



Patent Owner
Ouster, Inc.
Demonstratives

IPR2023-01421

December 17, 2024

DEMONSTRATIVE EXHIBIT

NOT EVIDENCE

Overview

- Grounds 3 and 4 – Hall/Borowski/Spector
- Grounds 1 and 2 – Pacala/Droz
 - No “stop region” as properly construed
 - No reasonable expectation of success
- Secondary considerations of nonobviousness

Grounds 3 and 4

Hall-Borowski-Spector / Hall-Borowski-Spector-Droz

Grounds 3 and 4
A POSITA Would Not Have Been
Motivated to Combine
Hall and Spector

Hall/Spector combination

360° rotation

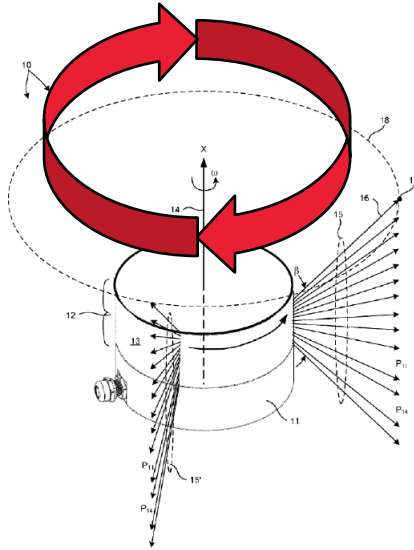


FIG. 2

Hall

EX1008, Fig. 2 (colored annotations added); POR at 15-17, 49-56; EX2010, ¶¶77-83, 136-42

Stationary view of single scene

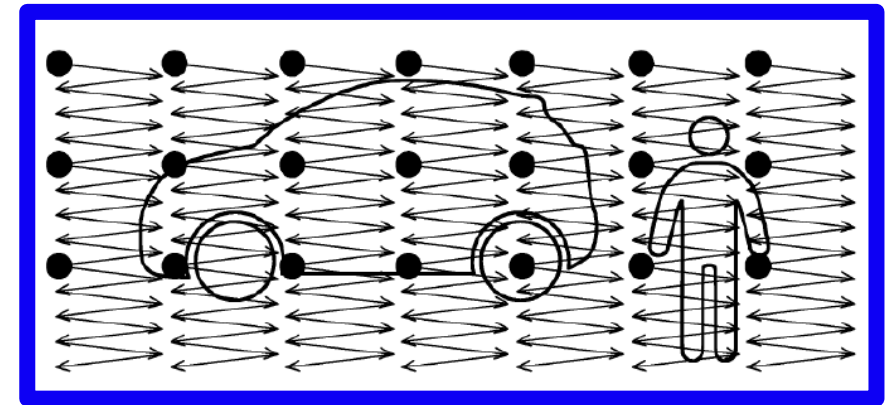
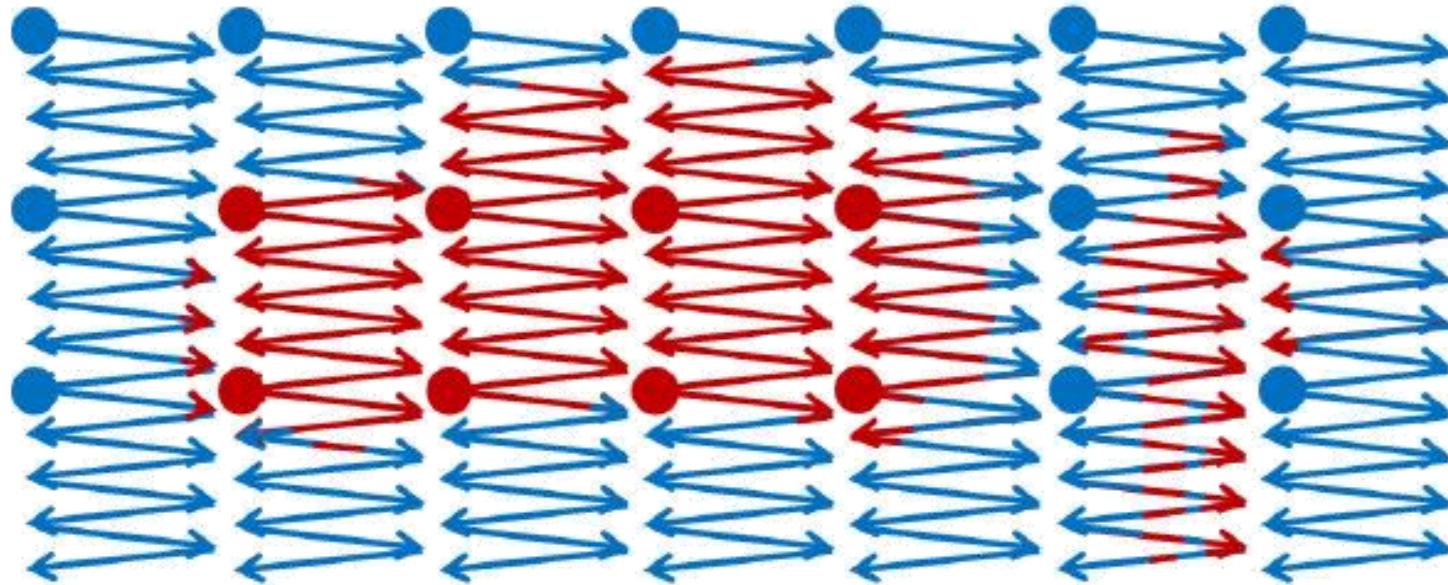


