showing the receiving lens and pixel array:



Id., Figs. 1-2.

56. As shown in Figure 1, the input circuit includes a plurality of apertures and a filter layer positioned between the receiving lens and pixels. *Id.* As shown in Figure 2, the pixels are arranged in a plurality of columns, with the pixels in column-1 horizontally and vertically offset from the pixels in column-2.

Id. According to the specification, the arrangement allows each pixel to have an increased height dimension compared to the same number of pixels arranged in a single vertical column. *Id.*, 5:15-22.

57. The specification states that each pixel may “include an array of single-photon avalanche diode detectors (‘SPADs’) or ‘any other type of pixel including any other number of detectors.’” *Id.*, 6:8-15. The emitters in the output circuit may include a “monolithic VCSEL array.” *Id.*, 11:15-17. And the input and output circuits can be rotated via an actuator—an example of which is an electric motor—to collect time-of-flight distance measurements in 360-degrees around the device. *Id.*, 12:18-38.

C. Prosecution History

58. I understand the application underlying the ‘236 Patent was filed on December 15, 2021 with twenty-seven claims. EX1002. On February 28, 2022, the Examiner issued a non-final rejection finding certain claims obvious based on so-called non-statutory double patenting in view of co-owned U.S. Patent No. 10,222,458. *Id.*, 182-190. The Examiner objected to the remaining claims and indicated they would be allowable if written in independent form. *Id.* I understand the applicant submitted a terminal disclaimer to overcome the double patenting rejection and the claims were then allowed in their original form.

VII. LEVEL OF ORDINARY SKILL IN THE ART

59. In my opinion, a POSITA as of August 24, 2016 would have had an undergraduate degree in mechanical or electrical engineering or physics and two to three years of experience in LiDAR design. The following factors support my opinion.

60. 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 a student on track for a degree in mechanical or electrical engineering or physics would have sufficient exposure to optics principles to then work or conduct research in that area in academia or industry.

61. 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 '236 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 '236 Patent.

62. 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.

63. Fourth, the proposed level of skill is consistent with the sophistication of the technology claimed in the '236 Patent. The patent concerns LiDAR design, including the use of certain emitter and detector types, and optical features like the arrangement of emitter-detector pairs. The level of sophistication is such that an

advanced degree or work experience beyond 2-3 years would not be necessary to understand the technology and make informed design decisions.

64. For the above reasons, it is my opinion that the appropriate level of skill in the art is an undergraduate degree in electrical engineering, mechanical engineering, or physics and 2-3 years of experience in LiDAR design.

VIII. CLAIM CONSTRUCTION

65. 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 '236 Patent, and I have considered that meaning in the context of the patent and its prosecution history.

66. I understand that in the parallel ITC proceeding, Hesai and Ouster have submitted preliminary constructions for certain terms of the '236 Patent. EX1023. For the reasons detailed in the element-by-element analysis below, each of the prior art combinations that I analyze below map to the embodiments in the specification of the '236 Patent and therefore, in my opinion, meet the claim requirements under any proposed construction.

67. I reserve the right to offer additional claim construction opinions in other proceedings, including indefiniteness opinions that I understand are not at issue in this proceeding. I also reserve the right to respond to any claim construction positions put forward by Ouster.

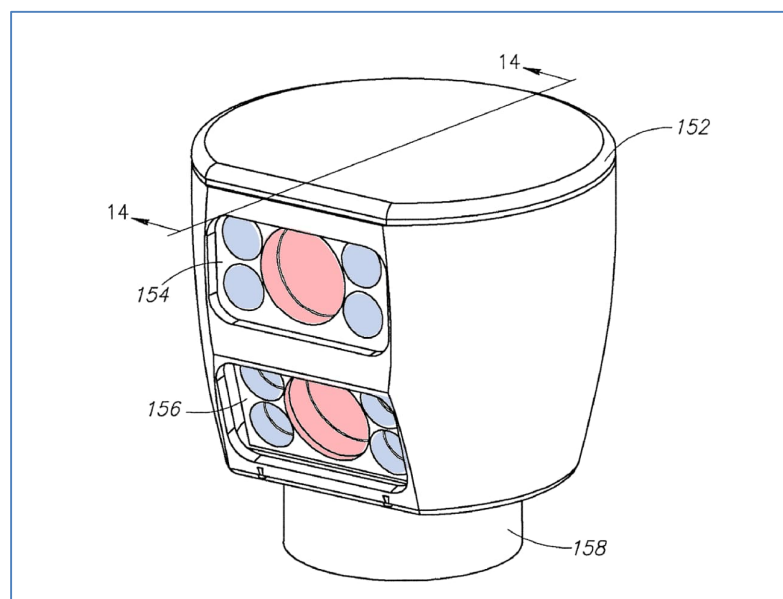
IX. OVERVIEW OF THE PRIOR ART

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

A. U.S. Patent No. 7,969,558 (“Hall”)

69. Hall is titled “*High Definition LiDAR System.*” EX1004. The reference was filed on July 13, 2007 and issued on June 28, 2011. *Id.*

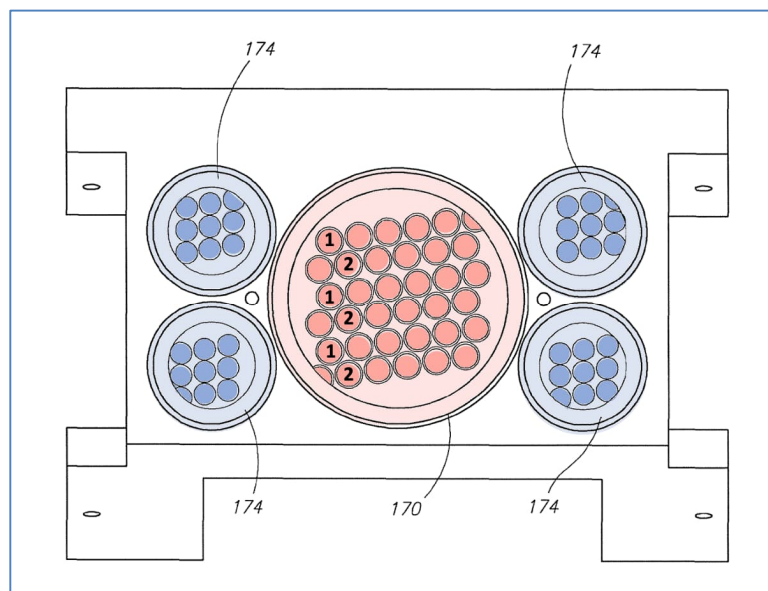
70. Hall is directed to a “lidar-based 3-D point cloud measuring system and method.” EX1004, Abstract. Hall proposes a LiDAR device that mounts multiple emitters and detectors in a housing that rotates around a stationary base. *Id.*, 6:42-63. An embodiment of the device is illustrated in Figure 13 below, where the transmit section of the device is shown in blue, and the reception section of the device is shown in red:



EX1004, Fig. 13.

71. The device includes first and second LiDAR systems 154, 156 designed to capture different angles across the vertical field-of-view. *Id.*, 6:64-7:9. Each system includes a plurality of emitters positioned behind four outer transmit lenses, and a plurality of photodetectors positioned behind a receive lens. *Id.*, 6:64-7:17. The emitters and detectors are mounted in a housing 152 that rotates about a base 158 via an actuator such as a DC motor. *Id.*, 6:42-63.

72. Hall teaches that the emitters and detectors are arranged in columns, whereby each emitter/detector in a given column is horizontally and vertically offset from the emitters/detectors in other columns. *Id.*, Fig. 22. This is illustrated with in Figure 22 below, where each detector in the first column labeled “1” is horizontally and vertically offset from each detector in the second column labeled “2”:



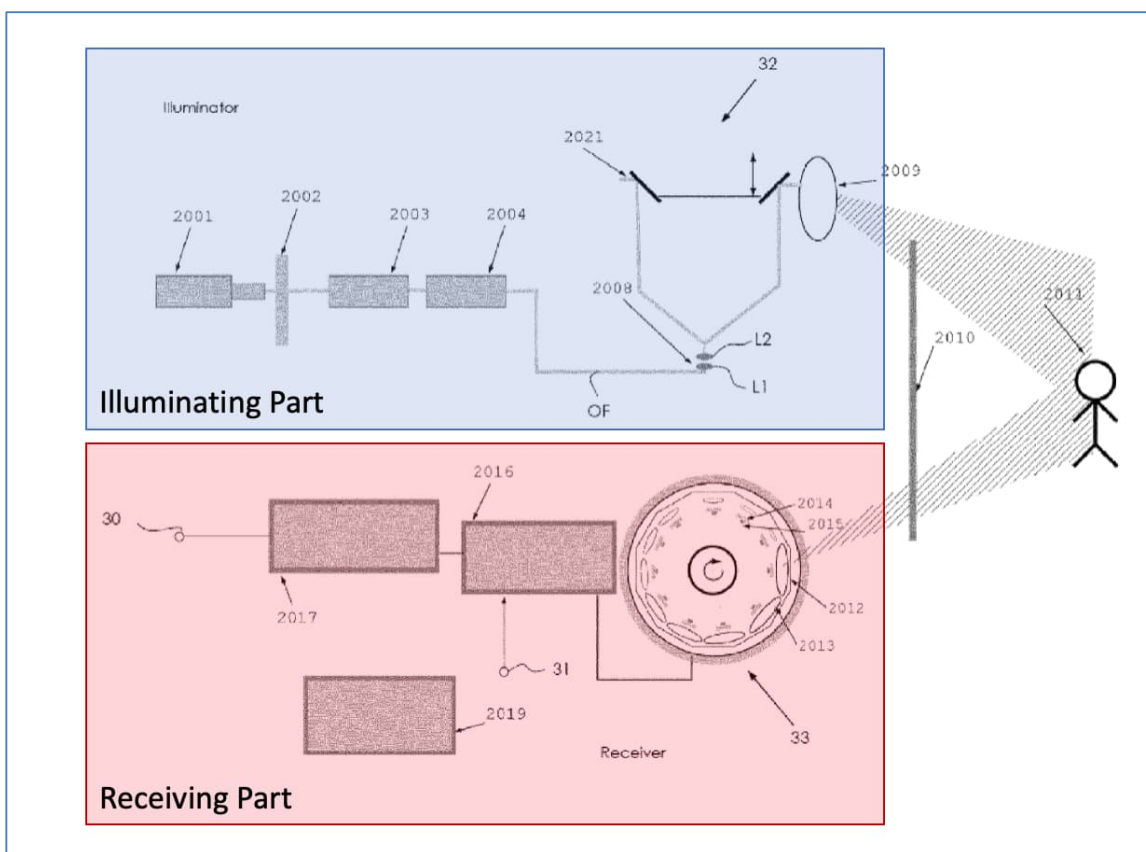
Id., Fig. 22.

73. A POSITA would recognize that the staggered arrangement allows each detector to trace a unique circular path as the device rotates through 360-degrees and thus achieve a wide horizontal and vertical field-of-view. *Id.*, 6:67-7:3, 7:14-17, 8:15-17. Hall explains that a device with the foregoing structure rotates at speeds of 200 RPM; provides a horizontal field-of-view of 360-degrees and a vertical field-of-view of 26.8 degrees with angular spacing between each emitter-detector pair of $1/3^\circ$; generates approximately one million time-of-flight measurements per second; and creates a dense three-dimensional point cloud for autonomous vehicle navigation. *Id.*, 4:3-13, 8:30-32.

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

74. Borowski is titled “*3D Landscape Real-Time Imager and Corresponding Imaging Methods.*” EX1005. Borowski was published on November 14, 2013.

75. Similar to Hall, Borowski is directed to a rotating 3D landscape imager that uses time-of-flight to obtain distance measurements. EX1005, [0001]-[0002], [0058]. The device includes an “illuminating part” to generate ultra-short laser pulses and distribute them into the surrounding environment, and a “receiving part” to detect returned photons. *Id.*, [0006]-[0007]. The illuminating part and receiving part are illustrated in Figure 2:



Id., Fig. 2.

76. The illuminating part includes one or more lasers emitting short pulses at the gigahertz frequency range. *Id.*, [0061]. The receiving part includes one or more SPAD arrays 2014 mounted on a rotating device 33. *Id.*, [0078]. Reading Borowski, a POSITA would recognize that a key focus is on its disclosure of the SPAD arrays, including their structure, operation, electronics and circuitry. *See generally id.*, [0040]-[0060], [0190]-[0192].

77. Borowski teaches that each “SPAD detector array is built onto a chip and includes mainly a detector part and a processing part.” *Id.*, [0079]. “The detector part comprises a set of SPAD detector cells which are arranged in a 2D

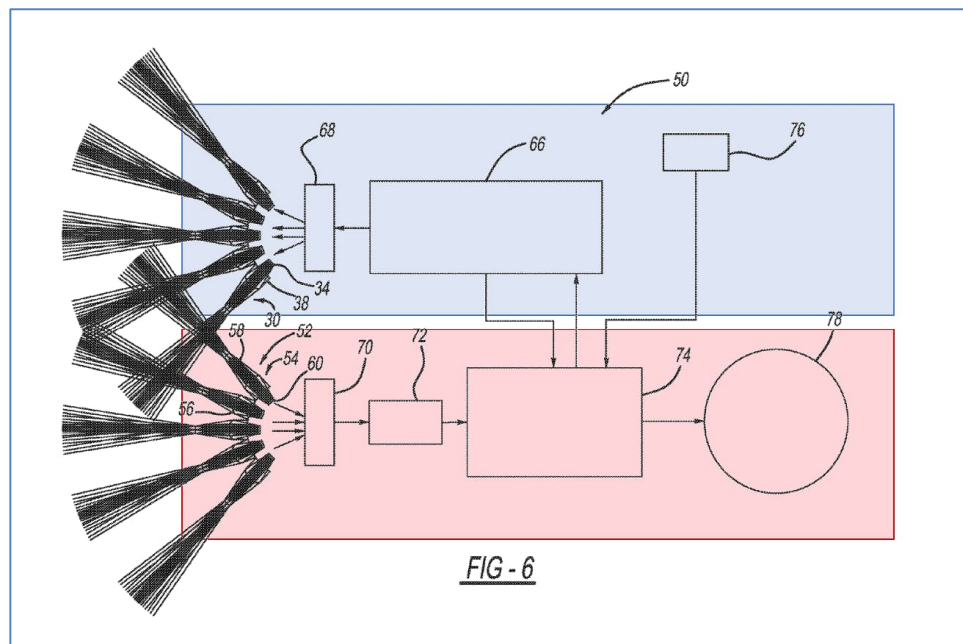
rectangular matrix.” *Id.* The electronics part includes time-to-digital converters (“TDC”) and digital-signal-processors (“DSP”) to process data at the level of an individual SPAD cell or “macro-cell.” *Id.*, [0050]-[0052]. The macro-cell refers to a cluster of individual SPAD cells that work together as a single pixel. *Id.* This provides the known benefit of multi-SPAD pixels: to allow for continuous and uninterrupted detection even if one or more of the SPAD cells is subject to dead time (*i.e.*, it is being quenched and reset). Indeed, Borowski explains that the macro-cell “acts as the equivalent of a single ‘perfect’ SPAD having no recovery time.” *Id.*, [0053], [0171], [0192].

78. In operation, the SPAD detector arrays rotate in synchrony with emission of the illuminating beams to generate time-of-flight data for distance measurements. *Id.*, [0018], [0102]. After a corresponding laser fires, “at least one photon from the reflected laser pulse received by the optical mechanism avalanches at least one SPAD detector cell of at least one SPAD detector array.” *Id.*, [0102]. The device also includes a “rotation sensor” to provide “angular orientation” that is used to associate the distance measurement with a specific position in the horizontal field-of-view. *Id.*, [0191]. As a result, 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], [0192].

C. U.S. Patent No. 9,831,630 (“Lipson”)

79. Lipson is titled “*Low Cost Small Size LiDAR for Automotive.*” EX1006. The reference was filed on February 3, 2015.

80. Lipson describes a LiDAR sensor that uses a plurality of VCSEL arrays and SPAD detectors to achieve a wide field-of-view for autonomous vehicles. *Id.*, 1:15-26, 3:8-18, 7:12-15. A simplified view of the device is shown in Figure 6, with transmit section (blue) and receive section (red):



Id., Fig. 6.

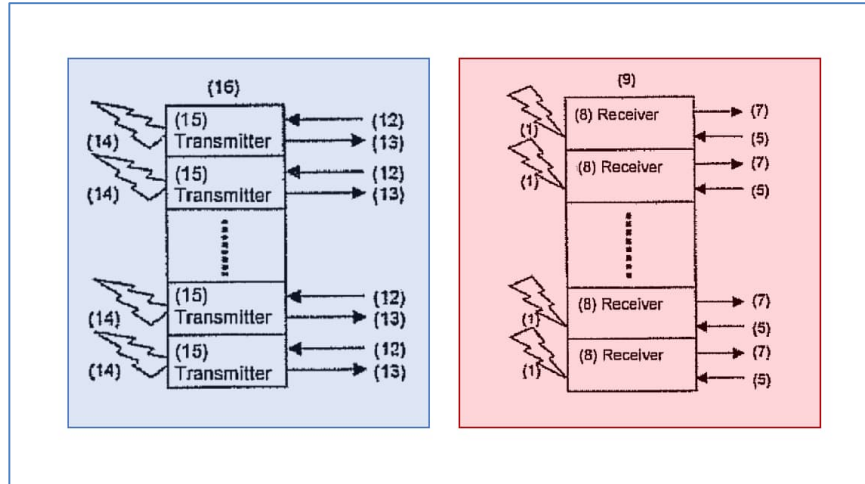
81. The transmit section includes laser arrays 34 that emit beams into the target environment. *Id.*, 6:24-29. The receive section includes receiver elements 54, each having a receiving lens 56 that receives optical beams from the target and focuses the beams on a detector 60. *Id.*, 6:1-7. Lipson teaches that the laser arrays

may use VCSELs, while the detectors may use SPADs. *Id.*, 6:61-7:15. Lipson further teaches the use of an optical filter to allow specific wavelength bands to pass through to the detectors while blocking unwanted background light. In particular, the receiver elements include a narrow bandpass filter positioned in front of the detectors to attenuate the unwanted wavelength ranges. *Id.*, 6:20-23 (“Typically, a narrow pass-band filter can be employed in front of the detector 60 to eliminate ambient light, such as from the sun, where the VCSEL array 34 has a unique wavelength....”). As I discuss in my analysis below, these types of filters were well known in the art as a tool to improve the signal-to-noise (“SNR”) ratio in LiDAR devices and other optical systems.

D. U.S. Patent No. 7,787,105 (“Hipp”)

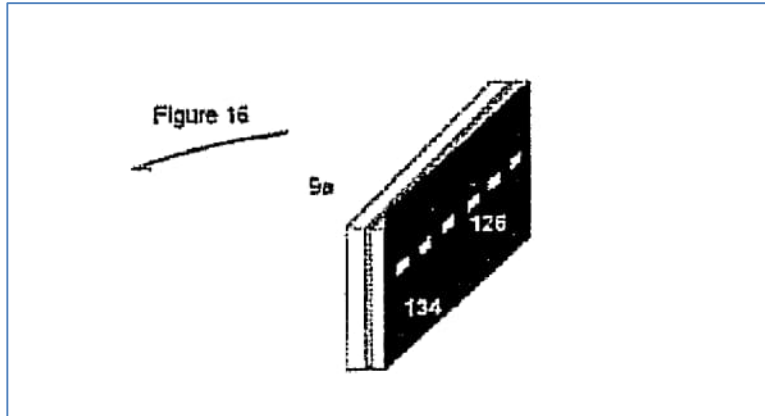
82. Hipp is titled “*Taking Distance Images.*” Hipp was filed on September 13, 2007, and issued on August 31, 2010. EX1007.

83. Hipp teaches a laser scanning device that uses pulsed time-of-flight to take distance measurements. *Id.*, 1:27-37. The goal of Hipp is to improve the speed of taking distance measurements over existing 2D and 3D devices. *Id.*, 4:27-33. The device includes a transmit section (annotated in blue) with an array of laser diodes and a receive section (annotated in red) with an array of APDs:



Id., Figs. 3, 6, 11:63-65, 12:16-22.

84. In one embodiment, the device includes sixteen lasers with sixty-four APD detectors. *Id.*, 19:43-48. In another, there is a one-to-one correspondence of lasers and APDs. *Id.*, 21:23-28. Hipp recognizes that a well-known problem for densely packed emitter and detector arrays is signal interference. *Id.*, 21:46-56 (“electrical interference pulses arise which superimpose themselves with the desired signals with is a basic problem of the array technique.”). To address that concern, Hipp teaches a “shadow mask ... designed such that only that light is transmitted which would also be incident on the active zones of the APDs.” *Id.*, 21:57-67. The shadow mask 134 is shown in Figure 16, and includes small holes that allow light to pass through to an intended detector:



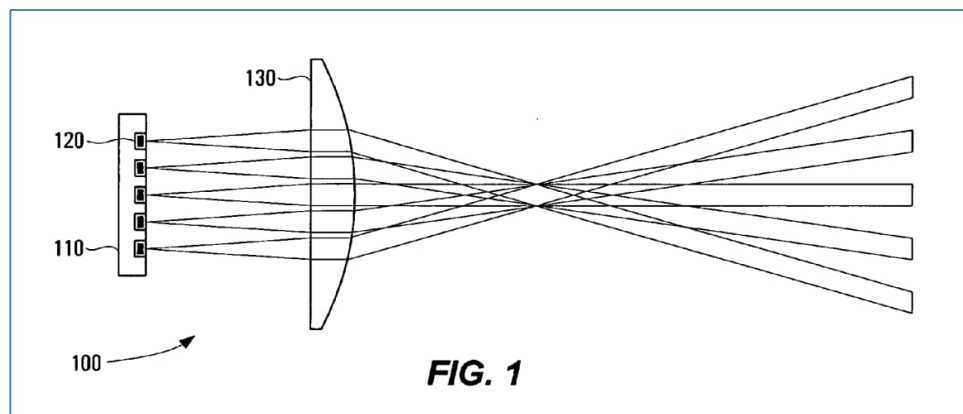
Id., Fig. 16.