FIG. 9

Spector

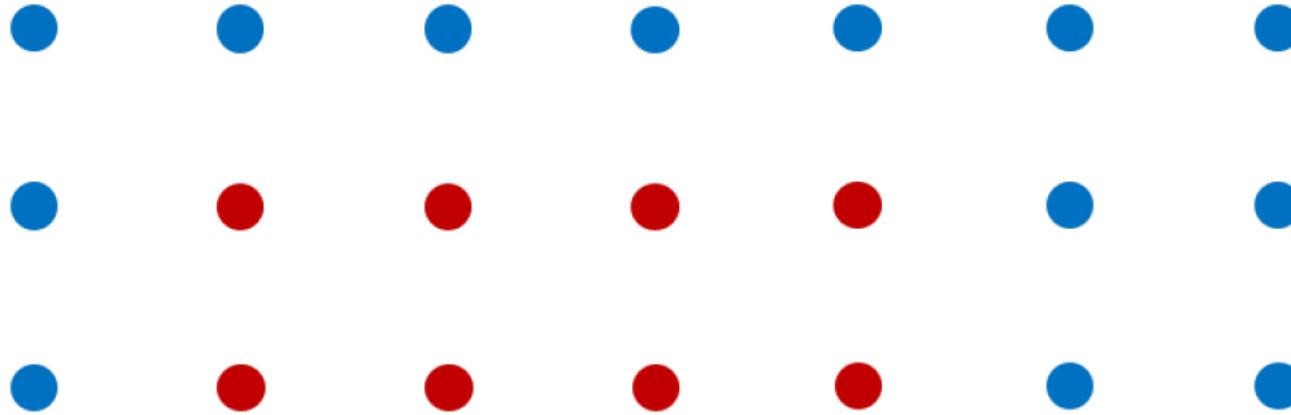
EX1005, Fig. 9 (colored annotations added); POR at 19-23, 49-56; EX2010, ¶¶88-91

Spector – With scanning system



EX1005, Fig. 9 (colored annotations); POR at 45-49; EX2010, ¶¶125-28, 132-34; PO Sur-Reply at 17-18

Spector – Without scanning system



EX1005, Fig. 9 (modified; colored annotations); POR at 46-49; EX2010, ¶¶125-28, 132-34; PO Sur-Reply at 17-18

Spector – Scanning system

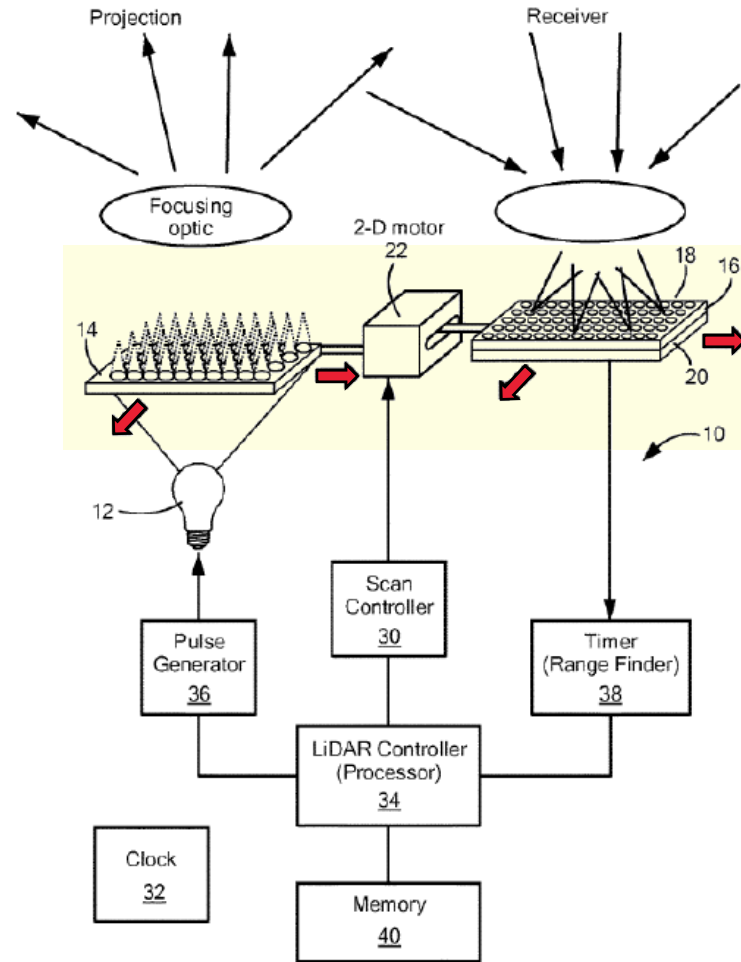


FIG. 1

EX1005, Fig. 1 (colored annotations added); POR at 45-49; EX2010, ¶¶125-28, 132-34; PO Sur-Reply at 17-18

No Spector scanning system in Hall/Spector combination

65; EX1010, 13). Petitioner does not propose including Spector's scanning system into Hall. POR 50. Contrary to PO's argument, any purported

Reply at 16 (emphasis added)

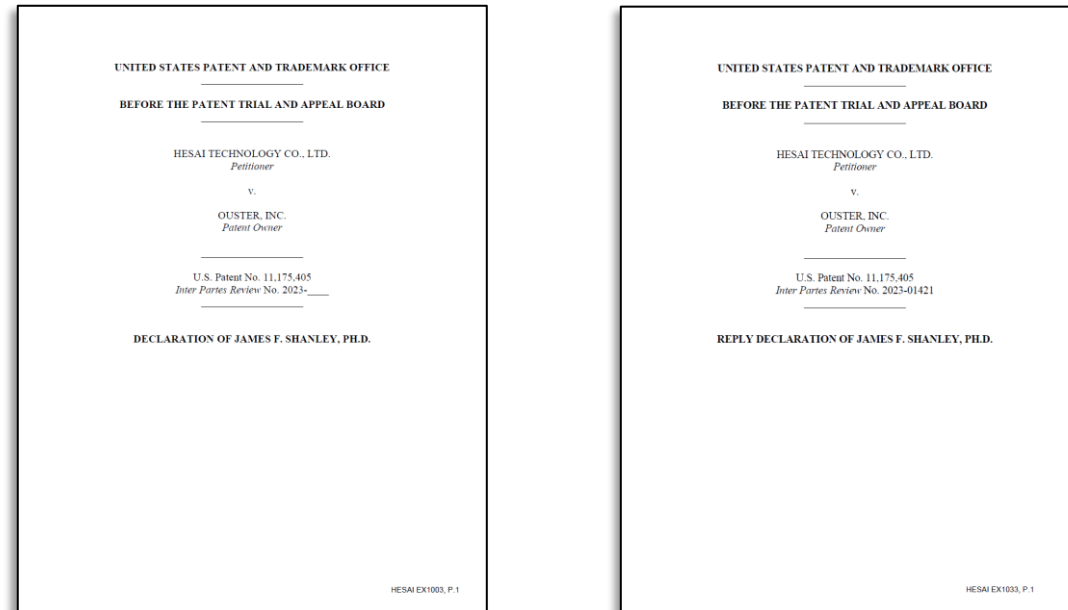
Petitioner's improper Hall/Spector reply argument

New argument on reply:

421 (2007). Plainly, a POSITA with ordinary creativity would have understood that if the aperture array does not move, then the apertures must be closer together in order to capture sufficient detail in a scene.