85. Hipp teaches that the shadow mask “is attached directly to the APD array,” and “[t]he remaining light can be avoided in that the shadow mask is mirror coated superficially, with it thus being achieved that the unwanted light does not enter into the region of the active zones at all or in that the shadow mask is printed onto the cover plate of the APD array or onto an APD with impermeable material.” *Id.*, 21:60-67. Hipp also recognizes that “some of the light which passes through the holes of the shadow mask could be reflected by the APD” and “backscattered” in a manner that causes interference with other APDs. *Id.*, 22:1-7. To prevent this, Hipp uses light-absorptive material on the underside of the shadow mask. *Id.*, 22:7-10. That material will absorb the backscattered light and prevent it from reaching the detectors.

E. U.S. Patent No. 7,544,945 (“Tan”)

86. Tan is titled “*Vertical Cavity Surface Emitting Laser (VCSEL) Array Laser Scanner.*” EX1008. Tan was filed on February 6, 2006, and issued on June 9, 2009. *Id.*

87. Tan discloses vehicle-based lidar systems that use multiple lasers to provide more compact and cost-effective lidar functionality. *Id.*, Abstract. As illustrated in Figure 1, the system includes a semiconductor laser array 110 and optics 130 to focus light into the external environment for the purpose of detecting objects. *Id.*, 3:1-11. The system also includes a plurality of photodetectors placed in proximity to the laser array 110 to collect light reflected off objects in the external environment:



Id., Fig. 1, 3:22-28.

88. A POSITA would have recognized that a key design aspect of Tan’s LiDAR device is the use of VCSEL emitters, which I discussed above in the technology background section. *Id.*, 4:51-56. Tan explains: “Although any type of

semiconductor laser can generally be used to implement lasers 120 and laser array 110, vertical cavity surface-emitting lasers (VCSELs) are particularly useful for the disclosed lidar applications because they have a small angular divergence and emit light normal to the surface of the wafer in which they are fabricated.” *Id.* Tan goes on to describe various benefits associated with VCSEL emitters, including tight spacing, high-speed activation, improved alignment, and ease of manufacturing—all of which are advantageous for LiDAR devices. *Id.*, 4:51-5:21. Again, I discussed these benefits in the Technology Background section above. In my opinion, the teachings of Tan reflect the known benefits of VCSELs that would be familiar to a POSITA long before the effective priority date of the ‘236 Patent.

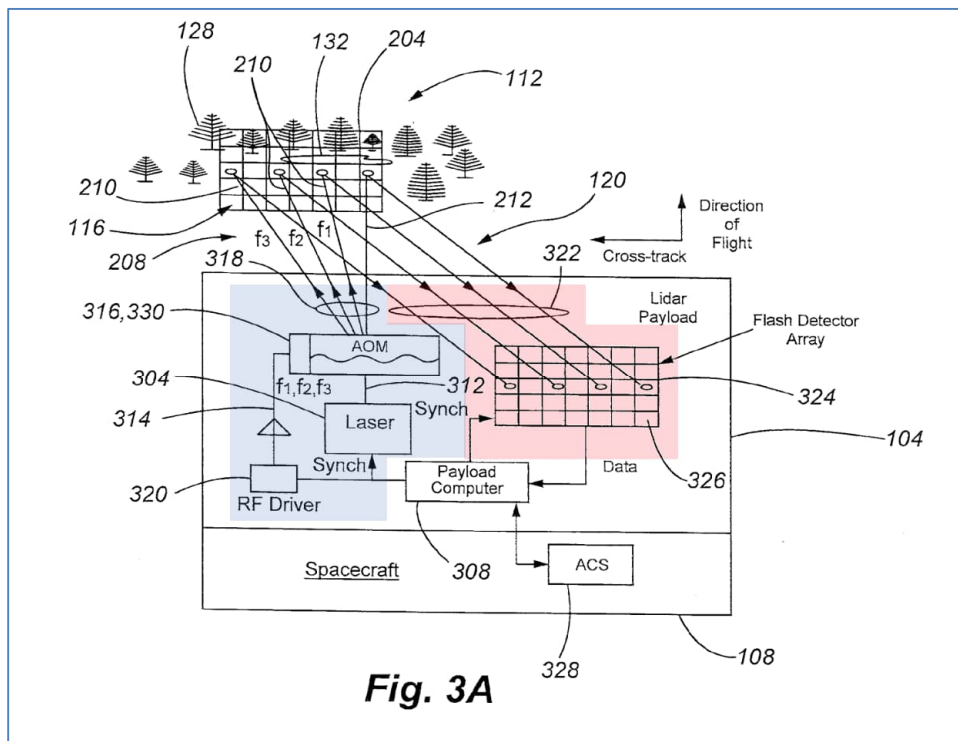
F. U.S. Patent No. 8,736,818 (“Weimer”)

89. Weimer is titled “*Electronically steered flash LIDAR.*” EX1029. Weimer was issued on May 27, 2014.

90. Weimer is directed to vehicle-based LiDAR devices and teaches the use of precise alignment between emitters and detectors in such devices. *Id.*, Figs. 1A-D, 4:4-6. Specifically, Weimer notes that a particular challenge is the ability to illuminate large scenes at long distances. *Id.*, 1:36-46. Weimer explains that: “Large fields of view per detector are not desirable because a wide field of view results in the acceptance of more background light than a narrower field of view, reducing the signal to noise ratio.” *Id.*, 1:53-56. Thus, “the goal for good daytime

performance has been to have the laser spot size only slightly smaller than the receiver's instantaneous field of view.” *Id.*, 1:56-59. To achieve that goal, Weimer teaches controlling the emission pattern of individual laser beams to match the field of view of a corresponding detector. *Id.*, 4:56-58.

91. An example embodiment is shown in Figure 3A. It includes a transmit section (annotated in blue) with a multi-beam laser output 208 passed through a bulk optic 318, and a receiver section (annotated in red) with a multi-pixel detector array 324 and a bulk optic 322:



Id., Fig. 3A, 10:17-45.

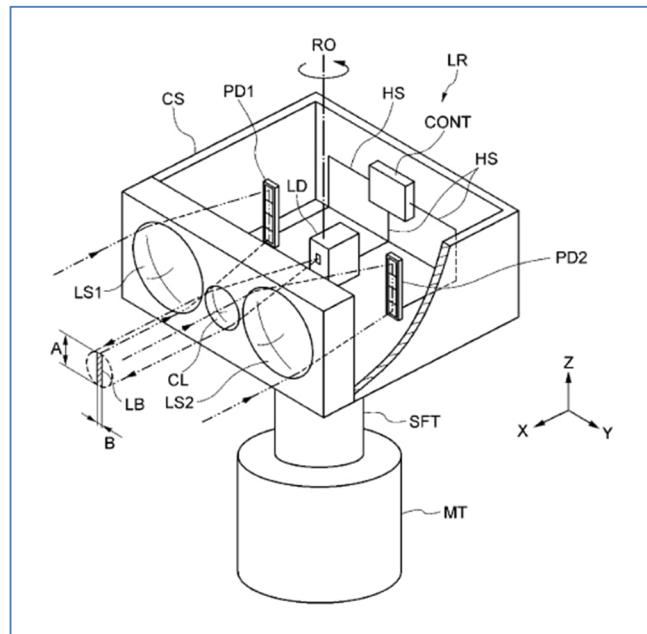
92. Consistent with other references like Tan and Lipson, Weimer explains that the illumination source may include a VCSEL array. *Id.*, 9:32, 11:39-

41. And Weimer teaches that “individual beams 208 can be directed to cover an area corresponding to a single pixel of the detector,” as shown in Figure 3A above. *Id.*, 4:56-58.

G. WIPO Pub. No. WO2017/110573 (“Matsui”)

93. Matsui is titled “*Light Projection/Reception Unit and Radar.*” EX1031. It was published June 29, 2017 and claims priority to a Japanese application filed December 24, 2015.⁴

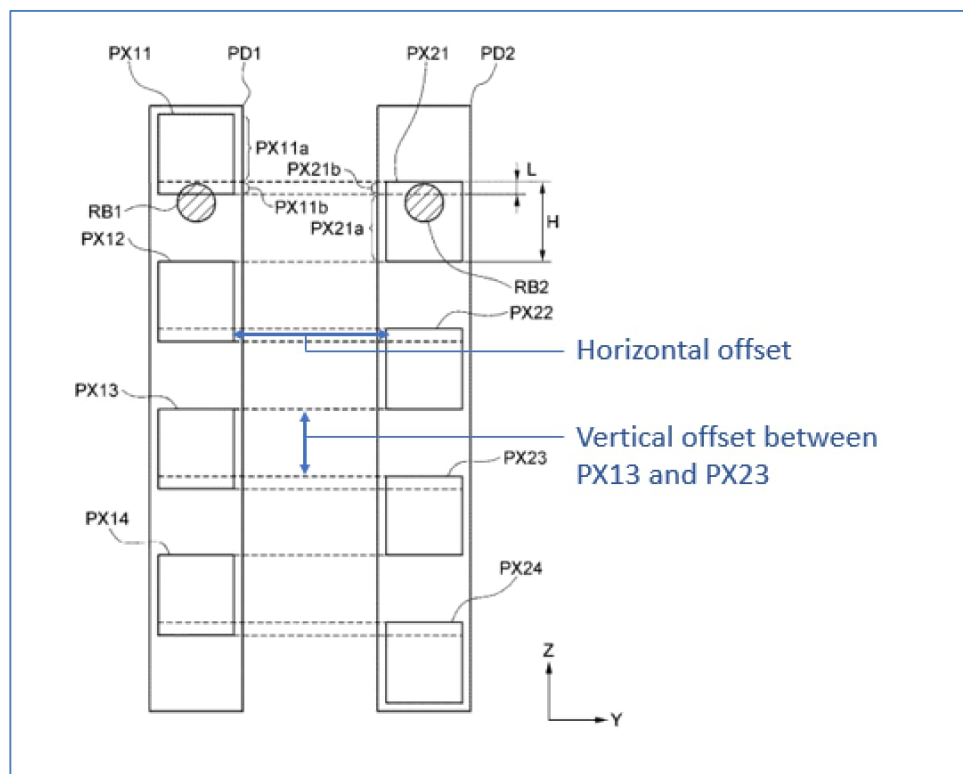
94. Matsui discloses a laser-radar device (LR) that includes a housing (referred to as casing (CS)) mounted on the rotary shaft (SFT) of a motor (MT):



⁴ EX1031 is an English translation of Matsui’s International PCT Publication, and EX1032 is an English translation of the underlying Japanese Patent Application No. 2015-251136. In my opinion, the two documents are substantively identical in terms of their figures, specification, and claims and both are cited herein to support my analysis.

EX1031/EX1032, Fig. 2.

95. The casing (CS) includes a semiconductor laser (LD) that emits pulsed laser light through a collimating lens (CL). *Id.* [0016]. The casing also includes first and second light-receiving parts (PD1, PD2) positioned behind light-receiving lenses (LS1, LS2). *Id.* [0019], [0036]. Matsui teaches that the light-receiving parts can be arranged in columns of pixels (PX11, PX12, etc.), with pixels in the first column (PD1) horizontally and vertically offset from pixels in the second column (PD2):



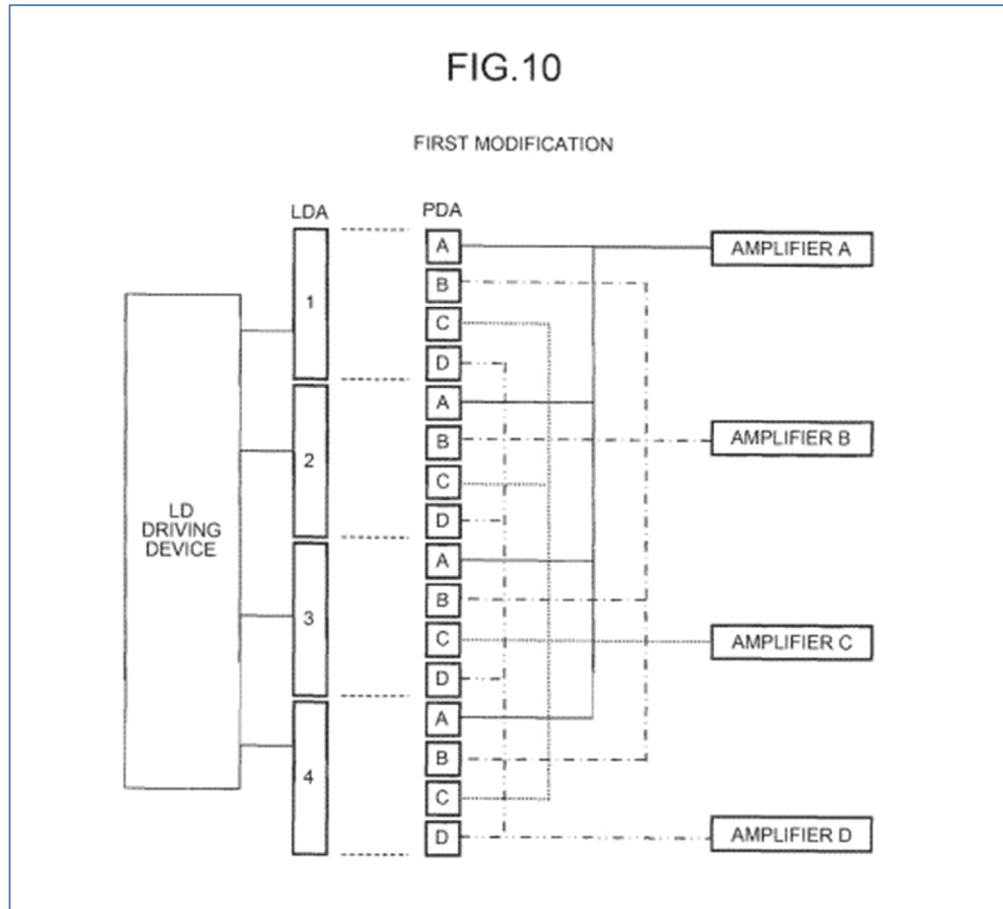
EX1031/EX1032, Fig. 14.

96. Matsui explains—and a POSITA would recognize—that the offset pixels “achieve high resolution and reduce detection failure” by eliminating “non-detection regions” of the device. *Id.*, [0029]-[0030].

H. U.S. Patent No. 10,114,110 (“Imai”)

97. Imai is titled “*Object Detecting Device, Sensing Device, and Mobile Object Device.*” EX1033. Imai was filed on March 14, 2015 and issued October 30, 2018.

98. Imai discloses a laser radar for measuring the distance to objects in the field. EX1033, 2:42-48, Fig. 1. The system includes a laser diode array (LDA) with a plurality of laser diode (LDs), each of which may include a VCSEL. *Id.*, 2:48-55, 3:5-12, 14:44-54. The system also includes a photodiode array (PDA) with a plurality of photodiodes (PDs), each of which may include a single-photon avalanche diode (SPAD). *Id.*, 6:24-28, 5:1-8. Imai describes different arrangements for the LDA and PDA. *Id.*, Figs. 7-11. In Figure 7, for example, sixteen PDs detect light emitted from a single LD. *Id.*, 7:10-20. Imai explains that using a single LD in this example is non-ideal because “the light quantity per one PD is small ... so that detection distance is forced to be shorter.” *Id.* To overcome that concern, the embodiment of Figure 10 includes four LDs (LD1-4), each of which corresponds to four PDs (PD1-16):



Id., Fig. 10, 10:17-20.

99. In this embodiment, “it is possible to efficiently irradiate the light receivable range, so that a light reception quantity in the light receivable range may be increased and detection accuracy and a detection distance may be improved.”

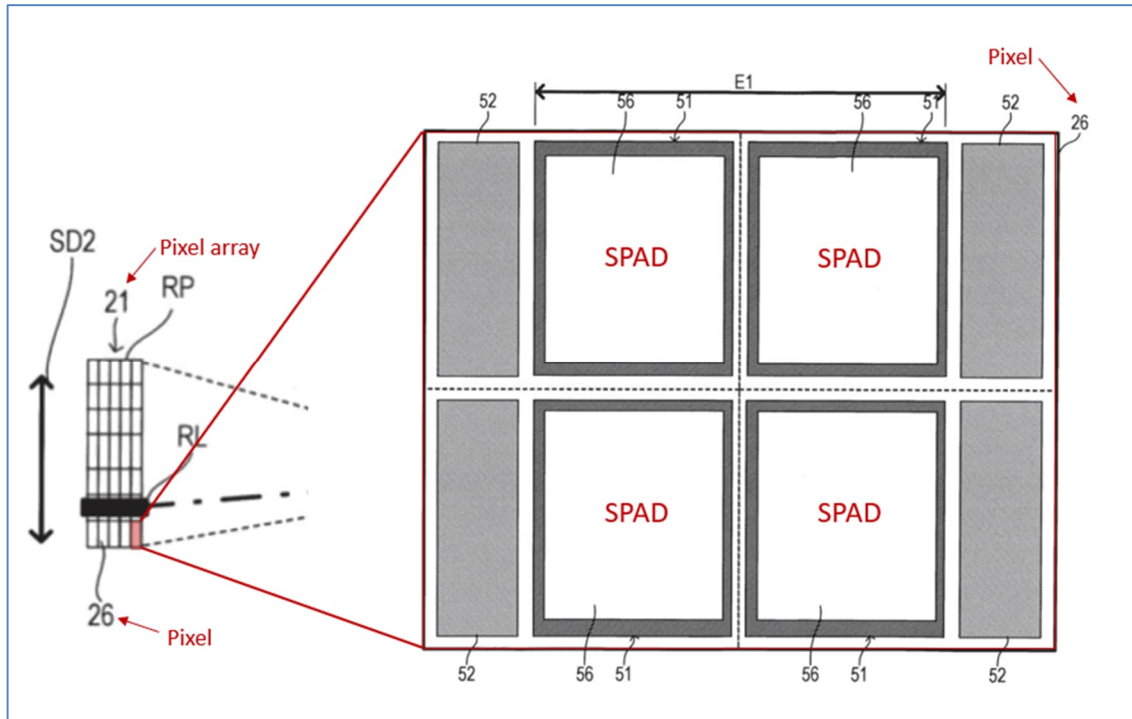
Id., 10:23-26.

**I. Japanese Patent Application Publication No. 2015-78953
 (“Higashi”)**

100. Higashi is titled “*Radar Device.*” EX1034. It was published on April 23, 2015.⁵

101. Higashi describes a vehicle-mounted laser-radar device that acquires distance measurements using time-of-flight. EX1034, [0002], [0015]. The device includes a semiconductor laser that emits light pulses into a scanning mirror that distributes the pulses into the surrounding environment. *Id.*, [0015]-[0017]. Light reflected off objects in the field returns to the device and is detected by a pixel array 21, which includes a plurality of pixels 26. *Id.*, [0018], [0024]. Each pixel, in turn, includes an array of light-receiving elements implemented as SPADs 51 with corresponding readout circuits 52. *Id.*, [0027]. This is shown in the portion of Figure 3 excerpted below to show its relationship with Figure 4:

⁵ EX1034 is an English translation of the Higashi patent application publication. The reference is referred to as “Higashi” in this declaration, which reflects the name change of the first lead inventor after the application issued as a patent.



Id., Figs. 3-4.

102. The pixel arrangement allows the device to “increase the number of times one pixel 26 is irradiated with the reflected light within a certain period of time [and] increase the number of detection results that can be accumulated for one pixel 26 within a certain period of time” to improve “detection accuracy.” *Id.*, [0068]. Higashi further teaches that “a bandpass filter corresponding to the wavelength of the pulsed laser light may be provided to eliminate the effect of background light.” *Id.*, [0086], [0006].

X. INVALIDITY ANALYSIS

103. In this section, I provide an analysis of how the prior art renders obvious claims 1, 2, and 7-27 of the ‘236 Patent. I have organized my analysis into

two groups of grounds: (1) Grounds 1A-G rely on the combination of Hall and Borowski, which is further combined with Lipson, Hipp, Tan, and Weimer; (2) Grounds 2A-D rely on the combination of Matsui and Imai, which is further combined with Higashi and Hipp. For each ground, I provide a summary of how the references would be combined, along with a discussion of motivation to combine and reasonable expectation of success. I also provide a limitation-by-limitation analysis of the claims subject to each ground. At the end of my analysis, I address secondary considerations.

A. Ground 1A: Hall and Borowski Render Obvious Claims 1, 7, 9-10, and 23

104. In my opinion, the combined teachings of Hall and Borowski render obvious claims 1, 7, 9-10, and 23 of the ‘236 Patent.

1. Combined Teachings of Hall and Borowski

105. As an initial matter, it is my opinion that Hall and Borowski are analogous art because they are in the same field of endeavor as the ‘236 Patent, which is generally directed to optical systems for distance measurement and more specifically LiDAR. EX1004, 1:11-31, 3:65-4:13; EX1005, [0001]-[0005], [0035], [0058]. Hall and Borowski are also pertinent to the problem addressed in the ‘236 Patent, which is to improve detection capability in such systems through the use of specific optical design features like emitter and detector arrays. *Id.* In light of

their disclosures, a POSITA would look to both Hall and Borowski when deciding how to improve a known time-of-flight optical system or LiDAR device.

106. In combining the teachings of Hall and Borowski, a POSITA would recognize that Hall describes the overall structure of a rotating LiDAR device, including transmit and receive modules, a plurality of emitters, and a plurality of pixels that are horizontally and vertically offset to trace unique circular paths as the device rotates. Borowski teaches the use of multi-SPAD pixels for improved detection capability in LiDAR devices. As detailed below, a POSITA would have been motivated to apply Borowski's multi-SPAD pixel teaching to the LiDAR device of Hall, which would improve its detection accuracy through a more sensitive sensor technology. A POSITA also would have had a reasonable expectation of success in achieving the claimed subject matter because incorporating SPADs into a LiDAR device was well-known and predictable, and because Borowski teaches precisely how to incorporate its SPAD arrays into a known LiDAR device.

107. **First**, a known benefit of SPADs—which was known years before the earliest priority date—was excellent detection sensitivity. EX1018, 8 (“SPADs have a very high sensitivity, with the ability to detect single photons”); EX1017, 4. The ability to detect individual photons with high sensitivity would have been particularly beneficial to a LiDAR device like Hall, which has a wide horizontal

and vertical field-of-view, and is designed for long-range detection in all weather conditions. These factors would impact the number of photons returned to the device; for example, a given object may need to be detected and classified with only a few photon returns. Using SPAD detectors in place of Hall's traditional APDs would have increased sensitivity and thus improved the ability of the device to detect objects in the field, without having to increase the number of lasers or their intensity and power consumption.

108. **Second**, another known benefit of SPADs was their ability to be grouped in an array or pixel. EX1018, 8 ("SPADs ... can be easily incorporated into an array since their operating voltage is low."); EX1009, [0049]-[0050], [0138]-[0139]. As detailed in the Technology Background, the array concept was beneficial because each individual SPAD will have a "dead time" during which it is quenched and reset. By grouping multiple SPADs together, one could design an array or pixel that would continue to register detections, even if one of the SPADs is subject to "dead time." Borowski recognizes this advantage through its teaching of a multi-SPAD pixel (*i.e.*, the macro-pixel discussed above) that can be filtered and averaged such that it "acts as the equivalent of a single 'perfect' SPAD having no recovery time." EX1005, [0053]. When applying the teachings of Borowski to Hall, a POSITA would have been motivated to replace each of Hall's traditional APDs with a multi-SPAD pixel as taught by Borowski to modernize Hall's device

and take advantage of SPAD technology that had matured in the years following Hall's initial concept.

109. **Third**, another known benefit of SPADs was their fast detection speed and data output. EX1010, 1:19-26, 1:42-52 (“The ability to produce arrays of photodiodes and read them out at high data rates is important for ... LADAR”). In this regard, Borowski expressly teaches that its multi-SPAD arrays allow photons to be “efficiently detected” in a “ultrafast” manner. EX1005, [0022], [0053], [0190]-[0193]. This benefit would have further motivated a POSITA to use multi-SPAD pixels in place of Hall's traditional APDs, because faster detection and data output would have produced a higher-resolution point cloud—an express goal of Hall. EX1004, 2:35-49. In this regard, a POSITA in 2016 would have considered the digital operation and output of SPAD arrays to provide a significant advantage for a device like Hall, which relied on traditional analog APDs common in 2007. Again, the use of SPADs in this regard would modernize Hall's device and take advantage of improvements that became ubiquitous in the years after its release.

110. **Fourth**, additional known benefits of SPADs were compactness, low-power consumption, and ease of integration with circuitry. EX1010, 1:42-52, 3:66-4:4; EX1018, 7-8. In my opinion, these benefits would have further motivated a POSITA to use multi-SPAD pixels in Hall's LiDAR device to reduce cost while improving performance. Reducing cost was an important consideration

for LiDAR design, particularly to make the devices suitable for scaled autonomous vehicle applications. There would have been a significant motivation to look to cost-reducing features like SPAD arrays.

111. ***Fifth***, in my opinion a POSITA would have a reasonable expectation of success combining the multi-SPAD pixels of Borowski with the LiDAR device of Hall. Borowski teaches the electronics and associated circuitry necessary to integrate multi-SPAD arrays or pixels into a LiDAR device like Hall. The “SPAD detector array is built onto a chip and includes ... a detector part and a processing part.” EX1005, [0079]. “The detector part comprises a set of SPAD detector cells which are arranged in a 2D rectangular matrix having a high ratio of height to width.” *Id.* And the processing part includes TDCs local DSPs for each cell, data compressors, and a global DSP for the array. *Id.* Borowski also teaches a quenching circuit for each SPAD cell to reset it after a detection event. *Id.* [0036], [0051].

112. It would have been predictable for a POSITA to integrate Borowski’s SPAD arrays and associated electronics into Hall’s LiDAR device. In particular, a POSITA would have understood that APDs like those disclosed in Hall were typically mounted on a printed circuit board (“PCB”) with wire traces that connect to electronics and external circuits (*e.g.*, power supply). The same type of PCB could be used to mount the chips containing Borowski’s SPAD array and

associated electronics and connect them to Hall's power supply. The resulting device would process the digital output of Borowski's SPAD cells so the data could then be used to compute time-of-flight measurements and point clouds.

113. In this regard, Borowski teaches exactly how data from the SPAD arrays is processed. Detection events are timestamped and used to calculate time-of-flight distance measurements. EX1005, [0095]-[0106], [0190]. Local DSPs associate each distance measurement with an angular orientation of the device. *Id.*, [0191]. The data is filtered and averaged at the level of the macro-cell. *Id.*, [0192]. And the data may be combined to generate a 3D representation of the surrounding environment. *Id.*, [0043], [0106]. Borowski teaches further optimizations—such as blanking—to improve detection capability. *Id.*, [0052]. In view of these teachings, a POSITA would have a clear and predictable understanding of how Borowski's SPAD arrays would collect and process data when integrated into the structure of Hall.

114. The predictable nature of the combination is confirmed by evidence showing that the operation of SPAD arrays—and their application to LiDAR sensors—was well-understood at the time of the alleged priority date. References like Matsubara, Marino, Albert, Grzesik, and Borowski detail the structure, electronics, and circuitry associated with SPAD arrays and their integration into LiDAR systems, making the art as a whole predictable to a POSITA.

115. **Finally**, in my opinion, a POSITA would have understood that minor differences between Hall and Borowski—such as operating wavelength—amount to routine design choices that do not render the combination any less predictable. For example, Borowski teaches examples where the SPAD arrays are used with lasers having an operating wavelength at 1500-nm. EX1005, [0190]. A POSITA would have understood that the SPAD arrays could be selected to detect and process light at other wavelengths, including 905-nm as disclosed in an embodiment of Hall, without changing their principle of operation. EX1039, [0031] (disclosing different wavelengths for LiDAR sensors). Both wavelengths were commonly used for LiDAR applications and were known to be safe for the human eye. Alternatively, a POSITA would have found it obvious to use 1500-nm emitters in the combined structure. For example, Tan teaches VCSEL emitters for LiDAR applications can be “fabricated to emit light at various different wavelengths” including “in the approximately 1-1.5 μm range” which is “useful for lidar implementations because various wavelengths in that range have certain atmospheric transmission advantages, *e.g.*, low absorption.” EX1008, 5:12-15. These advantages would have motivated a POSITA to further adapt Hall to use VCSEL emitters, which clearly would have been compatible with Borowski. Likewise, a POSITA would have understood that the SPAD arrays in Borowski would operate in the same manner regardless of whether they receive light that was

distributed into the surrounding environment via a rotating mirror (as disclosed in embodiments of Borowski) or a rotating housing (as disclosed in Hall). In both cases, light is reflected off objects in the field and received as the SPAD cells as returned photons.

2. Application to the Challenged Claims

a) Claim 1

116. In my opinion, the combination of Hall and Borowski teaches the limitations of claim 1. The table below provides my analysis on a limitation-by-limitation basis, with relevant citations to the teachings of Hall and Borowski.

[1a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Hall teaches limitation 1(a). Hall teaches a “lidar-based 3-D point cloud measuring system and method.” EX1004, Abstract. The system “can collect approximately 1 million time of flight (TOF) distance points per second.” <i>Id.</i> , 4:9-11.
[1b] an optical imaging transmit module comprising a bulk transmitting optic and an illumination source comprising a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical emitter in the plurality of optical emitters can project light at a nominal wavelength	Hall teaches limitation 1(b). The device 150 includes first and second LiDAR systems 154 and 156, as illustrated in Figures 13-14:

through the bulk transmitting optic and into a field ahead of the optical system;

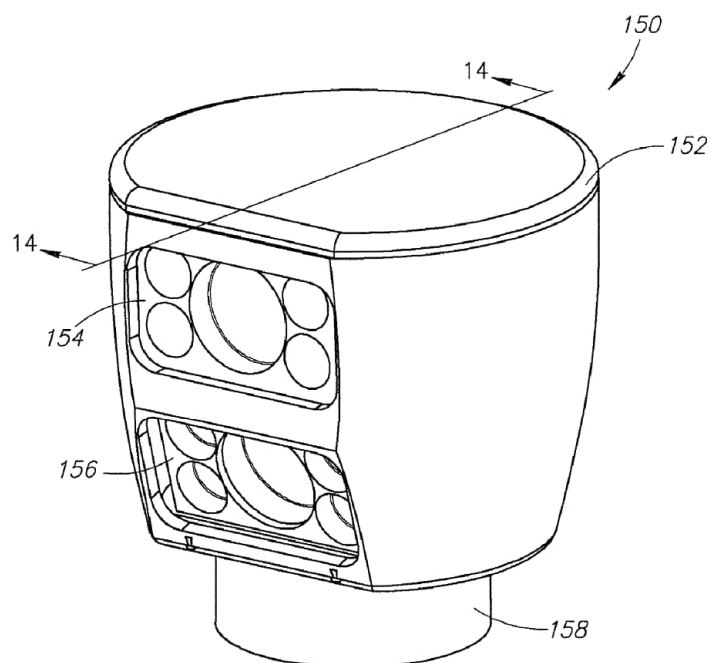
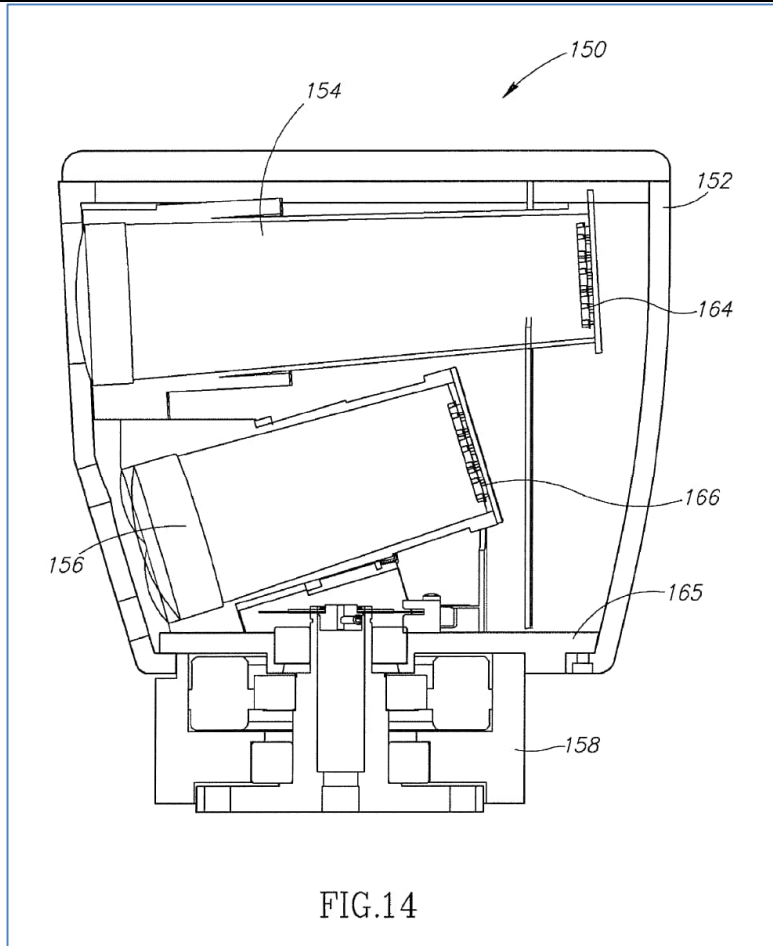
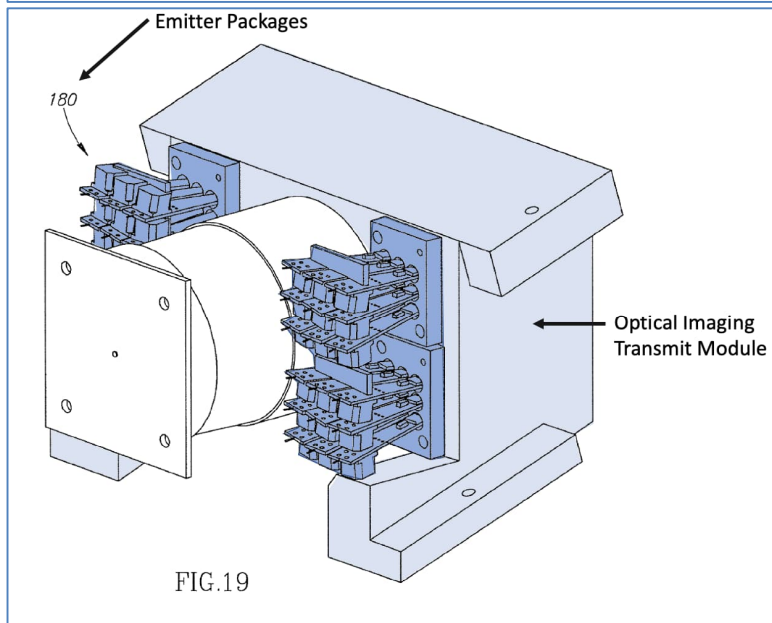
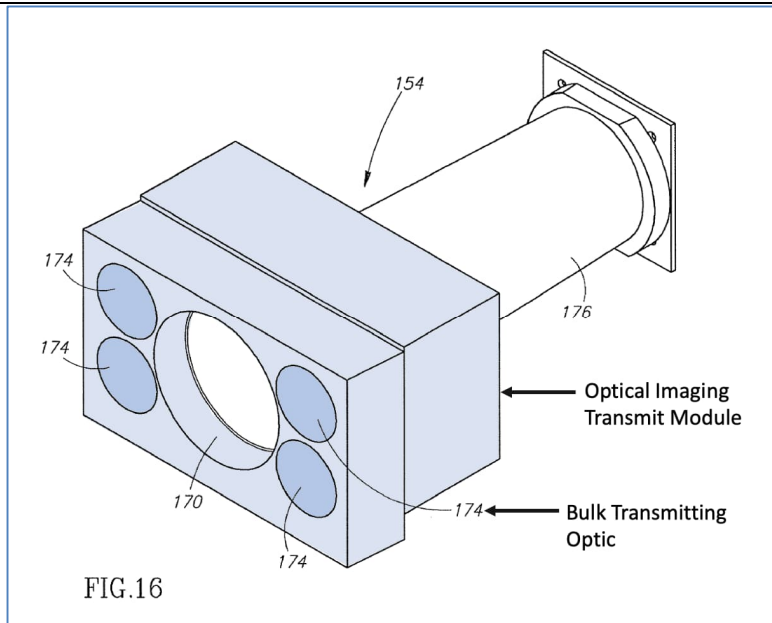


FIG.13



EX1004, Figs. 13-14, 6:43-49, 2:55-67, 7:5-8.

The first LiDAR system 154 includes four cavities 174, each with a lens positioned in front of emitter packages 180. *Id.*, 6:64-7:17. Each emitter package includes a plurality of emitters 188. *Id.* Figures 16 and 19 illustrate the structure of the cavities 174, their lenses, and corresponding emitter packages 180:



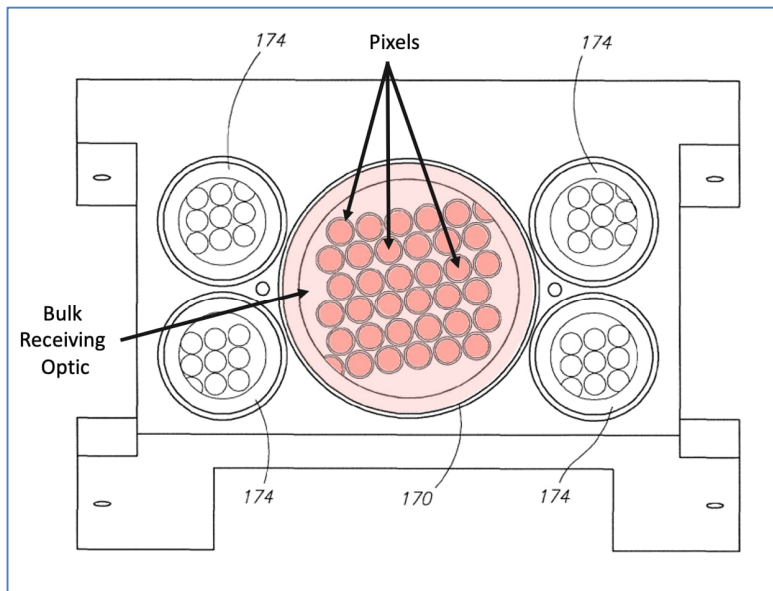
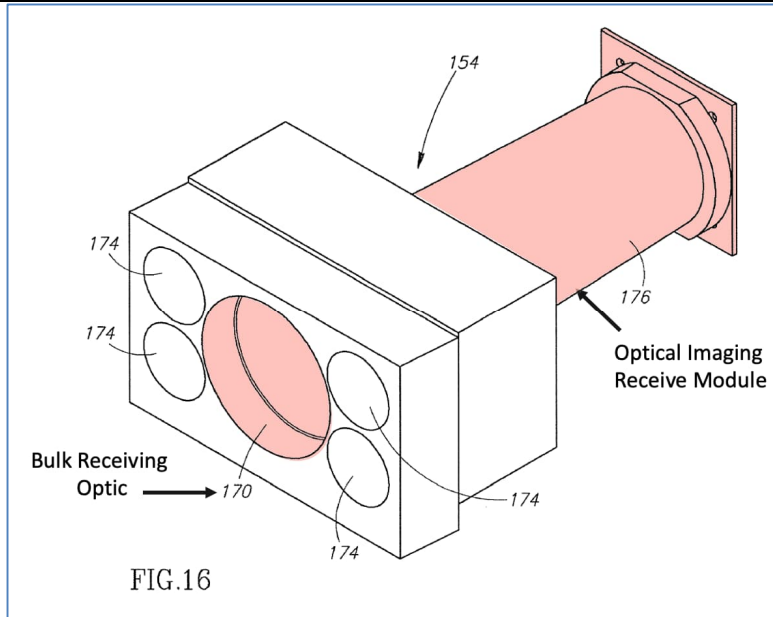
Id., Figs. 16, 19.

I note that Figure 19 represents a back view of the second LiDAR system 156; however, it reflects the manner in which the emitter packages are mounted in the first LiDAR system 154. EX1004, 7:5-14.

A POSITA would have understood that the emitter cavities and packages form an optical imaging transmit

	module, which is a structure to generate and transmit laser pulses. A POSITA would have also understood that the lenses positioned in cavities 174 comprise a bulk transmitting optic because they collect light from a plurality of emitters and pass it to the surrounding environment. This is the same structure as the embodiments of the bulk transmitting optic in the ‘236 Patent. EX1001, Fig. 1. A POSITA would have understood that the emitter packages 180 are an illumination source comprising a plurality of optical emitters 188 arranged behind the bulk transmitting optic. EX1004, Figs. 19, 22. And each emitter projects light at a nominal wavelength the bulk optic and into a field ahead of the optical system. <i>Id.</i>, 5:5-7, 8:52-54. Hall provides an example nominal wavelength of 905-nm, which was a well-known choice for LiDAR applications because of its eye-safety and absorption characteristics.
[1c] an optical imaging receive module comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged	In my opinion, Hall and Borowski teach limitation 1(c). Hall teaches that the first LiDAR system 154 includes a cavity 170 with a detector lens positioned in front of a plurality of detectors mounted in tube 176. EX1004, 6:64-7:9. Figures 16 and 22 illustrate the structure:

in a second column horizontally and vertically offset from the first column; and

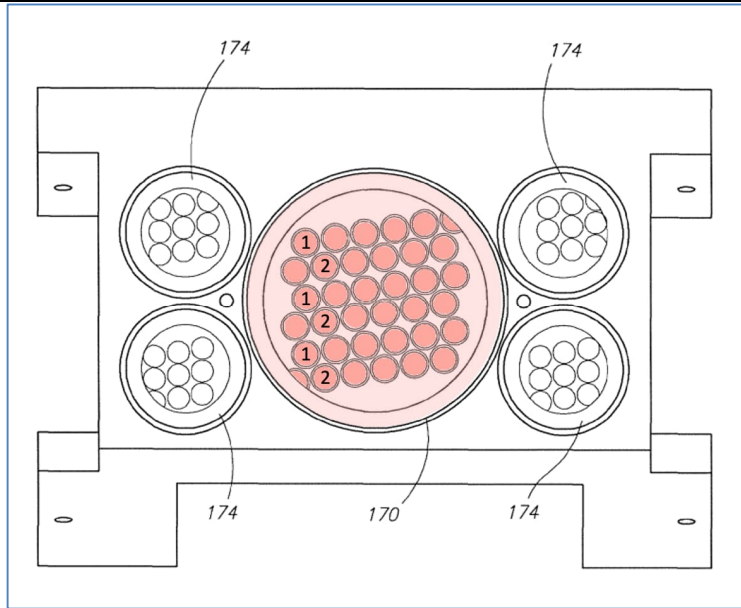


Id., Figs. 16, 22.

In my opinion, a POSITA would have understood that the cavity 170, lens, and tube 176 form an optical imaging receive module, which is a combined structure to detect photons returning to the device. Again, this is the same general structure as disclosed in embodiments of the '236 Patent.

A POSITA would have also understood that the lens

	positioned in cavity 170 is a bulk receiving optic because it collects light from the surrounding environment and focuses it on a plurality of detectors in the same manner as the bulk receiving optic in the '236 Patent. EX1001, Fig. 1. In my opinion, a POSITA would have understood that each detector is a pixel because it collects incident light for a specific location in the array. EX1004, 5:5-7, Fig. 22. In this regard, the array can be thought of as providing an image composed of multiple pixels. Each detector represents a pixel in the array. This is the same operation and configuration of the pixels in the '236 Patent, which in fact explains that a pixel may comprise a single detector. EX1001, 5:50-53, Fig. 2. In my opinion, Hall further teaches the pixels are arranged in columns, including a first set defining a first column and a second set defining a second column that is horizontally and vertically offset from the first column. EX1004, Fig. 22. The arrangement is shown in Figure 22, with the second set of pixels (annotated as "2") horizontally and vertically offset from the first set of pixels (annotated as "1"):
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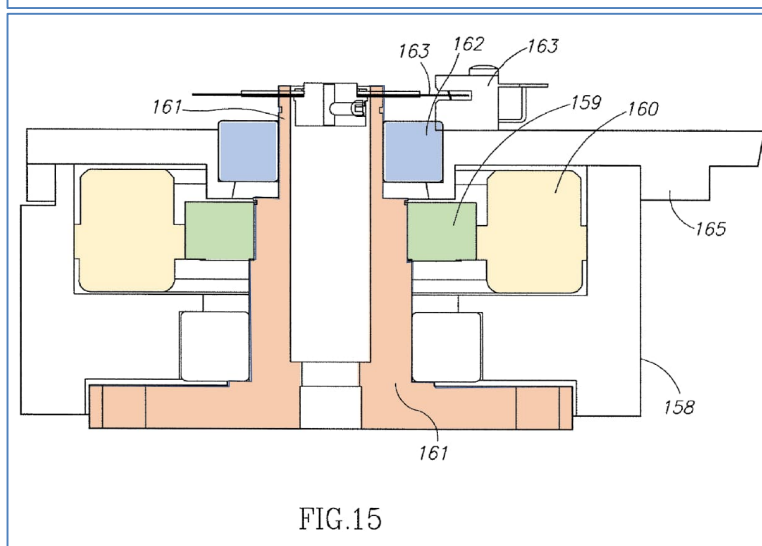
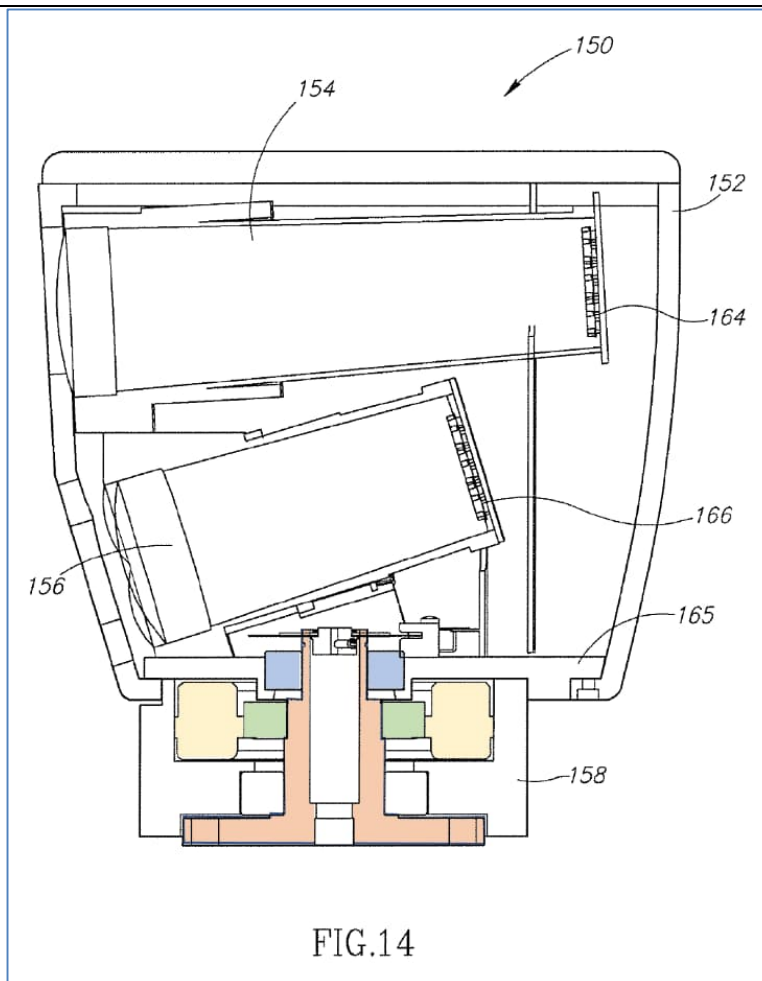
Id.

In my opinion, Figure 22 informs a POSITA of the particular offset arrangement of pixels that Hall selected for its device. Rather than showing the pixels in a uniform grid—which a POSITA would understand is wasteful because the pixels in a given row would all trace the same path and therefore capture the same data leading to poor resolution—Figure 22 illustrates a staggered relationship where each pixel traces a unique path as the device rotates. The design ensures maximum density of the resulting point cloud without any wasted detections. This is also the same type of “skewed grid” design described in the ‘236 Patent. EX1001, Fig. 2.

To the extent Ouster contends Hall does not disclose horizontal and vertical offset pixels, it is my opinion that a POSITA would have found it obvious to arrange the pixels in this manner. Hall teaches the desire to achieve a high resolution, with sixty-four emitter-detector pairs and an angular separation of $1/3^\circ$. To achieve that goal, a POSITA would have organized the emitters and detectors in arrays with an offset arrangement as was well known in the art. The staggered array design would allow for more emitter-detector pairs without compromising the height of

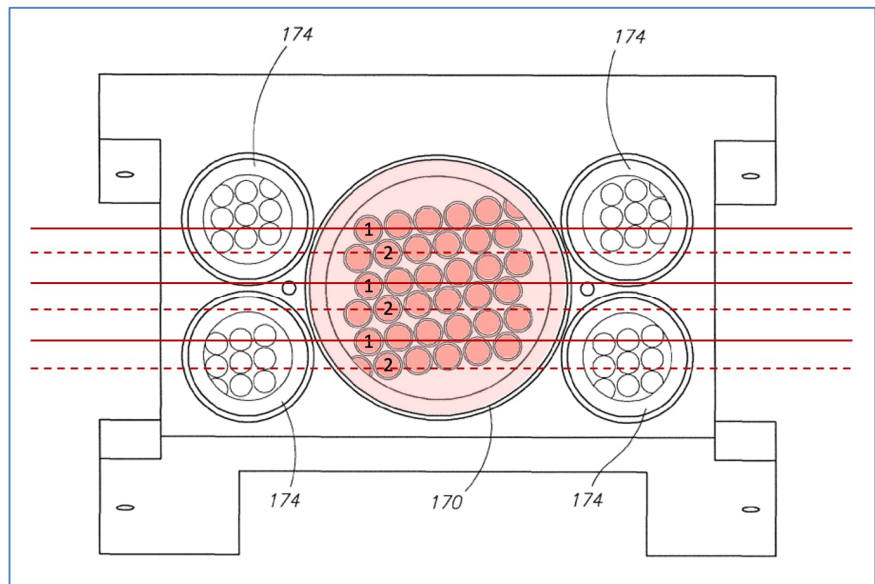
	the device. The offset arrangement would also allow for tight angular separation of each emitter-detector pair without any two pairs tracing the same path, which would be wasteful. Both design features—and their benefits for LiDAR devices—were well known in the art and the figures in Hall confirm that its device was designed to implement them as shown in Figure 22. Indeed, as discussed in Section V.B.2 above, the known benefits of using an offset arrangement were the avoidance of wasted emissions and allowing for a more compact design (as compared to a single linear arrangement of emitter-detector pairs). These design principles would have motivated a POSITA to implement Hall’s LiDAR with an offset arrangement A POSITA would have recognized that Hall does not expressly teach that each pixel includes a plurality of SPADs. EX1004, 5:5-7. In my opinion, however, it would have been obvious for a POSITA to modify Hall to include this limitation in view of Borowski as detailed above. Borowski teaches a laser scanning device with a plurality of photodetectors on a rotating mount, where each photodetector includes an array of SPAD detector cells. EX1005, [0040], [0078]. Each “SPAD detector array is built onto a chip and includes mainly a detector part and a processing part.” <i>Id.</i>, [0079]. “The detector part comprises a set of SPAD detector cells which are arranged in a 2D rectangular matrix” and “[t]he detection voltage which appears at the output of the respective SPAD corresponds to an event which is detected and then timestamped to measure the time of flight...” <i>Id.</i>, [0079]. Borowski advantageously teaches that a group of SPAD cells in an array may be formed into “macro cells,” each of which includes a cluster of “several SPAD detector cells.” <i>Id.</i>, [0053]. Each macro-cell is programmed such that it “acts as the equivalent of a single ‘perfect’ SPAD,” such that time-of-flight operations can be computed at the level of the macro-cell. <i>Id.</i>, [0051]-[0053], [0092].
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	A POSITA would have been motivated to apply that teaching and benefit to Hall as discussed above. And he or she would have understood that when the teachings of Borowski are applied to Hall, the resulting device would implement each of Hall's pixels as a plurality of pixels in a manner that meets limitation 1(c).
[1d] an actuator operable to rotate the optical imaging receive module about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the optical imaging receive module is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system;	In my opinion, Hall teaches limitation 1(d). The LiDAR device is mounted on a rotating platform driven by an actuator that rotates the optical imaging receive module about a vertical axis through 360-degrees. EX1004, 5:39-40 ("A simple DC motor controller driving a high reliability brushed motor controls the rotation of the emitter/detectors."), 8:30-32. The motor components are shown in Figures 14 and 15, including a rotary coupling 161, bearing 162, rotor 159 and stator 160:



Id., Figs. 14-15, 6:50-63.

In my opinion, a POSITA would have understood that as the device rotates, each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system. These distinct paths are illustrated in the annotated version of Figure 22 below, which shows the path each pixel in the first and second columns traverses in operation. The path of pixels in the first column is shown with solid lines, and the path of pixels in the second column is shown with dashed lines:



EX1004, Fig. 22.

To the extent Ouster contends Hall does not disclose each pixel tracing a unique circular path as the device rotates, it is my opinion that Hall renders the limitation obvious as discussed with respect to limitation 1(c). That is, a POSITA would have found it obvious to position pixels in the array to trace unique paths in order to achieve the tight angular spacing described in Hall and avoid wasted emissions.

[1e] wherein the optical system generates, for each of a

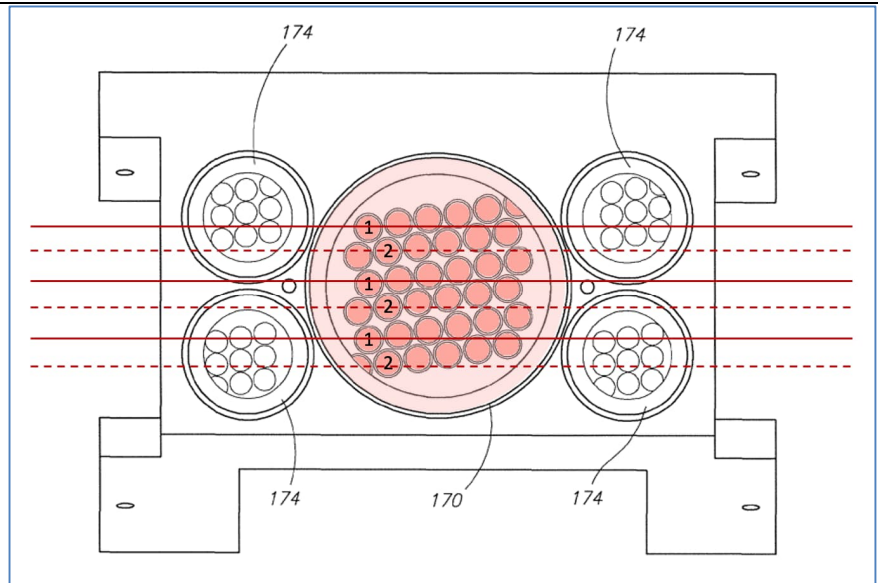
In my opinion, Hall teaches limitation 1(e). Hall explains that the LiDAR device rotates at 200 RPM, which corresponds to a scan cycle of approximately 0.33

plurality of arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system.	seconds. EX1004, 4:9-14, 8:65-67. Hall also explains the device collects about 1 million distance measurements per second, or 300,000 measurements per scan cycle. <i>Id.</i> The device rotates through a 360-degree horizontal FOV and includes a rotary encoder to determine the rotational position of the device as measurements are taken. <i>Id.</i>, 5:11-15, 5:39-44. These disclosures confirm that the device has a 360-degree scan cycle, and takes measurements at specific angular intervals (<i>i.e.</i>, arcuate sampling positions) within that cycle. <i>Id.</i> The rotary encoder then helps correlate each distance measurement with a particular sampling position and thereby create a dense 3D point cloud. <i>Id.</i> Indeed, a POSITA would have understood that this is the very purpose of a rotary encoder: to provide precise arcuate positions so that a given distance measurement can be associated with a distance measurement; otherwise, the 3-D point cloud cannot be accurately computed.
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b) *Claim 7*

117. In my opinion, the combination of Hall and Borowski teaches claim 7 as detailed below.

[7] The optical system of claim 1 wherein the circular paths traversed by pixels from the second set of pixels in the second column are interleaved with the circular paths traversed by pixels from the first set of pixels in the first column.	In my opinion, Hall teaches that the pixels in the second column are interleaved with the pixels in the first column. EX1004, Fig. 22. In my opinion, a POSITA would have understood that when the device rotates, the pixels in the second column will traverse paths that are interleaved with the paths traversed by pixels in the first column, which is illustrated in the annotated version of Figure 22 below:
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EX1004, Fig. 22.

The interleaving occurs because each pixel occupies a unique vertical position in the array. Thus, as the array rotates about a vertical axis, each pixel has a path that is interleaved with the paths of surrounding pixels.

c) Claim 9

118. In my opinion, the combination of Hall and Borowski teaches claim 9 as detailed below.

[9] The optical system of claim 1 wherein the optical system implements time of flight techniques to determine distances from the optical system to external surfaces in the field.	As detailed above, the LiDAR device in Hall uses time-of-flight techniques to measure distances between the device and objects in the surrounding environment. EX1004, 1:11-18, 4:9-11 (“At this configuration, the system can collect approximately 1 million time of flight (TOF) distance points per second”), 4:47-49.
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d) Claim 10

119. In my opinion, the combination of Hall and Borowski teaches the limitations of claim 10.

[10a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Hall teaches limitation 10(a) for the same reasons discussed above with respect to limitation 1(a). <i>See</i> Section X.A.2(a) above regarding limitation 1(a).
[10b]: an output circuit comprising a bulk transmitting optic and an illumination source configured to output light at a nominal wavelength, the illumination source including a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical emitter can project an illuminating beam at the nominal wavelength through the bulk transmitting optic and into a field ahead of the optical system;	In my opinion, Hall teaches limitation 10(b) for the same reasons discussed above with respect to limitation 1(b). A POSITA would recognize that the “output circuit” of claim 10 is synonymous with the “transmit module” of claim 1, which Hall discloses. <i>See</i> Section X.A.2(a) above regarding limitation 1(b).
[10c] an input circuit comprising a bulk receiving optic disposed adjacent to the bulk transmitting optic and a plurality of pixels arranged behind the bulk receiving optic, wherein	In my opinion, Hall and Borowski teach limitation 10(c) for the same reasons discussed above with respect to limitation 1(c). A POSITA would have recognized that the “input circuit” of claim 10 is synonymous with the “receive module” of claim 1, which Hall discloses as discussed above. <i>See</i> Section X.A.2(a) above regarding limitation 1(c).

each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and	Limitation 10(c) also requires “a bulk receiving optic disposed adjacent to the bulk transmitting optic.” In my opinion, Hall teaches this requirement. As shown in Fig. 16, Hall’s bulk receiving optic (lens in cavity 170) is disposed adjacent to bulk transmitting optic (lens in cavities 174). EX1004, Fig. 16.
[10d] an electric motor configured to rotate the input circuit about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the input circuit is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by each other pixel in the optical system;	In my opinion, Hall teaches limitation 10(d) for the same reasons discussed above with respect to limitation 1(d). Limitation 10(d) requires an “electric motor,” which Hall teaches as discussed above. See Section X.A.2(a) above regarding limitation 1(d).
[10e] wherein the optical system collects data from each pixel in the plurality of pixels at a plurality of different arcuate sampling position as the input circuit is rotated	In my opinion, Hall teach limitation 10(e) for the same reasons discussed above with respect to limitation 1(e). See Section X.A.2(a) above regarding limitation 1(e).

through 360 degrees during each scan cycle.	
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e) Claim 23

120. In my opinion, the combination of Hall and Borowski teaches the limitations of claim 23.

[23a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Hall teaches limitation 23(a) for the same reasons discussed above with respect to limitation 1(a). See Section X.A.2(a) above regarding limitation 1(a).
[23b] an optical imaging transmit module comprising a bulk transmitting optic and an illumination source comprising a plurality of optical emitters arranged behind the bulk transmitting optic, wherein the plurality of optical emitters project a plurality of beams of light at an operating wavelength through the bulk transmitting optic and into a field ahead of the optical system;	In my opinion, Hall teaches limitation 23(b) for the same reasons discussed above with respect to limitation 1(b). See Section X.A.2(a) above regarding limitation 1(b). I note that limitation 23(b) also requires that “the plurality of optical emitters project a plurality of beams of light at an operating wavelength,” which is not recited verbatim in limitation 1(b). In my opinion, Hall teaches this requirement, however, through its disclosure of a plurality of emitters that project beams at an operating wavelength of, for example, 905 nanometers. EX1004, 5:5-7, 8:52-54. I also note that in the context of the ‘236 Patent claims, a POSITA would consider the “operating wavelength” in claim 23 to have the same meaning as the “nominal wavelength” in claim 1. Both terms refer to the peak emission wavelength of the laser diode where it emits the maximum intensity of light.
[23c] an optical imaging receive module comprising a bulk receiving optic and a	In my opinion, Hall and Borowski teach limitation 23(c) for the same reasons discussed above with respect to limitation 1(c). See Section X.A.2(a) above regarding limitation 1(c).

plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and	
[23d] an actuator operable to rotate the optical imaging receive module about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the optical imaging receive module is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system;	In my opinion, Hall teaches limitation 23(d) for the same reasons discussed above with respect to limitation 1(d). See Section X.A.2(a) above regarding limitation 1(d).
[23e] wherein the optical system generates, for each of a plurality of	In my opinion, Hall teach limitation 23(e) for the same reasons discussed above with respect to limitation 1(e). See Section X.A.2(a) above regarding limitation 1(e).

arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system.	
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B. Ground 1B: Hall, Borowski, and Lipson Render Obvious Claims 2, 15, and 24

121. In my opinion, the combined teachings of Hall, Borowski, and Lipson render obvious claims 2, 15, and 24 of the ‘236 Patent.

1. Combined Teachings of Hall, Borowski, and Lipson

122. As an initial matter, like Hall and Borowski, Lipson is analogous art because it is in the same field of endeavor as the ‘236 Patent—optical systems for distance measurement—and pertinent to the problem of improving detection capability in such systems. EX1006, 1:15-26, 3:8-18, 7:12-15. Additionally, the combination of Hall, Borowski, and Lipson provides a number of benefits to the resulting LiDAR system, and a POSITA would have a reasonable expectation of success combining the references.

123. **First**, consistent with well-known design principles, a POSITA would have been motivated to use Lipson’s bandpass filter to improve the signal-to-noise ratio (“SNR”) of the Hall-Borowski LiDAR system. A POSITA would have understood that unwanted light, such as background light from the sun, may enter a

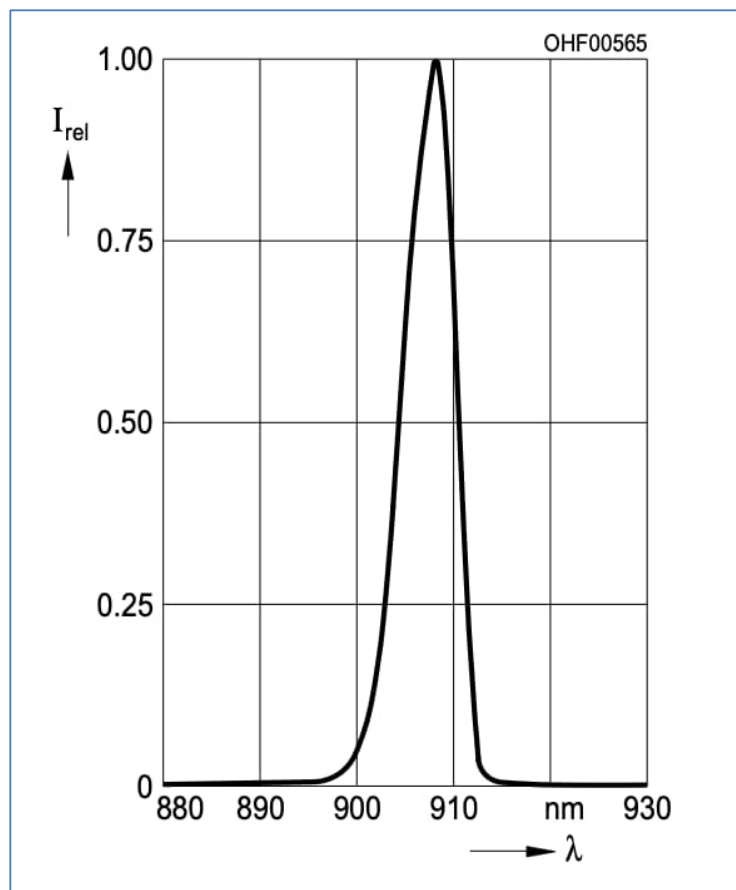
LiDAR device and cause interference or false detections by triggering detection events. Bandpass filters as described in Lipson were a well-known design technique to substantially block unwanted wavelengths, while allowing a desired band to pass through to the detectors, which improved SNR and detection accuracy, *i.e.*, reducing noise increases the signal-to-noise ratio.

124. **Second**, in my opinion, a POSITA would have recognized that the teachings of Lipson are complementary to the Hall-Borowski device. In this regard, a POSITA would recognize that Hall teaches a “filter to reject sunlight,” but does not detail the exact arrangement of the filter. EX1004, 4:18-20. The bandpass filter of Lipson, placed in front of SPAD detectors, would fulfill the design goal with a predictable design feature known to improve SNR. EX1006, 6:20-23, 6:61-7:15.

125. **Third**, in my opinion a POSITA also would have been motivated to position the bandpass filter between the SPAD array and bulk receiving optic to ensure maximum filtering of unwanted light and minimize the size of the filter (as it would correspond to the area of light focused on the detectors). This common design choice is reflected in Albert, which teaches a filter layer formed on the surface of a receiver comprising an array of SPAD detectors such that it is positioned between the array and a bulk lens. EX1009, [0138]-[0139], [0146], Fig. 8. A POSITA would have been motivated to use this known design technique to

easily and cost-effectively integrate the optical filter of Lipson into pixel array of Hall and Borowski and also to minimize the size of the filter by placing it in close proximity to the detectors on which light will be focused.

126. **Fourth**, a POSITA would have been motivated to select a narrowband filter centered on the operating wavelength of the emitters—*e.g.*, 905 nm for Hall. That is because the wavelength profile for a typical emitter has a peak emission at the operating wavelength and tapering intensity at values above and below. EX1026. This is shown in the image below, taken from a datasheet for a 905-nm laser diode manufactured by Osram:



Id.

127. A narrowband filter centered on the operating wavelength provided a margin of error for slightly off-peak emissions while still blocking non-desired bands. For this reason, designers selected narrowband filters centered on the operating wavelength of the optical system's emitters. This is described in the Rodrigo and Lorenzoni references, both of which teach the selection of optical filters centered on the wavelength of interest. EX1027 at [0017] (“‘narrow band’ is to be understood as the filter having a pass-band with a narrow frequency/spectral width, relative to the center frequency/wavelength”), [0019] (“the frequency width of the pass-band, Δf , is selected for a given lasing center wavelength”); EX1028, 7:37-41.

128. **Finally**, a POSITA would have had a reasonable expectation of success combining the teachings of Hall, Borowski, and Lipson, because the use and implementation of optical filters in LiDAR devices was widely known and highly predictable before the priority date. For example, Albert teaches vapor deposition of an optical filter over a SPAD array, and Retterath teaches integration of an optical filter into the layers of a semiconductor substrate. EX1009, [0146] EX1032, 12:57-66. Using these known techniques, a POSITA would have had a reasonable expectation of success implementing a narrow-band filter in a known LiDAR device.

2. Application to the Challenged Claims

a) *Claims 2 and 15*

129. In my opinion, the combination of Hall, Borowski, and Lipson teaches claims 2 and 15 as detailed below.

[2] The optical system of claim 1 further comprising an optical filter disposed in front of each pixel in the plurality of pixels and operable to allow a set of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the set of wavelengths of light from reaching the plurality of pixels. [15] The optical system of claim 10 further comprising and an optical filter disposed between the bulk receiving optic and the plurality of pixels and configured to allow a narrow band of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the narrow band.	In my opinion, Lipson teaches an optical filter positioned in front of each pixel to allow a narrow set of wavelengths, including that of the emitters, to pass through while blocking non-desirable wavelength bands. EX1006, 6:20-23. Applying this teaching to Hall and Borowski, a POSITA would have positioned the filter between each SPAD pixel and the bulk imaging optic to ensure the pixels receive only a desired band of wavelengths.
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b) *Claim 24*

130. In my opinion, the combination of Hall, Borowski, and Lipson teaches claim 24 as detailed below.

[24] The optical system of claim 23 wherein the optical system further comprises an optical bandpass filter disposed between the bulk transmitting optic and the plurality of pixels and having a center wavelength matched to the operating wavelength of the plurality of optical emitters.	In my opinion, Lipson teaches an optical bandpass filter positioned in front of SPAD pixels as discussed above for claim 2. EX1006, 6:20-23. I note that claim 24 requires the filter to be “disposed between the bulk <i>transmitting</i> optic and the plurality of pixels,” which is inconsistent with the specification and drawings of the ‘236 Patent, which show the filter placed between the <i>receiving</i> optic and pixels. EX1001, Fig. 1. In either case, it is my opinion that Lipson renders the claim requirement obvious because the filter is “employed in front of the detector 60” and therefore is positioned in an optical path between the pixels and the bulk optics. EX1006, 6:20-23. A POSITA would have been motivated to use the same placement in the combined device of Hall and Borowski, and to select a bandpass filter centered on the peak wavelength of Hall’s emitters as detailed in Sections X.B.1.
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C. Ground 1C: Hall, Borowski, and Hipp Render Obvious Claims 8 and 25

131. In my opinion, the combined teachings of Hall, Borowski, and Hipp render obvious claims 8 and 25 of the ‘236 Patent.

1. Combined Teachings of Hall, Borowski, and Hipp

132. As an initial matter, like Hall and Borowski, Hipp is analogous art because it is in the same field of endeavor as the ‘236 Patent—optical systems for

distance measurement—and pertinent to the problem of improving detection capability in such systems (e.g., minimizing interference). EX1007, 1:27-37, 4:27-33. Additionally, the combination of Hall, Borowski, and Hipp provides a number of benefits to the resulting LiDAR system, and a POSITA would have a reasonable expectation of success combining the references.

133. **First**, a POSITA would have had an express motivation to use Hipp’s shadow mask to improve SNR. Signal interference (a form of noise) was a well-known concern for multi-beam LiDAR devices, and Hipp’s shadow mask was designed specifically to address it. EX1007, 21:46-56. The shadow mask is designed “such that only that light is transmitted which would also be incident on the active zones of the APDs.” *Id.*, 21:57-60. And “remaining light can be avoided” such that “the unwanted light does not enter into the region of the active zones at all....” *Id.*, 21:60-67. By blocking this interference (noise), Hipp lowers the value of the “denominator” in the SNR, which provides a significant benefit to the overall system in the form of increased accuracy. For this reason, a POSITA would have been highly motivated to use a shadow mask or similar aperture layer in Hall and Borowski.

134. **Second**, Hipp’s shadow mask would complement the Hall-Borowski device. Hall relies on an array of pixels, while Hipp teaches a shadow mask designed to improve detection efficiency for multi-pixel sensors. EX1004, Fig. 22;

EX1007, 21:46-67. Indeed, both Hall and Hipp teach embodiments with sixty-four pixels. EX1004, 4:59-61; EX1007, 19:43-48. When looking to improve the detection accuracy of a multi-pixel array like Hall, a POSITA naturally would have looked to design features used in similar types of arrays, which is what Hipp teaches. In the same respect, Borowski aims to improve detection efficiency in a SPAD array that would benefit from blocking interference as taught by Hipp, whose shadow mask is designed for pixel arrays. EX1005, [0022].

135. **Third**, a POSITA would have had a reasonable expectation of success when combining the teachings of Hall, Borowski, and Hipp. The use of elements like Hipp's shadow mask would fall squarely within the level of skill of a POSITA, who would be familiar with optical design techniques, like the formation of lenses and apertures over detector arrays in order to narrow each detector's field of view and block unwanted light. In this regard, Hipp teaches that the shadow mask can be attached to the detector array, with apertures in the mask aligned with individual detectors. EX1007, 21:60-67, Fig. 16. Similar designs were well known in the art, including in Grzesik, which teaches a cross-talk absorption layer with apertures formed in a light-absorbing material. EX1010, 4:65-5:18; Fig. 3. In my opinion, a POSITA would have predictably used these types of known techniques to implement the shadow mask of Hipp in a known LiDAR device like Hall.

2. Application to the Challenged Claims

a) Claims 8 and 25

136. In my opinion, the combination of Hall, Borowski, and Hipp teaches claims 8 and 25 as detailed below.

[8] The optical system of claim 1 wherein the optical imaging receive module further comprises a plurality of apertures and a stop region disposed between adjacent apertures in the plurality of apertures, wherein the plurality of apertures includes a first aperture and a second aperture horizontally and vertically offset from the first aperture, the first set of pixels includes a first pixel disposed in a first optical path that extends through the first aperture and the second set of pixels includes a second pixel disposed in a second optical path that extends through the second aperture. [25] The optical system of claim 23 wherein the optical imaging receive module further comprises a plurality of	As detailed above, Hipp teaches a “shadow mask” comprising a plurality of apertures formed over pixels in a detector array, and a stop region formed between the apertures to block undesired light from entering the pixels and thereby define a field-of-view for each pixel. EX1007, 21:57-67, Fig. 16. In my opinion, a POSITA would have understood that when the teachings of Hipp are applied to Hall and Borowski, the resulting structure would include a plurality of pixels, each having a SPAD array, aperture, and stop region, with the offset arrangement disclosed in Hall. The first set of pixels would include a first pixel disposed in a first optical path that extends through the first aperture, and the second set of pixels would include a second pixel disposed in a second optical path that extends through the second aperture. A POSITA would have understood that this configuration would meet the requirements of claims 8 and 25.
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apertures and a stop region disposed between adjacent apertures in the plurality of apertures, wherein the plurality of apertures includes a first aperture and a second aperture horizontally and vertically offset from the first aperture, the first set of pixels includes a first pixel disposed in a first optical path that extends through the first aperture and the second set of pixels includes a second pixel disposed in a second optical path that extends through the second aperture.	
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D. Ground 1D: Hall, Borowski, and Tan Render Obvious Claims 26 and 27

137. In my opinion, the combined teachings of Hall, Borowski, and Tan render obvious claims 26 and 27 of the ‘236 Patent.

1. Combined Teachings of Hall, Borowski, and Tan

138. As an initial matter, like Hall and Borowski, Tan is analogous art because it is in the same field of endeavor as the ‘236 Patent—optical systems for distance measurement—and pertinent to the problem of improving performances and reducing costs in such systems. EX1008, Abstract, 1:25-62, 1:65-2:8, 3:1-35,

4:51-56. Additionally, the combination of Hall, Borowski, and Tan provides a number of benefits to the resulting LiDAR system, and a POSITA would have a reasonable expectation of success combining the references.

139. **First**, a POSITA would have recognized that Tan details numerous known benefits for the use of VCSEL emitters in LiDAR devices:

- “VCSELs[] are particularly useful for the disclosed lidar applications because they have a small angular divergence and emit light normal to the surface of the wafer in which they are fabricated.”
- “VCSELs ... allow for fabrication of integrated one-dimensional or two-dimensional laser arrays with close device spacing....”
- VCSELs “emit circularly symmetric Gaussian beams, as compared to highly eccentric elliptical beams of edge emitting lasers.”
- “VCSELs can be fabricated with relatively small active areas, they can be activated quickly, *e.g.*, on the order of picoseconds.”
- “The inherently integrated nature of VCSEL arrays provides additional opportunities to integrate optics.... This allows for simpler lidar device manufacturing and reduction in overall device complexity and cost.”

Id., 4:51-5:21.

140. These benefits were known more than a decade before the earliest priority date of the '236 Patent. And a POSITA would have understood that the benefits are directly applicable to a LiDAR device like Hall-Borowski—a point Tan makes throughout its disclosure. EX1008, 4:51-56, 5:12-15, 5:19-21.

141. **Second**, Tan's VCSEL array would further improve the operation of Hall and Borowski. As noted above, Hall describes an early LiDAR device for autonomous vehicles that employed traditional laser diodes. Incorporating the VCSEL emitters disclosed in Tan would allow Hall to maintain the same principle of operation, but with improved laser output that is faster and more accurate, thus furthering Hall's goal to generate dense 3D point clouds. The VCSELs of Tan are also complementary to Borowski because they operate at example wavelengths of 1-1.5 μm —which Borowski identifies as desirable for eye safety. *Id.*; EX1008, 5:12-15; EX1005, [0003].

142. **Third**, Tan's teaching of can be predictably applied to the Hall-Borowski LiDAR devices with reasonable expectation of success because VCSEL technology had been widely studied and integrated into LiDAR devices before the priority date. This is evident from Tan and other prior art references that identify VCSEL among the class of emitters suitable for automotive LiDAR. EX1008, 4:51-5:21, EX1034, 4:55-62.

143. **Finally**, a POSITA would have understood that techniques for integrating VCSELs into a LiDAR device were well-known and predictable. Tan teaches VCSELs fabricated in one-dimensional or two-dimensional arrays and integrated with optic elements in a single package. EX1008, 4:67-5:3, 5:16-19. These same designs could be used to integrate the VCSELs of Tan in place of Hall's traditional laser diodes, which would not only improve performance but also simplify the overall device by allowing the emitter arrays to be fabricated on a single printed circuit board rather than individual boards.

2. Application to the Challenged Claims

a) Claim 26

144. In my opinion, the combination of Hall, Borowski, and Tan teaches claim 26 as detailed below.

[26] The optical system of claim 23 wherein the illumination source comprises a plurality of vertical cavity surface emitting lasers (VCSELs).	Hall discloses the use of laser diodes as an illumination source for the disclosed LiDAR system, but does not expressly disclose VCSELs. EX1004, 5:5-7. Tan teaches a vehicle LiDAR system “using multiple lasers to provide more compact and cost-effective lidar functionality.” EX1008, Abstract. To achieve that goal, Tan uses VCSEL emitters, which are “particularly useful for the disclosed lidar applications because they have a small angular divergence and emit light normal to the surface of the wafer in which they are fabricated.” <i>Id.</i>, 4:51-56. In my opinion, a POSITA would have understood that in the combined structure, the VCSELs of Tan would be predictably used in place of the laser diodes of Hall to improve device performance and cost.
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b) Claim 27

145. In my opinion, the combination of Hall, Borowski, and Tan teaches claim 27 as detailed below.

[27] The optical system of claim 26 wherein the optical system implements time of flight techniques to determine distances from the optical system to external surfaces in the field.	In my opinion, Hall teaches time-of-flight techniques to measure distances between the device and objects in the external environment. EX1004, 1:11-18; 4:9-11; 4:47-49.
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E. Ground 1E: Hall, Borowski, and Weimer Render Obvious Claims 11-13, 16-17, and 22

146. In my opinion, the combined teachings of Hall, Borowski, and Weimer render obvious claims 11-13, 16-17, and 22 of the ‘236 Patent.

1. Combined Teachings of Hall, Borowski, and Weimer

147. As an initial matter, like Hall and Borowski, Weimer is analogous art because it is in the same field of endeavor as the ‘236 Patent—optical systems for distance measurement—and pertinent to the problem of improving the performance in such systems (*e.g.*, improving signal-to-noise ratio). EX1029, 15:49-60, 1:53-61, 4:56-58. Additionally, the combination of Hall, Borowski, and Weimer provides a number of benefits to the resulting LiDAR system, and a POSITA would have a reasonable expectation of success combining the references.

148. **First**, a POSITA would have had an express motivation to use Weimer's disclosed technique because it would improve the optical alignment and efficiency of the overall system. As Weimer explains: "Large fields of view per detector are not desirable because a wide field-of-view results in the acceptance of more background light than a narrower field-of-view, reducing the signal to noise ratio." EX1029, 1:53-56. By controlling the emission pattern of individual laser beams to match the field-of-view of a corresponding pixel, Weimer avoids background light and improves SNR. *Id.*, 1:56-61, 4:56-58. Again, as noted above, SNR is an important design characteristic in LiDAR devices, and therefore a POSITA would have been motivated to use techniques like Weimer to improve SNR. The Weimer design in particular would offer a significant benefit to the Hall-Borowski device, by allowing it to achieve a high-resolution point cloud with reduced interference.

149. **Second**, a POSITA would have recognized that Weimer's improved and efficient alignment technique is complementary to the Hall-Borowski device. Hall teaches a pixel array with a tight angular separation of $1/3^\circ$ to achieve high resolution in a LiDAR device. EX1004, 8:14-17. To implement this angular separation in a compact form factor, a POSITA would want to ensure precise alignment of emitters and detectors. Weimer teaches techniques to improve SNR in a pixel array, by matching the field-of-view of each pixel to the emission region

of a corresponding illumination beam in a manner that achieves this type of precise alignment. EX1029, 1:53-61, 4:56-58. This known benefit would have motivated a POSITA to use Weimer's technique in a device like Hall-Borowski.

150. **Third**, a POSITA would have had a reasonable expectation of success when combining the teachings of Hall, Borowski, and Weimer. Techniques to define the emission region of a laser and match it to the field-of-view of a corresponding pixel were well known in the art. As detailed in Ground 1C above, for example, Hipp teaches the use of a shadow mask with apertures to define the field-of-view for a corresponding pixel, which could be sized and shaped to the emission pattern of a given emitter. EX1007, 21:57-67. And Retterath teaches the use of collimating lenses, directional lenses, and angular waveguides to match the pattern and direction of an emitter with the field-of-view for a corresponding detector. EX1032, Figs 4-10, 8:36-50, 9:29-10:22. A POSITA would have had a reasonable expectation of success using these known techniques to implement the teachings of Weimer in a LiDAR device like Hall.

2. Application to the Challenged Claims

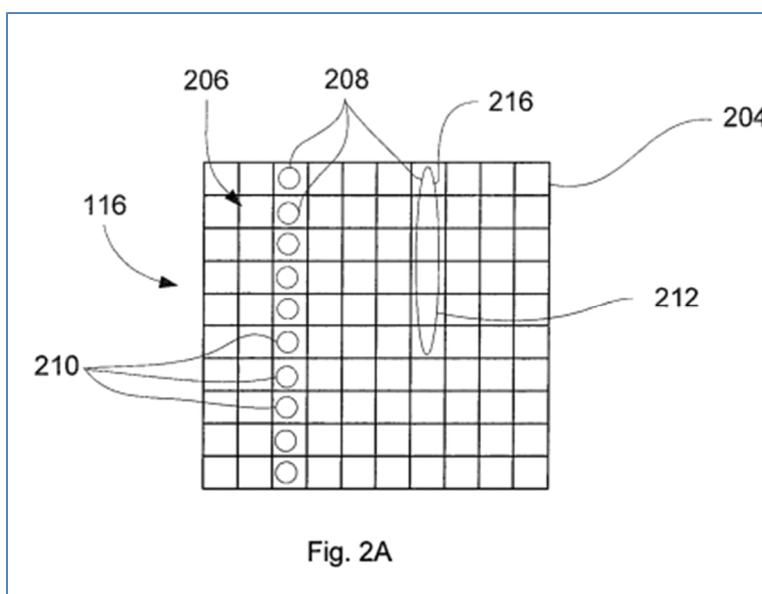
a) Claim 11

151. In my opinion, the combination of Hall, Borowski, and Weimer teaches claim 11 as detailed below.

[11] The optical system of claim 10 wherein	Hall teaches that each pixel has a non-overlapping field-of-view with all other pixels, defined by an angular
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each pixel in the plurality of pixels has a field of view that is non-overlapping with fields of view of all other pixels in the plurality of pixels, and the illumination source is configured to project illuminating beams into the field ahead of the optical system according to an illumination pattern where each beam in the illumination pattern is coincident with a field of view of one pixel in the plurality of pixels.

separation of $1/3^\circ$, but does not expressly state that the field-of-view for each pixel is coincident with the emission beam of a corresponding emitter. EX1004, 8:15-17. Weimer teaches an optical system comprising an illumination source 304 that projects a plurality of beams 208 into the field ahead. EX1029, Fig. 3A. Each beam has a discrete, non-overlapping emission region as shown in Figure 2A:



Id., Fig. 2A.

Weimer further teaches a pixel array 324, where each pixel 326 has a field-of-view that matches a corresponding beam 208 from the illumination source 304. *Id.*, Fig. 3A, 10:17-45. In this regard, Weimer teaches a “laser spot size only slightly smaller than the receivers instantaneous field-of-view” such that “individual beams 208 can be directed to cover an area corresponding to a single pixel of the detector.” *Id.*, 1:56-59, 4:56-58. Thus, each pixel field-of-view is coincident with the emission region of a corresponding illumination beam. *Id.* And the field-of-view for each pixel is non-overlapping with the fields-of-view for all other pixels. *Id.*

	Applying the teachings of Weimer to Hall and Borowski, a POSITA would have understood that the resulting device would include a plurality of pixels, each with a non-overlapping field-of-view and coincident alignment with a corresponding illumination beam.
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b) Claim 12

152. In my opinion, the combination of Hall, Borowski, and Weimer teaches claim 12 as detailed below.

[12] The optical system of claim 11 wherein each scan cycle includes a plurality of sampling periods and, during each sampling period in the plurality of sampling periods, the optical system activates each emitter in the plurality of optical emitters to project the illumination pattern and determines a number of SPADs in each pixel that recorded an incident photon since a previous sampling period.	Hall teaches a scan cycle that includes a plurality of sampling periods as discussed in Section X.A.2(a) with respect to limitation 1(e). Hall explains that each cycle includes 300,000 measurements; thus each sampling period involves firing each emitter in the plurality of emitters. EX1004, 5:40-42. Borowski likewise teaches a scan cycle comprising sampling periods at specific angular orientations, during which emitters in the device are fired and return pulses are measured by multi-SPAD pixels. EX1005, [0051]-[0053], [0102]-[0106], [0190]-[0192]. Borowski explains that each SPAD cell in a multi-SPAD pixel is measured and the outputs are added together to determine both an average value and intensity for the pixel. <i>Id.</i> This summing and averaging is performed to determine the pixel output while accounting for the potential dead time or non-detection at individual SPAD cells in the pixel. <i>Id.</i> When combined, a POSITA would have been motivated to use Borowski's processing technique to process photon returns from the laser firing sequence of Hall. The resulting Hall-Borowski-Weimer device would operate such that, for a given sampling period, each emitter is activated (as Hall teaches) and the number of SPADs in each pixel that record an incident photon
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	since the last period are determined (as Borowski teaches). This would ensure that the device generates highly accurate distance measurements at each sampling period and therefore provides a highly accurate overall 360-degree point cloud.
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c) Claim 13

153. In my opinion, the combination of Hall, Borowski, and Weimer teaches claim 13 as detailed below.

[13] The optical system of claim 12 wherein, during each sampling period of the plurality of sampling periods within one scan cycle, the optical system determines distances to objects in the field based on a difference between a time at which an optical emitter is fired and a time at which incident photons are detected at a pixel having a field of view that overlaps with a field of view of the fired optical emitter.	In my opinion, Hall and Borowski teach time-of-flight distance measurements for each sampling period within a cycle, where each measurement is based on a difference between the laser firing time and the pixel detection time. EX1004, 1:11-18, 4:9-11; EX1005, [0051]-[0053], [0102]-[0106]. Weimer teaches that each pixel has a field-of-view that overlaps with a field-of-view of the fired optical emitter. EX1029, 1:56-59, 4:56-58, Fig. 3A.
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d) Claim 16

154. In my opinion, the combination of Hall, Borowski, and Weimer teaches the limitations of claim 16.

[16a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Hall teaches limitation 16(a) for the same reasons discussed above with respect to limitation 1(a). <i>See</i> Section X.A.2(a) above regarding limitation 1(a).
[16b] a light receiving unit comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and has a field of view that is non-overlapping with the fields of view of all other pixels in the plurality of pixels, and wherein the plurality of pixels includes a first set of pixels arranged in a first pixel column and a second set of pixels arranged in a second pixel column horizontally and vertically offset from the first pixel column;	In my opinion, Hall teaches limitation 16(b) for the same reasons discussed above with respect to limitation 1(c) and claim 11. <i>See</i> Section X.A.2(a) above regarding limitation 1(c) and Section X.E.2(a) above regarding claim 11.
[16c] a light transmitting unit comprising a bulk transmitting optic spaced apart from the bulk receiving optic and an illumination source configured to output light at a nominal wavelength, the illumination source	In my opinion, Hall teaches limitation 16(c) for the same reasons discussed above with respect to limitation 1(b) and claim 11. <i>See</i> Section X.A.2(a) above regarding limitation 1(b) and Section X.E.2(a) above regarding claim 11. Weimer further teaches that the illuminating beams produce an illumination pattern that substantially matches, in size and geometry, across a range of

including a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical emitter projects an illuminating beam at the nominal wavelength through the bulk transmitting optic and into a field ahead of the optical system such that the plurality of optical emitters project a plurality of illuminating beams according to an illumination pattern that substantially matches, in size and geometry across a range of distances from the optical system, the fields of view of the plurality of pixels; and	distances, the fields of view of the plurality of pixels. The geometry of the beam pattern matches that of the pixels. EX1029, Fig. 3A, 10:17-45. The beam spot size is “only slightly smaller than the receiver’s instantaneous field-of-view” such that “individual beams 208 can be directed to cover an area corresponding to a single pixel of the detector.” <i>Id.</i>, 1:56-59, 4:56-58. And a POSITA would have understood that the range of distances includes the distances of a target scene described in Weimer. <i>Id.</i>, Fig. 3A, 15:49-60.
[16d] an electric motor operable to rotate the light receiving unit about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the light receiving unit is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by the other pixels in the plurality of	In my opinion, Hall teaches limitation 16(d) for the same reasons discussed above with respect to limitation 1(d) and claim 11. <i>See</i> Section X.A.2(a) above regarding limitation 1(d).

pixels.	
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e) Claim 17

155. In my opinion, the combination of Hall, Borowski, and Weimer teaches claim 17 as detailed below.

[17] The optical system of claim 16 wherein the optical system generates, for each of a plurality of arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system and implements time of flight techniques to transform the generated data into distances from the optical system.	In my opinion, Hall teaches claim 17 for the same reasons discussed above with respect to limitation 1(e) and claim 9. See Section X.A.2(a) above regarding limitation 1(e) and Section X.A.2(c) regarding claim 9.
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f) Claim 22

156. In my opinion, the combination of Hall, Borowski, and Weimer teaches claim 22 as detailed below.

[22] The optical system of claim 16 wherein the circular paths traversed	In my opinion, Hall teaches claim 22 for the same reasons discussed above with respect to claim 7. See Section X.A.2(b) above regarding claim 7.
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by pixels from the second set of pixels in the second pixel column are interleaved with the circular paths traversed by pixels from the first set of pixels in the first pixel column.	
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F. Ground 1F: Hall, Borowski, Hipp, and Weimer Render Obvious Claims 14 and 19-21

157. In my opinion, the combined teachings of Hall, Borowski, Hipp, and Weimer render obvious claims 14 and 19-21 of the '236 Patent.

1. Combined Teachings of Hall, Borowski, and Lipson

158. In my opinion, a POSITA would have found it obvious to combine the teachings of Hall, Borowski, Hipp, and Weimer for the reasons discussed in Sections X.A.1, X.C.1, and X.E.1. It is also my opinion that a POSITA also would have found Weimer and Hipp highly compatible because Weimer teaches the benefit of a narrow field-of-view for pixels in an array, and Hipp teaches a shadow mask to define a narrow field-of-view and reduce cross-talk interference in a similar array. EX1029, 1:51-61, EX1007, 21:57-67. Thus, a POSITA would have looked to combine their teachings to achieve their shared benefit.

2. Application to the Challenged Claims

a) Claim 14

159. In my opinion, the combination of Hall, Borowski, and Hipp teaches claim 14 as detailed below.

[14a] The optical system of claim 10 wherein [14b] the input circuit further comprises a plurality of apertures and stop region disposed between adjacent apertures in the plurality of apertures, wherein the plurality of apertures comprises a first aperture, a second aperture horizontally and vertically offset from the first aperture, a third aperture aligned vertically with the first aperture and vertically offset from the first and second apertures; and a fourth aperture aligned vertically with the second aperture and vertically offset from the first, second and third apertures; [14c] the first set of pixels includes a first pixel and a third pixel and the second set of pixels includes a second pixel and a fourth pixel; [14d] the plurality of optical emitters includes a first emitter, a second emitter, a third emitter and a fourth emitter; and [14e] the first pixel has a field of view coincident with the first emitter such that the first pixel is operable to detect photons emitted from the first emitter and received through the bulk imaging optic after being reflected from surfaces within the field and	Hall and Borowski render obvious claim 10 as discussed in Ground 1A. <i>See</i> Section X.A.2(d) regarding claim 10. Hipp teaches a shadow mask that defines a plurality of apertures. <i>See</i> Section X.C.2 above regarding claims 8 and 15. Weimer teaches a pixel array, where each pixel has a field-of-view coincident with the emission region of a corresponding beam. <i>See</i> Section X.E.2 above regarding claim 11. In my opinion, A POSITA would have understood that when the teachings of the references are combined, the input circuit in Hall's LiDAR device would include a plurality of pixels, each comprising a SPAD array and dedicated aperture to define a field-of-view coincident with a corresponding beam emission, and a stop region between adjacent apertures to block stray light. The position of each aperture would correspond to Hall's offset pixel layout, with first, second, third, and fourth pixels and apertures meeting
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passed through the first aperture; the second pixel has a field of view coincident with the second emitter such that the second pixel is operable to detect photons emitted from the second emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the second aperture; the third pixel has a field of view coincident with the third emitter such that the third pixel is operable to detect photons emitted from the third emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the third aperture; and the fourth pixel has a field of view coincident with the fourth emitter such that the fourth pixel is operable to detect photons emitted from the fourth emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the fourth aperture.	the positional requirements of limitation 14(b). EX1004, Fig. 22.
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b) Claims 19, 20, and 21

160. In my opinion, the combination of Hall, Borowski, and Weimer teaches claims 19, 20, and 21 as detailed below.

[19] The optical system of claim 16 wherein: the first set of pixels includes a first pixel and the second set of pixels includes a second pixel; the light receiving unit further comprises a plurality of apertures including a first aperture and a second aperture horizontally and vertically offset from the first aperture;	Hall, Borowski, and Weimer render obvious claim 16 as discussed above. See Section X.E.2(d) regarding claim 16. Hipp teaches a shadow mask that defines a plurality of apertures. See Section X.C.2 regarding claims 8 and 25.
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the first aperture is disposed in a first optical path that extends from the bulk imaging optic, through the first aperture and to the first pixel; and the first aperture is disposed in a second optical path that extends from the bulk imaging optic, through the second aperture and to the second pixel. [20] The optical system of claim 19 wherein: the plurality of optical emitters includes a first emitter and a second emitter; and the first pixel has a field of view that is coincident with the first emitter such that the first pixel is operable to detect photons emitted from the first emitter and received through the bulk receiving optic after being reflected from surfaces within the field and passed through the first aperture; and the second pixel has a field of view that is coincident with the second emitter such that the second pixel is operable to detect photons emitted from the second emitter and received through the bulk receiving optic after being reflected from surfaces within the field and passed through the second aperture. [21] The optical system of claim 16 wherein: the light receiving unit further comprises a	A POSITA would have understood that when the teachings of the references are combined, the resulting device would meet the requirements of claims 19, 20, and 21 for the reasons discussed with respect to claim 14. See Section X.F.2(a). I also note that Claim 19 contains an error referring to the “the first aperture [] disposed in a second optical path....” Hall, Borowski, Weimer, and Hipp teach the same structure disclosed in the specification, where the first aperture is disposed in a first optical path. EX1001, Fig. 1.
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plurality of apertures including a first aperture, a second aperture horizontally and vertically offset from the first aperture, a third aperture aligned vertically with the first aperture and vertically offset from the first and second apertures; and a fourth aperture aligned vertically with the second aperture and vertically offset from the first, second and third apertures; the first set of pixels includes a first pixel and a third pixel and the second set of pixels includes a second pixel and a fourth pixel; the plurality of optical emitters includes a first emitter, a second emitter, a third emitter and a fourth emitter; and the first pixel has a field of view coincident with the first emitter such that the first pixel is operable to detect photons emitted from the first emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the first aperture; the second pixel has a field of view coincident with the second emitter such that the second pixel is operable to detect photons emitted from the second emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the second aperture; the third pixel has a field of view coincident with the third emitter such that the third pixel is operable to detect photons emitted from the third emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the third aperture; and the fourth pixel has a	
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field of view coincident with the fourth emitter such that the fourth pixel is operable to detect photons emitted from the fourth emitter and received through the bulk imaging optic after being reflected from surfaces within the field and passed through the fourth aperture.	
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G. Ground 1G: Hall, Borowski, Weimer, and Lipson Render Obvious Claim 18

161. In my opinion, the combined teachings of Hall, Borowski, Weimer, and Lipson render obvious claim 18 of the '236 Patent.

1. Combined Teachings of Hall, Borowski, Weimer, and Lipson

162. In my opinion, a POSITA would have found it obvious to combine the teachings of Hall, Borowski, Weimer, and Lipson for the reasons discussed in Sections X.A.1, X.B.1, and X.E.1.

2. Application to the Challenged Claims

a) Claim 18

163. In my opinion, the combination of Hall, Borowski, Weimer, and Lipson teach claim 18 as detailed below.

[18] The optical system of claim 16 further comprising and an optical filter disposed between the bulk receiving optic and each pixel in the plurality of pixels, wherein the	Hall, Borowski, and Weimer render obvious claim 16 as discussed above. See Section X.E.2(d). Lipson teaches a narrowband filter as discussed in Section X.B.2 (a) regarding claims 2 and 15. A POSITA would have understood that when the teachings of the references are combined, the resulting device would meet the requirements of claim 18.
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optical filter is configured to allow a set of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the set of wavelengths of light from reaching the plurality of pixels.	
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H. Ground 2A: Matsui and Imai Render Obvious Claims 1, 7, 9-13, 16-17, 22-23, 26-27

164. In my opinion, the combined teachings of Matsui and Imai render obvious claims 1, 7, 9-13, 16-17, 22-23, 26-27 of the '236 Patent.

1. Combined Teachings of Matsui and Imai

165. A POSITA would have recognized that Matsui teaches the overall structure of a rotating laser-radar device with a semiconductor laser and plurality of pixels. Imai teaches the benefit of using multiple lasers as opposed to a single laser, in order to improve detection distance and accuracy. EX1033, 7:10-20, 10:23-26. Imai also teaches the benefit of using VCSELs and SPADs, both of which were known to improve detection distance and accuracy as detailed in the Technical Background above. *Id.*, 5:6-8. In my opinion, a POSITA would have been motivated to apply these teachings to Matsui to achieve the same benefits.

166. In the combined device, the transmission section of Matsui would use multiple VCSEL emitters (*e.g.*, four or a number corresponding to the selected number of pixels) as disclosed in Imai. This would allow the device to improve detection distance and accuracy as taught in Imai, without overly compromising cost—an express goal of Matsui. Furthermore, each pixel in Matsui would be implemented with a plurality of SPADs (*e.g.*, four) as disclosed in Imai, which would further the goal of improved detection accuracy. In my opinion, a POSITA would have been motivated to pursue the combined device, with a reasonable expectation of success as follows.

167. As an initial matter, Matsui and Imai are analogous art because they are in the same field of endeavor as the '236 Patent—optical systems for distance measurement—and pertinent to the problem of improving detection capability in such systems. EX1031/EX1032, [0015]-[0016]; EX1033, 2:48-55, 3:5-12, 14:44-54. The combination of Matsui and Imai also provides a number of benefits to the resulting LiDAR device, and a POSITA would have a reasonable expectation of success combining the references.

168. **First**, a POSITA would have been motivated to use Imai's plurality of lasers in place of Matsui's single laser. Imai expressly teaches that the use of a single laser in combination with multiple detectors limits detection distance of the overall device due to low light reception at each detector. EX1033, 7:15-20, Fig.

7. To improve detection distance, Imai teaches increasing the number of lasers, with each laser corresponding to multiple SPADs. *Id.* Fig. 10, 10:17-26. In effect, by increasing the number of lasers, the number of photons returned per pixel over a given time increases and therefore provides for more accurate detection at greater distances. *Id.* In my opinion, a POSITA would have been motivated to apply that teaching to Matsui to improve its detection distance and broaden its utility to long-range applications in the field of autonomous-vehicle navigation. Indeed, Matsui aims to provide sensors for that same application and thus would benefit from Imai's teachings. EX1031/EX1032, [0002].

169. In my opinion, a POSITA also would have understood that the modification could be implemented in a manner that is not overly cost prohibitive. While a POSITA would recognize that Matsui seeks to minimize costs, increasing from one laser to four while maintaining the same number of SPADs—as disclosed in Imai—would lead to only a minor increase in cost while improving detection distance and accuracy. EX1033 Figs. 7, 10. In view of these teachings, a POSITA would have understood that the number of lasers could be selected and scaled to balance cost and performance of the device. A POSITA would also realize additional benefits of using multiple lasers, such as improved system reliability and redundancy, allowing the device to continue operating if one or a few lasers fails to

fire. These benefits would have motivated a POSITA to increase the number of lasers in Matsui notwithstanding the relatively minor impact in cost.

170. **Second**, a POSITA would have been motivated to use VCSELs as disclosed in Imai to achieve the known benefits of reduced angular divergence, symmetric beam profiles, fast activation time, and improved integration that allows for simpler device design and reduced manufacturing costs, which I discussed above in the Technology Background and Ground 1D. EX1008, 4:51-5:21. These benefits were known to be applicable for laser-radar devices like Matsui, and they would have furthered Matsui's goal of providing accurate detection for automotive and robotics applications, while ensuring low cost and complexity. *Id.*; EX1033, [0002], [0016].

171. **Third**, a POSITA would have been motivated to implement each of Matsui's pixels using multiple SPADs as taught in Imai in order to improve sensitivity. As detailed in the Technology Background and Ground 1A, a known benefit of SPADs was excellent detection sensitivity. EX1018, 8; EX1017, 4. The ability to detect individual photons with high sensitivity was beneficial to laser-radar devices like Matsui designed for autonomous-vehicle applications. Indeed, Imai teaches that SPADs provide for "higher sensitivity" and "are advantageous in detection accuracy and detection distance." EX1033, 5:1-8.

172. **Fourth**, a POSITA would have recognized that using multiple SPADs for each pixel in Matsui would take advantage of the SPADs' ability to be grouped into an array or macro-cell. EX1018, 8; EX1009 [0049]-[0050], [0138]-[0139]. Each individual SPAD will have a dead time during which it is quenched and reset. Thus, by grouping multiple SPADs together, the pixel can continue to register detections, even if one or more SPADs is subject to dead time. *Id.* Matsui would benefit from this known design technique, which would ensure that its pixels remain active during the entire detection interval. It would further benefit from summing and averaging techniques available via multi-SPAD pixels, which provide for more accurate and reliable distance measurements.

173. **Fifth**, another known benefit of multi-SPAD pixels was fast detection speed and data output. EX1010, 1:19-26, 1:42-52; EX1005, [0022], [0053], [0190]-[0193]. This benefit would have further motivated a POSITA to implement each of Matsui's use multi-SPAD pixels to generate a higher-resolution point cloud.

174. **Sixth**, additional known benefits of SPADs were compactness, low-power consumption, and ease of integration with circuitry. EX1010, 1:42-52, 3:66-4:4; EX1018, 7-8. These benefits would have further motivated a POSITA to use multi-SPAD pixels in Matsui's LiDAR device to improve performance while maintaining low cost.

175. ***Finally***, it is my opinion that a POSITA would have had a reasonable expectation of success when modifying Matsui to include multi-SPAD pixels and VCSEL emitters as disclosed in Imai. Imai teaches electronics and associated circuitry to process output of the SPADs and calculate time-of-flight measurements. EX1033, 5:9-42. A POSITA would have found it predictable to integrate these components into the device of Matsui, which is agnostic to the type of detection circuitry employed in the device. Indeed, as discussed above in X.A.1, a POSITA would have understood that techniques for integrating SPAD arrays in laser-radar devices and processing their output were widely known before the priority date. References like Matsubara, Marino, Albert, Grzesik, and Borowski detail the structure, electronics, and circuitry associated with SPAD arrays and their integration into LiDAR systems, making the art as a whole predictable to a POSITA. Techniques to integrate VCSEL emitters into known LiDAR devices were likewise well-known and predictable long before the earliest priority date as discussed in Section X.D.1.

2. Application to the Challenged Claims

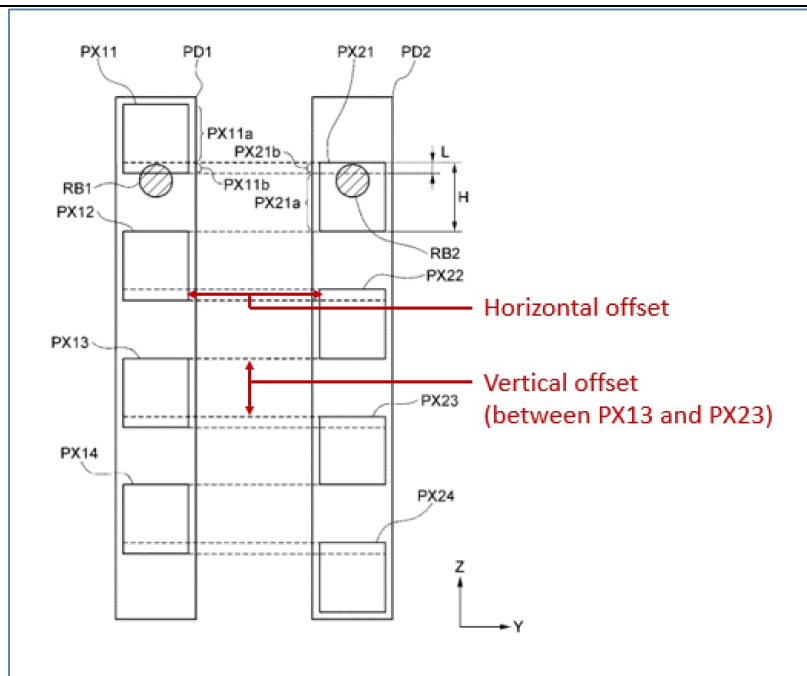
a) Claim 1

176. In my opinion, the combination of Matsui and Imai teaches the limitations of claim 1. The table below provides my analysis on a limitation-by-limitation basis, with relevant citations to the teachings of Matsui and Imai.

[1a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Matsui teaches a laser-radar device that uses time-of-flight to measure the distance to objects in the surrounding environment. EX1031/EX1032, Abstract, [0001], [0003]. Specifically, the system “measures the distance to the object based on the difference between the emission time of the semiconductor laser LD and the light reception time of the [light receiving parts].” <i>Id.</i>, [0025].
[1b] an optical imaging transmit module comprising a bulk transmitting optic and an illumination source comprising a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical emitter in the plurality of optical emitters can project light at a nominal wavelength through the bulk transmitting optic and into a field ahead of the optical system;	The laser radar (LR) in Matsui includes an illumination source in the form of semiconductor laser (LD), which is arranged behind a collimating lens (CL) and configured to emit pulsed light through the lens into a field ahead of the device: EX1031/EX1032, FIG. 2, [0016]-[0017]. In my opinion, a POSITA would have understood that the collimating lens is a bulk transmitting optic because it collects light from an emission source and passes it to the surrounding environment, which is the same configuration of the bulk transmitting optic in the ‘236 Patent. In the combined structure, the semiconductor laser (LD) is implemented using the laser-diode array (LDA) from Imai, which includes a plurality of VCSEL emitters configured to output light at a nominal or operating wavelength.

	EX1033, 6:11-20, 14:40-54. A POSITA would have understood that an optical laser would have an operating or nominal wavelength corresponding to the wavelength at which the laser emits its peak intensity. This was a known characteristic of all laser diodes, which have a peak emission wavelength and a tapered distribution where the intensity of light becomes lower at values above and below the peak. This is shown in the Osram datasheet of EX1026. It is also discussed in references like Tan, Lipson, Rodrigo, and Lorenzi, which teach nominal or operating wavelengths associated with their emitters. EX1008, 5:12-15; EX1007, 6:20-23; EX1027 at [0017]-[0019]. Alternatively, a POSITA would have found it obvious to select a known nominal wavelength for LiDAR applications, such as 905-nm or 1.5-μm, both of which were known for low absorption and human-eye safety. EX1008, 5:12-15. Together, the collimating lens and laser-diode array are an optical imaging transmit module with the same structural elements as the '236 Patent.
[1c] an optical imaging receive module comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels	In my opinion, a POSITA would have understood that the laser-radar device in Matsui includes lenses (LS1, LS2) which comprise a bulk receiving optic because they collect returned light from the surrounding environment and focus it onto a plurality of pixels in the same manner as the '236 Patent embodiments. EX1031/EX1032, [0017]-[0019], Figs. 2-3. As shown in Figure 14, for example, the plurality of pixels includes a first set of pixels (PX11, PX12, PX13, PX14) arranged in a first column (PD1) and a second set of pixels (PX21, PX22, PX23, PX24) arranged in a second column (PD2) horizontally and vertically offset from the first column:

arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and

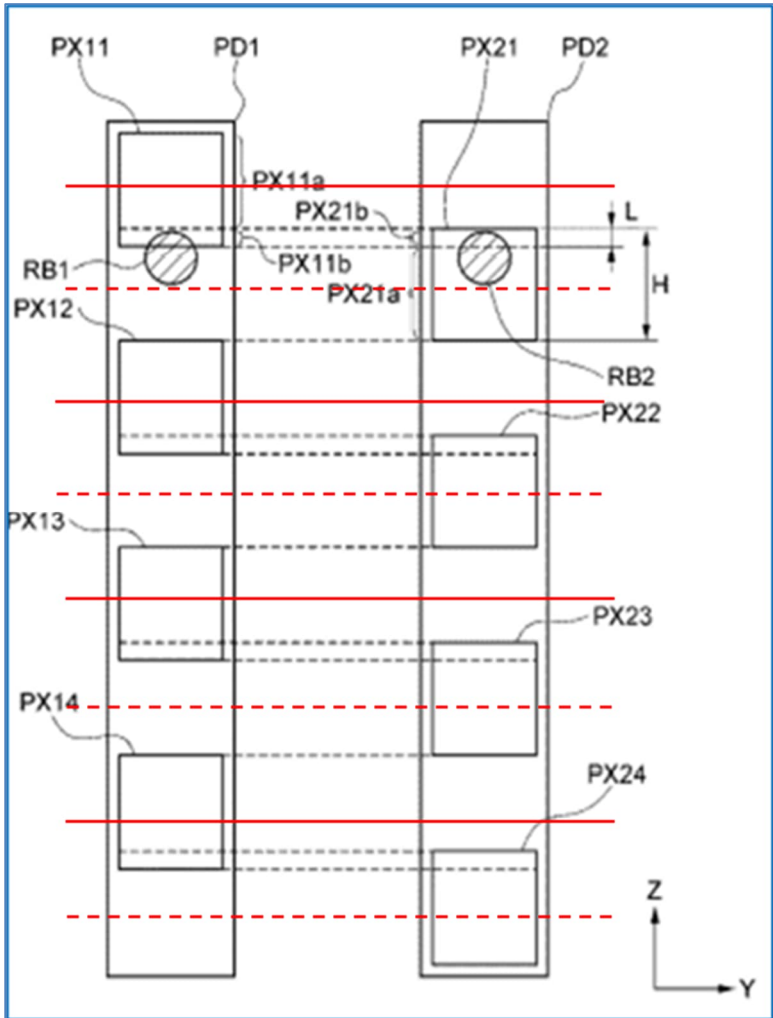


EX1031/EX1032, Fig. 14, [0036]-[0038], [0045], Fig. 11.

In the combined structure, each pixel (PX11, PX12, etc.) is implemented using a plurality of SPADs as taught in Imai. EX1033, 6:24-28, 5:1-8. A POSITA would have understood that the lenses (LS1, LS2) and plurality of multi-SPAD pixels comprise an optical imaging receive module with the same structural elements as the '236 Patent.

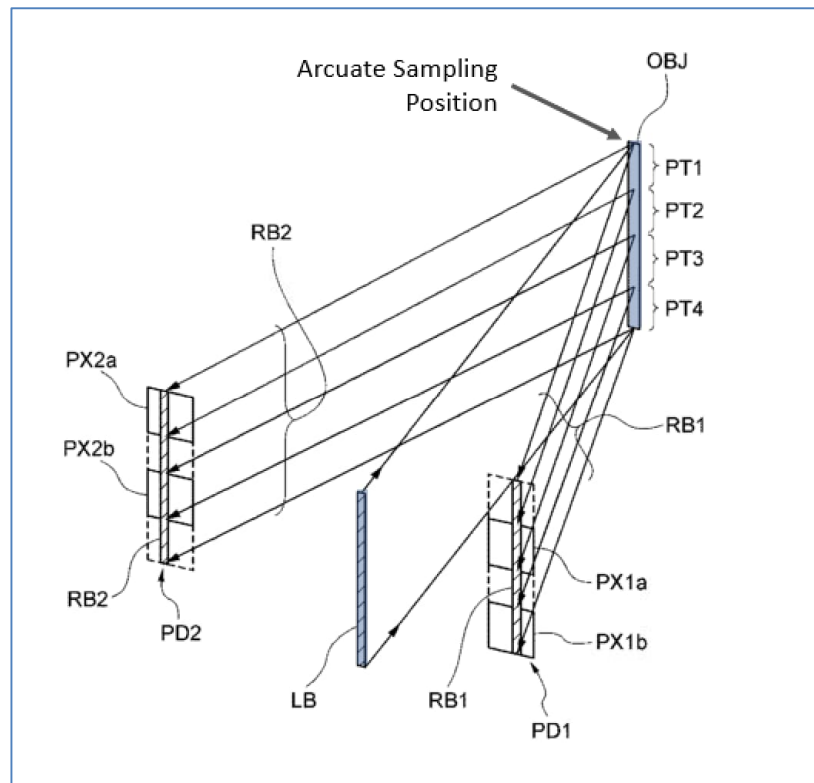
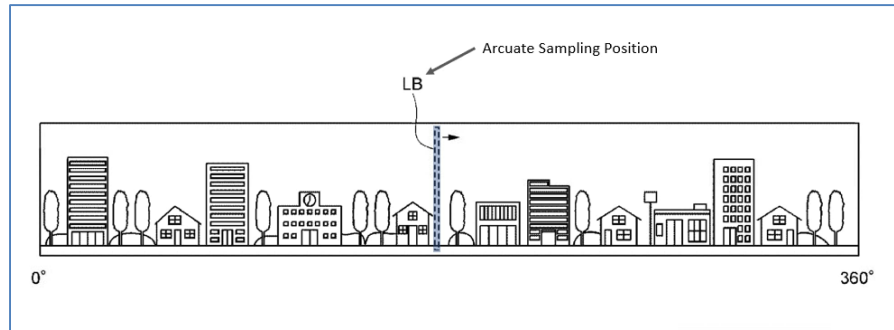
[1d] an actuator operable to rotate the optical imaging receive module about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the optical imaging receive module is rotated 360 degrees such that each pixel in the

The laser radar includes an actuator in the form of motor (MT) operable to rotate casing (CS)—including the lenses (LS) and pixels (PX) of the optical imaging receive module—about a vertical axis of rotation (RO). EX1031/EX1032, Fig. 2, [0016], [0024]. The motor rotates the device through 360-degrees, which corresponds to a single scan cycle as shown in Figure 5. *Id.* (“Here, since the casing CS is rotated about the axis of rotation RO by the motor MT, the collimated light beam LB will be scanned horizontally 360 degrees in the external world where the object is present, in accordance with the rotation of the casing CS (see FIG. 5).”).

plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system;	A POSITA would have understood that as the device rotates, each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel. This is evident from the annotated version of Figure 14 below, which shows the unique path each pixel in the first (solid) and second (dashed) columns traverses in operation:  EX1031/EX1032, Fig. 14, [0036]-[0038], [0045].
[1e] wherein the optical system generates, for each of a plurality of arcuate sampling positions	In my opinion, Matsui teaches limitation 1(e). The laser-radar device captures distance measurements at discrete locations using the collimated light beam (LB). EX1031/EX1032, [0018]. As shown in Figures 5 and 6, each location of an object that the light beam (LB)

within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system.

illuminates corresponds to an arcuate sampling position within a 360-degree scan cycle:



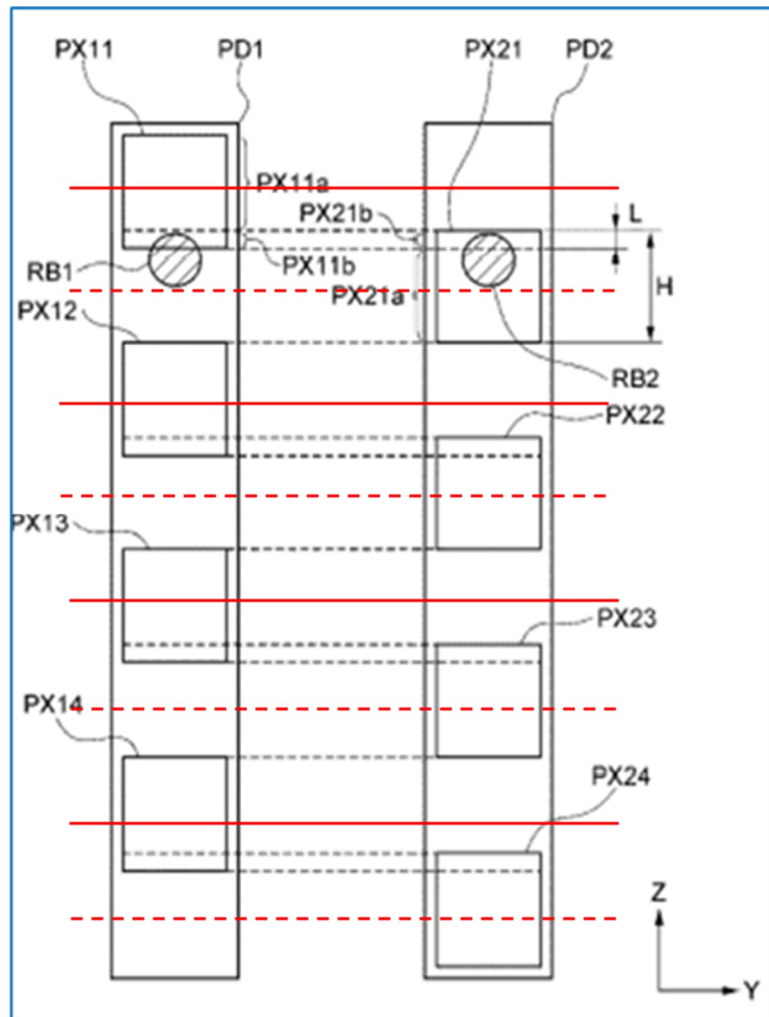
Id., Figs. 5-6.

b) Claim 7

177. In my opinion, the combination of Matsui and Imai teaches claim 7 as detailed below.

[7] The optical system of claim 1 wherein the circular paths traversed by pixels from the second set of pixels in the second column are interleaved with the circular paths traversed by pixels from the first set of pixels in the first column.

In my opinion, Matsui teaches that the pixels (PX21, PX22, PX23, PX24) in the second column (PD2) are interleaved with the pixels (PX11, PX12, PX13, PX14) in the first column (PD1). EX1031/EX1032, Figs. 11, 14, [0036]-[0038], [0045]. Thus, as the device rotates, the pixels in the second column will traverse paths that are interleaved with the paths traversed by pixels in the first column, as shown in the annotated version of Figure 14 below:



EX1031/EX1032, Fig. 14.

c) Claim 9

178. In my opinion, the combination of Imai and Matsui teaches claim 9 as detailed below.

[9] The optical system of claim 1 wherein the optical system implements time of flight techniques to determine distances from the optical system to external surfaces in the field.	As detailed above, the laser-radar device in Matsui uses time-of-flight “to measure the distance to an object by measuring the time it takes for pulsed laser light to strike an object and return.” EX1031/EX1032, [0003], [0025].
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d) Claim 10

179. In my opinion, the combination of Matsui and Imai teaches the limitations of claim 10.

[10a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Matsui teaches limitation 10(a) for the same reasons discussed above with respect to limitation 1(a). See Section X.H.2(a) above regarding limitation 1(a).
[10b]: an output circuit comprising a bulk transmitting optic and an illumination source configured to output light at a nominal wavelength, the illumination source including a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical	In my opinion, Matsui teaches limitation 10(b) for the same reasons discussed above with respect to limitation 1(b). The “output circuit” of claim 10 is synonymous with the “transmit module” of claim 1, which Matsui discloses. See Section X.H.2(a) above regarding limitation 1(b).

emitter can project an illuminating beam at the nominal wavelength through the bulk transmitting optic and into a field ahead of the optical system;	
[10c] an input circuit comprising a bulk receiving optic disposed adjacent to the bulk transmitting optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and	In my opinion, Matsui and Imai teach limitation 10(c) for the same reasons discussed above with respect to limitation 1(c). A POSITA would have understood that the “input circuit” in limitation 1(c) is synonymous with the “receive module” in claim 1(c), which Matsui discloses. <i>See</i> Section X.H.2(a) above regarding limitation 1(c). Limitation 10(c) further requires “a bulk receiving optic disposed adjacent to the bulk transmitting optic.” Matsui teaches this requirement in Figure 2, where lenses LS1, LS2 (i.e., bulk receiving optic) are adjacent to collimating lens CL (i.e., bulk transmitting optic). EX1031/EX1032, Fig. 2.
[10d] an electric motor configured to rotate the input circuit about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the input circuit is rotated 360 degrees such that each	In my opinion, Matsui teaches limitation 10(d) for the same reasons discussed above with respect to limitation 1(d). <i>See</i> Section X.H.2(a) above regarding limitation 1(d). A POSITA would have understood that Matsui’s motor (MT) is an electric motor, which would have been necessary to drive rotation of the casing (CS) within the size constraint of the overall laser radar device. A

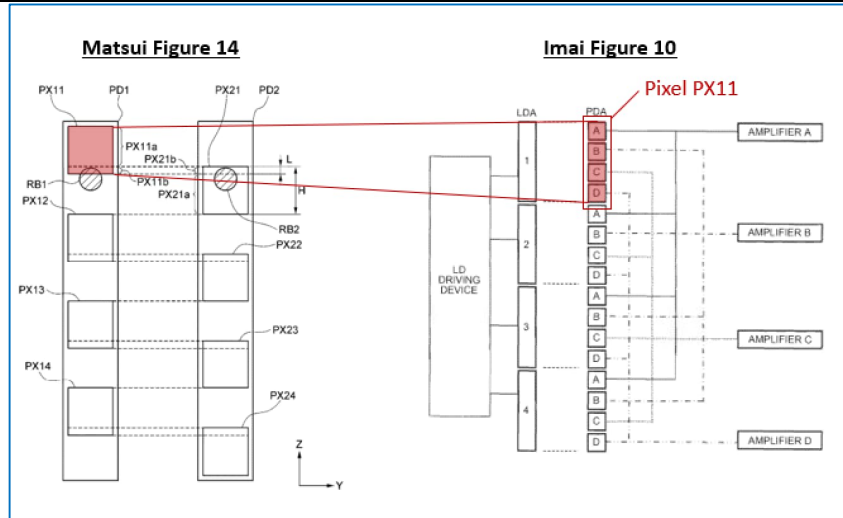
pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by each other pixel in the optical system;	POSITA also would have found it obvious to implement Matsui's motor (MT) as an electric motor, which was a widely known, reliable, and predictable structure for driving rotation of LiDAR devices. This is evident from Hall, discussed above, which teaches a widely known rotational LiDAR device driven by a simple DC motor. EX1004, 5:39-40.
[10e] wherein the optical system collects data from each pixel in the plurality of pixels at a plurality of different arcuate sampling position as the input circuit is rotated through 360 degrees during each scan cycle.	In my opinion, Matsui teaches limitation 10(e) for the same reasons discussed above with respect to limitation 1(e). See Section X.H.2(a) above regarding limitation 1(e).

e) Claim 11

180. In my opinion, the combination of Matsui and Imai teaches claim 11 as detailed below.

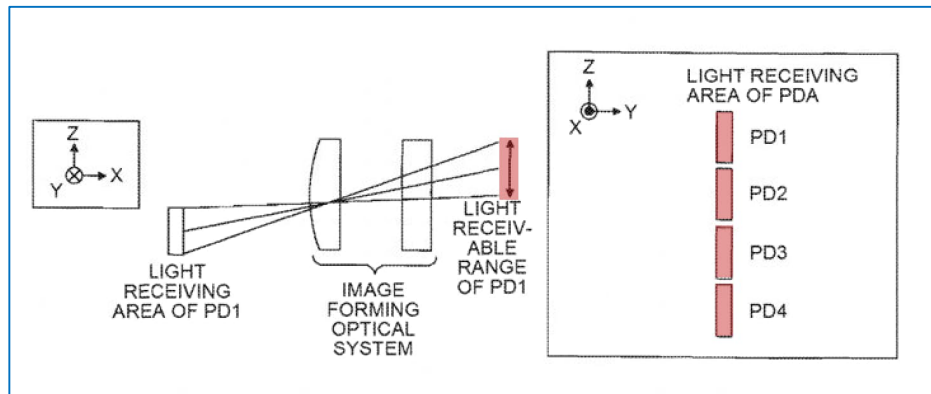
[11] The optical system of claim 10 wherein each pixel in the plurality of pixels has a field of view that is non-overlapping with fields of view of all other pixels in the plurality of pixels, and the illumination source is configured to	As detailed above, a POSITA would have combined the teachings of Matsui and Imai such that each pixel in Matsui (PX11, PX12, PX13, etc.) would be implemented as an array of SPADs as disclosed in Imai. This is shown in the image below, where pixel PX11 in Matsui is implemented as the plurality of SPADs from Imai Figure 10:
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project illuminating beams into the field ahead of the optical system according to an illumination pattern where each beam in the illumination pattern is coincident with a field of view of one pixel in the plurality of pixels.



Id.; EX1031/EX1032, Fig. 14; EX1033, Fig. 10.

Imai further teaches that individual pixels—represented by photodiodes (PD1, PD2, etc.)—have light-receiving areas that define their field of view external to the device. *Id.*, Fig. 4B. As shown in Figure 4B below, the light-receiving areas—and therefore the fields-of-view—are non-overlapping:



EX1033, Fig. 4B.

In my opinion, a POSITA would have applied this teaching to the combined Matsui-Imai structure such that the field-of-view for each pixel in Matsui (PX11, PX21, PX12, PX22, etc.) is non-overlapping with the field-of-view for each other pixel. The arrangement would beneficially avoid interference among pixels and further Matsui's goal of ensuring that each pixel detects a specific point in the field. EX1031/EX1032,

	[0026], Fig. 6. Finally, it is my opinion that Imai teaches that LDs in the LDA project illuminating beams into the field ahead of the optical system according to an illumination pattern where each beam in the illumination pattern is coincident with a field of view of one pixel in the plurality of pixels. EX1033, Fig. 4, 10:21-22. In the combined structure, the field-of-view for each pixel in Matsui would be coincident with the beam of an LD.
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f) Claim 12

181. In my opinion, the combination of Matsui and Imai teaches claim 12 as detailed below.

[12] The optical system of claim 11 wherein each scan cycle includes a plurality of sampling periods and, during each sampling period in the plurality of sampling periods, the optical system activates each emitter in the plurality of optical emitters to project the illumination pattern and determines a number of SPADs in each pixel that recorded an incident photon since a previous sampling period.	In my opinion, Matsui teaches a scan cycle with a plurality of sampling periods corresponding to the position of light beam (LB) as discussed above in Section X.H.2(a) with respect to limitation 1(e). EX1031/EX1032, Figs. 5-6. In the combined structure of Matsui and Imai, the light beam would be generated by a plurality of lasers as taught in Imai, each of which would fire for each sampling period to capture points (PT) along the detected object (OBJ). <i>Id.</i>; EX1033, 10:10-20. Furthermore, in the combined structure, each pixel of Matsui would be implemented as a plurality of SPADs as taught by Imai and discussed in Section X.H.2(a) with respect to limitation 1(c). In implementing that teaching, a POSITA would have found it obvious to determine the number of SPADs in a pixel that detect an incident photon in a given sampling period. See Section V.C.2 above. This was the fundamental operation of multi-SPAD pixels: they allowed photons to be counted, summed, and averaged to obtain a precise representation
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	of the amount of light received at a pixel. For example, photon count was useful to determine whether a threshold value had been met before registering a detection event, which avoided false hits and improved SNR. Photon count also provided an indication of intensity useful to improve the accuracy of distance measurements. By implementing these teachings for each sampling period, the combined device would generate a highly-accurate overall point cloud for the entire scanning interval.
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g) Claim 13

182. In my opinion, the combination of Matsui and Imai teaches claim 13 as detailed below.

[13] The optical system of claim 12 wherein, during each sampling period of the plurality of sampling periods within one scan cycle, the optical system determines distances to objects in the field based on a difference between a time at which an optical emitter is fired and a time at which incident photons are detected at a pixel having a field of view that overlaps with a field of view of the fired optical emitter.	In my opinion, Matsui teaches time-of-flight distance measurements for each sampling period within a cycle, where each measurement is based on a difference between the laser firing time and the pixel detection time. EX1031/EX1032, [0003], [0025]; Section X.H.2(c) above regarding claim 9. Furthermore, in the combined structure, the field-of-view of each multi-SPAD pixel would overlap with the field-of-view for a fired laser emitter as taught in Imai. EX1033, 10:10-30; <i>see</i> Section X.H.2(e) regarding claim 11.
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h) Claim 16

183. In my opinion, the combination of Matsui and Imai teaches the limitations of claim 16.

[16a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Matsui teaches limitation 16(a) for the same reasons discussed above with respect to limitation 1(a). <i>See</i> Section X.H.2(a).
[16b] a light receiving unit comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and has a field of view that is non-overlapping with the fields of view of all other pixels in the plurality of pixels, and wherein the plurality of pixels includes a first set of pixels arranged in a first pixel column and a second set of pixels arranged in a second pixel column horizontally and vertically offset from the first pixel column;	In my opinion, Matsui and Imai teach limitation 16(b) for the same reasons discussed above with respect to limitation 1(c) and claim 11. <i>See</i> Sections X.H.2(a), (e).
[16c] a light transmitting unit comprising a bulk transmitting optic spaced apart from the bulk	In my opinion, Matsui and Imai teach limitation 16(c) for the same reasons discussed above with respect to limitation 1(b) and claim 11. <i>See</i> Section X.H.2(a), (e).

receiving optic and an illumination source configured to output light at a nominal wavelength, the illumination source including a plurality of optical emitters arranged behind the bulk transmitting optic, wherein each optical emitter projects an illuminating beam at the nominal wavelength through the bulk transmitting optic and into a field ahead of the optical system such that the plurality of optical emitters project a plurality of illuminating beams according to an illumination pattern that substantially matches, in size and geometry across a range of distances from the optical system, the fields of view of the plurality of pixels; and	
[16d] an electric motor operable to rotate the light receiving unit about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the light receiving unit is rotated 360 degrees such that each pixel in the plurality of pixels traverses a unique	In my opinion, Matsui teaches limitation 16(d) for the same reasons discussed above with respect to limitation 1(d). See Section X.H.2(a) regarding limitation 1(d).

circular path parallel to and vertically offset from a unique circular path traversed by the other pixels in the plurality of pixels.	
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i) Claim 17

184. In my opinion, the combination of Matsui and Imai teaches claim 17 as detailed below.

[17] The optical system of claim 16 wherein the optical system generates, for each of a plurality of arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system and implements time of flight techniques to transform the generated data into distances from the optical system.	Matsui and Imai teach claim 17 for the same reasons discussed above with respect to limitation 1(e) and claim 9. See Sections Section X.H.2(a), (c).
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j) Claim 22

185. In my opinion, the combination of Matsui and Imai teaches claim 22 as detailed below.

[22] The optical system of claim 16 wherein the circular paths traversed by pixels from the second set of pixels in the second pixel column are interleaved with the circular paths traversed by pixels from the first set of pixels in the first pixel column.	Matsui and Imai teach claim 22 for the same reasons discussed with respect to claim 7. <i>See</i> Section X.H.2(b).
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k) Claim 23

186. In my opinion, the combination of Matsui and Imai teaches the limitations of claim 23.

[23a] An optical system for collecting distance information, the optical system comprising:	In my opinion, Matsui teaches limitation 23(a) for the reasons discussed above with respect to limitation 1(a). <i>See</i> Section X.H.2(a).
[23b] an optical imaging transmit module comprising a bulk transmitting optic and an illumination source comprising a plurality of optical emitters arranged behind the bulk transmitting optic, wherein the plurality of	In my opinion, Matsui and Imai teach limitation 23(b) for the reasons discussed above with respect to limitation 1(b). <i>See</i> Section X.H.2(a) regarding limitation 1(b). As noted above, a POSITA would have understood that in the context of the ‘236 Patent, the term “operating wavelength” is synonymous with “nominal wavelength,” which Matsui and Imai teach.

optical emitters project a plurality of beams of light at an operating wavelength through the bulk transmitting optic and into a field ahead of the optical system;	
[23c] an optical imaging receive module comprising a bulk receiving optic and a plurality of pixels arranged behind the bulk receiving optic, wherein each pixel in the plurality of pixels comprises a plurality of single photon avalanche diodes (SPADs) and wherein the plurality of pixels includes a first set of pixels arranged in a first column and a second set of pixels arranged in a second column horizontally and vertically offset from the first column; and	In my opinion, Matsui and Imai teach limitation 23(c) for the reasons discussed above with respect to limitation 1(c). <i>See</i> Section X.H.2(a) regarding limitation 1(c).
[23d] an actuator operable to rotate the optical imaging receive module about a vertical axis over a plurality of scan cycles in which, during each scan cycle, the optical imaging receive module is rotated 360 degrees such that	In my opinion, Matsui teaches limitation 23(d) for the reasons discussed above with respect to limitation 1(d). <i>See</i> Section X.H.2(a) regarding limitation 1(d).

each pixel in the plurality of pixels traverses a unique circular path parallel to and vertically offset from a unique circular path traversed by every other pixel in the optical system;	
[23e] wherein the optical system generates, for each of a plurality of arcuate sampling positions within one scan cycle, data that represents distances from the optical system to external surfaces in the field 360 degrees around the optical system.	In my opinion, Matsui discloses limitation 23(e) for the reasons discussed above with respect to limitation 1(e). See Section X.H.2(a) regarding limitation 1(e).

l) Claim 26

187. In my opinion, the combination of Matsui and Imai teaches claim 26 as detailed below.

[26] The optical system of claim 23 wherein the illumination source comprises a plurality of vertical cavity surface emitting lasers (VCSELs).	In the combined structure of Matsui and Imai, the illumination source of Matsui would be implemented using “a plurality of VCSELs” arranged in an array, as taught in Imai. EX1033, 14:44-54.
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m) Claim 27

188. In my opinion, the combination of Matsui and Imai teaches claim 27 as detailed below.

[27] The optical system of claim 26 wherein the optical system implements time of flight techniques to determine distances from the optical system to external surfaces in the field.	Matsui and Imai teach claim 27 for the reasons discussed with respect to claim 9. See Section X.H.2(c).
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I. Ground 2B: Matsui, Imai, and Higashi Render Obvious Claims 1-2, 7, 9-13, 15-18, 22-24, 26-27

189. In my opinion, the combined teachings of Matsui, Imai, and Higashi render obvious claims 1-2, 7, 9-13, 15-18, 22-24, 26-27 of the '236 Patent.

1. Combined Teachings of Matsui, Imai, and Higashi

190. Matsui and Imai render obvious claims 1, 7, 9-13, 16-17, 22-23, and 26-27 as detailed in Ground 2A. To the extent Ouster contends the pixels in the combined Matsui-Imai device do not include a plurality of SPADs, it is my opinion that a POSITA would have found it obvious to further modify the device based on the teachings of Higashi. Like Matsui and Imai, Higashi teaches an array of pixels arranged in columns. EX1034, [0027], Figs. 3-4. Higashi further teaches that each pixel can be advantageously implemented as a plurality of SPAD cells to improve

detection accuracy—which was well known in the art as I have discussed previously and which would directly benefit time-of-flight devices like Matsui and Imai. *Id.* Higashi teaches additional features that would benefit such devices, including the bandpass filter to eliminate background light. *Id.*, [0086], [0006]. A POSITA would have found it obvious to apply Higashi’s multi-SPAD pixels to the LiDAR device of Matsui and Imai.

191. As an initial matter, like Matsui and Imai, Higashi is analogous art because it is in the same field of endeavor as the ‘236 Patent—optical systems for distance measurement—and pertinent to the problem of improving detection capability in such systems. EX1034, [0006]-[0008], [0013]. Additionally, the combination of Matsui, Imai, and Higashi provide a number of benefits to the resulting LiDAR system, and a POSITA would have a reasonable expectation of success combining the references. In this discussion, I incorporate by reference my discussion of the benefits associated with multi-SPAD pixels and bandpass filters from the Technical Background and Ground 1A.

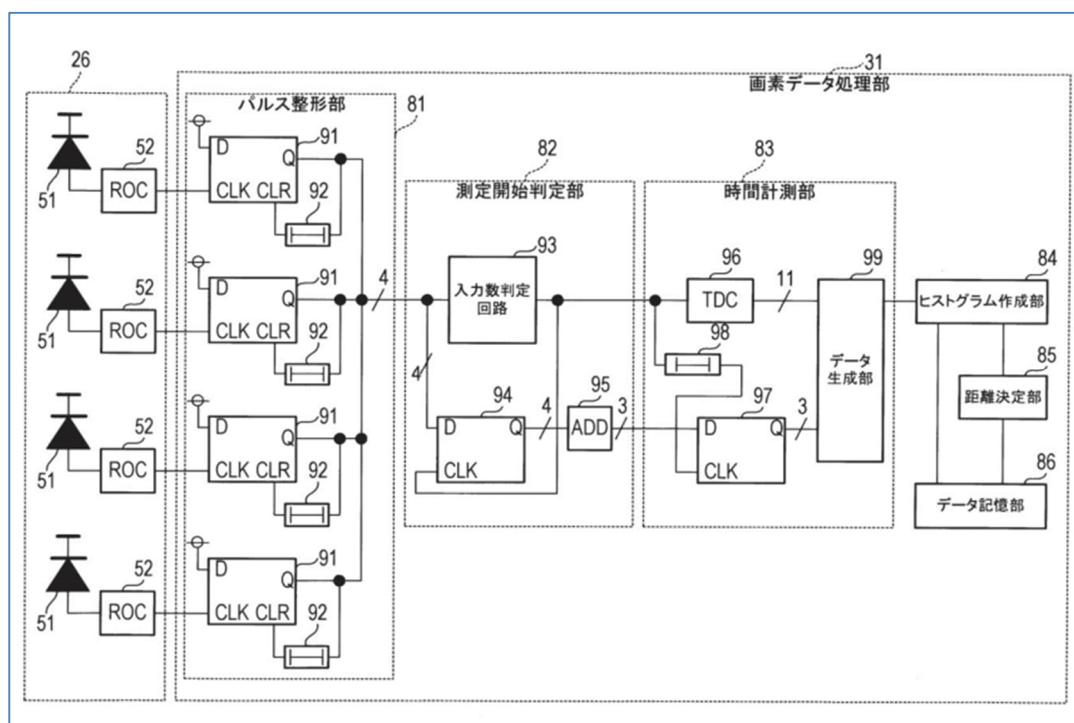
192. **First**, the use of multi-SPAD pixels as disclosed Higashi would provide the known benefits associated with SPAD technology, including increased detection sensitivity, fast detection speed and data output, compactness, reduced power consumption, and ease of integration. See Sections V.C.2, X.A.1.

193. **Second**, a POSITA would have recognized that Higashi's teaching of multi-SPAD pixels ensures uninterrupted detection at each pixel. Each individual SPAD cell will have a dead time during which it is quenched and reset. EX1018, 8; EX1009 [0049]-[0050], [0138]-[0139]. By grouping multiple SPADs together, each pixel in Higashi continues to register detection events even if one of the SPADs is subject to dead time. Matsui and Imai would benefit from this known design technique, which would ensure each pixel remains active during the detection interval.

194. **Third**, the multi-SPAD pixels and associated circuitry in Higashi provide for advantageous data processing techniques, including summation of photon counts and histogram generation. EX1034, [0027] ("As such, the SPAD can output a signal indicating that the photon has detected the incident"), [0049] ("In FIG. 6, because the number of light receiving elements 51 is four, the count value is any one of 0, 1, 2, 3, and 4. Because three bits are required to digitally represent integer values from 0 to 4, the addition circuit 95 has three signal output lines for outputting the digital signal representing the count value."); [0055]-[0056]. Further advantages of photon counting known to a POSITA were the ability to determine a threshold value for detection events and calculate intensity for returns at a given pixel. A POSITA would have been motivated to apply these

techniques to the combined structure of Matsui and Imai to improve its detection accuracy.

195. **Fourth**, a POSITA would have a reasonable expectation of success modifying Matsui and Imai to include multi-SPAD pixels as disclosed in Higashi. Higashi provides extensive detail concerning the circuitry and electronics used to detect incident photons, generate output signals, compute time-of-flight distance measurements for objects in the surrounding environment, and quench and reset individual SPADs. EX1034, [0031]-[0054]. Figure 6, for example, illustrates the relationship between SPADs 51 in a given pixel 26, their readout circuits 52, a pulse shaping unit 81 to generate and output light-detection signals, and a pixel data processing unit to compute time-of-flight measurements:



Id., Fig. 6.

196. In my opinion, a POSITA would have found it predictable to integrate these components into the device of Matsui and Imai, based on the express teachings of Higashi and the known techniques for integrating SPAD arrays and associated electronics into laser-radar devices. Section X.A.1.

197. **Finally**, a POSITA would have been motivated to incorporate the bandpass filter of Higashi in front of the pixels in the combined structure of Matsui and Imai. The known benefit of a bandpass filter was to allow light having the operational or nominal wavelength of the emitters to pass through to the pixels, while blocking “background light” as disclosed in Higashi. EX1034, [0086], [0006]. In this way, the bandpass filter of Higashi would improve accuracy and SNR in the combined structure of Matsui and Imai, while reducing the likelihood of false detections at a given pixel. Likewise, a POSITA would have had a reasonable expectation of success implementing the bandpass filter of Higashi using design techniques widely known in the art, such as vapor deposition or integration into a semiconductor layer. Section X.B.1; EX1009, [0146]; EX1030, 12:57-66.

2. Application to the Challenged Claims

a) Claims 1, 7, 9-13, 16-17, 22-23, 26-27

198. To the extent Ouster contends Matsui and Imai do not teach individual pixels each comprising a plurality of SPADs as required by limitations 1(c), 10(c),

16(b), and 23(c), it is my opinion that Higashi teaches these requirements. Higashi teaches a pixel array 21 comprising a plurality of pixels 26, where each pixel includes a plurality of SPADs 51. EX1034, [0018], [0027], Fig. 4. Applying this teaching to Matsui and Imai, each pixel in Matsui would be implemented using the multi-SPAD pixel 26 in Higashi. The resulting structure would meet the requirements of claims 1, 7, 9-13, 16-17, 22-23, 26-27 as discussed in Ground 2A.

199. Further, to the extent Ouster contends the laser emitters in Matsui and Imai do not have a nominal or operating wavelength, Higashi teaches this requirement through its disclosure of a “wavelength of the pulsed laser light” that corresponds to a selected bandpass filter. EX1034, [0086]. A POSITA would have understood that the disclosed wavelength is a “nominal” or “operating” because it is the wavelength selected for detection by the plurality of pixels (whereas other background wavelengths are filtered out). In the combined structure, the illumination source and emitters of Matsui and Imai would operate at a nominal or operating wavelength corresponding to the bandpass filter and SPADs of Higashi.

b) Claims 2, 15, 18, 24

200. In my opinion, the combination of Matsui, Imai, and Higashi teaches claims 2, 15, 18, and 24 as detailed below.

[2] The optical system of claim 1 further comprising an optical filter	As discussed above, Higashi teaches “a bandpass filter corresponding to the
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disposed in front of each pixel in the plurality of pixels and operable to allow a set of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the set of wavelengths of light from reaching the plurality of pixels. [15] The optical system of claim 10 further comprising and an optical filter disposed between the bulk receiving optic and the plurality of pixels and configured to allow a narrow band of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the narrow band. [18] The optical system of claim 16 further comprising and an optical filter disposed between the bulk receiving optic and each pixel in the plurality of pixels, wherein the optical filter is configured to allow a set of wavelengths of light, including the nominal wavelength, to pass through the optical filter while blocking light outside the set of wavelengths of light from reaching the plurality of pixels. [24] The optical system of claim 23 wherein the optical system further comprises an optical bandpass filter disposed between the bulk transmitting optic and the plurality of pixels and having a center wavelength matched to the operating	wavelength of the pulsed laser light may be provided to eliminate the effect of background light.” EX1034, [0086], [0007]. Applying this teaching to the Matsui-Imai device, a POSITA would have predictably placed the bandpass filter in front of each pixel to ensure unwanted light is blocked from reaching the pixels. A POSITA also would have predictably selected a narrow bandpass filter, centered on the operating wavelength of the emitters. As detailed in Section X.B.1, this well-known design technique would ensure that light emitted at the peak wavelength of the emitters is allowed to pass through to the pixels, while also providing a margin for light emitted at slight higher and lower wavelengths. EX1026. The resulting structure would meet the requirements of claims 2, 15, 18, and 24. As discussed above in Section X.B.2(b), claim 24 requires the filter to be “disposed between the bulk <i>transmitting</i> optic and the plurality of pixels,” which conflicts with the specification and drawings of the ‘236 Patent. Higashi renders the limitation obvious regardless because a POSITA would have found it obvious to position the filter directly in front of the pixels.
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wavelength of the plurality of optical emitters.	
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c) *Claim 12*

201. In my opinion, the combination of Matsui, Imai, and Higashi teaches claim 12 as detailed below.

[12] The optical system of claim 11 wherein each scan cycle includes a plurality of sampling periods and, during each sampling period in the plurality of sampling periods, the optical system activates each emitter in the plurality of optical emitters to project the illumination pattern and determines a number of SPADs in each pixel that recorded an incident photon since a previous sampling period.	To the extent Ouster contends that Matsui and Imai fail to teach the additional requirements of claim 12, Higashi describes a scan cycle with a plurality of sampling periods corresponding to individual rows of the pixel array 21. EX1034, [0024]-[0025], Fig. 3. During each sampling period the system determines the number of SPADs in an illuminated pixel that recorded an incident photon since a previous sampling period. <i>Id.</i>, [0045]-[0050] (“The input count determination circuit 93 receives the light receiving detection signal from each of the D-type flip-flop circuits 91 that make up the pulse shaping unit 81. The input count determination circuit 93 outputs a pulse signal that continues to be high for a predetermined period of time when the number of input of the light reception detection signal is equal to or greater than a predetermined measurement start determination value (2 in the present embodiment).”), Figs. 6-7. In my opinion, a POSITA would have understood that combined with Matsui and Imai, the device would fire the plurality of laser diodes disclosed in Imai for each sampling period, and count the number of photons received at each multi-SPAD pixel as disclosed in Higashi. The resulting structure would meet claim 12, as well as claim 13, as discussed in Sections X.H.2(f)-(g).
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J. Ground 2C: Matsui, Imai, and Hipp Render Obvious Claims 8, 14, 19-21, and 25

202. In my opinion, the combined teachings of Matsui, Imai, and Hipp render obvious claims 8, 14, 19-21, and 25 of the '236 Patent.

1. Combined Teachings of Matsui, Imai, and Hipp

203. A POSITA would have found it obvious to apply the shadow mask of Hipp to the structure of Matsui and Imai.

204. **First**, a POSITA would have had an express motivation to use Hipp's shadow mask to reduce signal interference and improve the SNR. Hipp teaches that "interference pulses arise which superimpose themselves with the desired signals with is a basic problem of the array technique." EX1007, 21:46-56. The shadow mask solves that problem by ensuring that light from a given emitter is received at its corresponding pixel. *Id.*, 21:57-67, 22:1-10.

205. **Second**, a POSITA would have understood that Hipp's shadow mask would complement Matsui and Imai. Matsui teaches a laser-radar device with an array of pixels, while Hipp teaches a shadow mask designed to improve detection efficiency for multi-pixel sensors. EX1007, 21:46-67. Imai likewise teaches the desire for improved detection accuracy in a SPAD array, which would benefit from blocking unintended photons as taught by Hipp. *Id.*

206. **Third**, a POSITA would have had a reasonable expectation of success combining the teachings of Matsui, Imai, and Hipp. Hipp teaches that the shadow

mask can be attached to the detector array, with apertures in the mask aligned with individual detectors. EX1007, 21:60-67, Fig. 16. Similar designs were well-known in the art, including in Grzesik, which teaches a cross-talk absorption layer with apertures formed in a light-absorbing material. EX1010, 4:65-5:18; Fig. 3. A POSITA would have had a reasonable expectation of success using these known techniques to implement the shadow mask of Hipp in a known LiDAR device like Matsui and Imai.

2. Application to the Challenged Claims

207. Matsui and Imai render obvious claims 1, 10, 16, and 23 as detailed in Ground 2A. *See* Section X.H. When combined with Hipp, it is my opinion that the resulting device renders obvious claims 8, 14, 19-21, and 25. Hipp teaches a shadow mask comprising a plurality of apertures formed over pixels in a detector array, and a stop region formed between the apertures to block undesired light from entering the pixels and thereby define a field-of-view for each pixel. EX1007, 21:57-67, Fig. 16. Applied to Matsui and Imai, the resulting structure would include a plurality of pixels, each having a SPAD array, aperture, and stop region.

208. With respect to claims 8, 19, and 25, the first set of pixels would include a first pixel disposed in a first optical path that extends through the first aperture, and the second set of pixels would include a second pixel disposed in a

second optical path that extends through the second aperture, with the horizontal and vertical offset arrangement disclosed in Matsui. For claim 19, I again note that the claim language appears to contain an error referring to the “the first aperture [] disposed in a second optical path....” Matsui, Imai, and Hipp teach the structure disclosed in the specification, where the first aperture is disposed in a first optical path. EX1001, Fig. 1.

209. With respect to claims 14 and 21, the first set of pixels would further include a third pixel, and the second set of pixels would further include a fourth pixel.

210. With respect to claim 20, the first and second pixels in the resulting structure would have their respective fields-of-view coincident with first and second emitters as disclosed in Imai as discussed in Section X.H.2(e) regarding claim 11.

K. Ground 2D: Matsui, Imai, Higashi, and Hipp Render Obvious Claims 8, 14, 19-21, and 25

211. In my opinion, a POSITA would have found it obvious to combine the teachings of Matsui, Imai, Higashi, and Hipp for the reasons discussed in Sections X.I and X.J. A POSITA would have understood that the resulting device would meet the requirements of claims 8, 14, 19-21, and 25.

XI. SECONDARY CONSIDERATIONS

212. Having reviewed the evidence of record, I am not aware of any secondary considerations that would suggest non-obviousness of the challenged claims. Indeed, as discussed above, the claimed subject matter appears to be a combination of well-known LiDAR architectures and design features that would have been obvious to combine at the time of the alleged invention. To the extent Ouster identifies evidence of secondary considerations at a later point in the proceeding, I reserve the right to offer my opinions to address it at that time.

XII. CONCLUSION

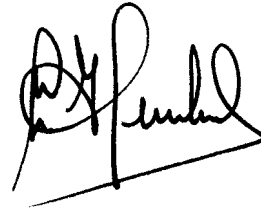
213. For the foregoing reasons, I am of the opinion that a POSITA would have found claims 1-2 and 7-27 of the '236 patent obvious based on the prior art cited herein.

Declaration of Prof. Lambertus Hesselink, Ph.D.

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 26, 2023

Respectfully Submitted

A handwritten signature in black ink, appearing to read 'L. Hesselink', written over a horizontal line.

Prof. Lambertus Hesselink, Ph.D.