Reply at 16 (emphasis added)

New Hall/Spector reply argument unsupported by expert testimony



Petitioner's expert provided
NO opinions
supporting new
“aperture spacing” theory

Sur-Reply at 18-19

New Hall/Spector reply argument unsupported by expert testimony

Relates to Pacala-Droz
combination—
NOT Hall-Spector

55

1 A. I can't -- I haven't calculated mass
2 distribution in many, many years. So, you know -- and
3 not knowing the form and the materials and all of that
4 involved, I couldn't venture a guess.

5 Q. So what would you need to know before you
6 could calculate the mass distribution for the Pacala-
7 Droz system?

8 MR. HAGLZ: Objection, scope.

9 A. I'd need to know all the materials in the
10 system. There's a whole bunch of physics parameters
11 that I'd have to know. I'd have to know all the --
12 you're talking about optics and things like that.

13 Yeah, I would venture not to guess. And
14 usually what they do in the industry is, basically,
15 the mechanical CAD programs will talk with the optical
16 CAD programs and come up with the optimum design.
17 Then you can get all of these quantities out of those
18 programs, including the -- you know, you can run the
19 PTRAN and thermal analysis and all the other things.
20 And that flops out of all the CAD programs today.
21 Back in the old days we had to do all of that stuff.
22 It wasn't easy.

56

1 Q. Would a POSITA have had that information?

2 A. Would who?

3 MR. HAGLZ: Objection to form.

4 A. Oh. Yeah. Oh, yeah. I mean, myself, today,
5 I myself can run the CAD programs and top-level. But
6 a mechanical engineer out of school or an optical
7 engineer or an electrical engineer, they all can run
8 these programs that does it.

9 And basically, between the optical CAD and
10 the mechanical CAD, it talks about how you wrap metal
11 around these objects once you've done your optical
12 design. It gives you the whole list of materials and
13 all the parameters associated with the materials and
14 the optics. And then the same thing happens with the
15 CAD programs. And then there's interfaces that marry
16 the two. And you can get all this information, just
17 drops out.

18 So you'll get the form, fit, and function,
19 including weight and all this right out of those
20 systems.

21 Q. But you didn't do that analysis for the
22 Pacala-Droz combination; correct?

Hesai's only alleged
expert support for new
"pixel resolution"
theory

EX2011 at 55-56; Sur-Reply at 18-19

Petitioners may not raise new obviousness arguments on reply



Henny Penny Corp. v. Frymaster LLC
938 F.3d 1324, 1331 (Fed. Cir. 2019)

“But the petition says nothing about [the reply obviousness theory]. Nor did HPC submit any expert testimony with its petition about how to do so. ... We conclude that the Board did not abuse its discretion in holding HPC to its word and **disregarding its new theory first raised in reply.**”

POSITA would have considered Hall & Spector incompatible

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HESAI TECHNOLOGY CO., LTD.
Petitioner

v.

OUSTER, INC.
Patent Owner

Case IPR 2023-01421
U.S. Patent No. 11,175,405
Issue Date: November 16, 2021

Title: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND
STATIONARY WINDOW

CORRECTED¹ DECLARATION OF JASON A. JANÉT, PH.D.

¹ This declaration is identical to the Declaration of Jason A. Janét, Ph.D. filed on June 25, 2024 as EX2010 but for the fact that it has been corrected to include an oath from Dr. Janét (p. 96) that was inadvertently not included in the June 25, 2024 declaration.

It is my opinion that a POSITA would have considered the Hall and Spector systems to be fundamentally incompatible with each other. A POSITA would have understood that the use of micro-optic and aperture arrays in the Spector system requires the two-dimensional scanning motion disclosed by Spector to fill in the scene. ... Neither Spector, Hall, nor Dr. Shanley's opinions about the knowledge of a POSITA provide any indication as to how a POSITA would have overcome the clear incompatibility of these systems. **Accordingly, a POSITA would not have considered the Hall and Spector references to be combinable references.**

Decl. of Jason A. Janét, Ph.D. (EX2010), ¶131 (emphasis added); see also id., ¶¶124-30, 132-42

Grounds 3 and 4
A POSITA Would Not Have Been
Motivated to Combine
Borowski and Spector

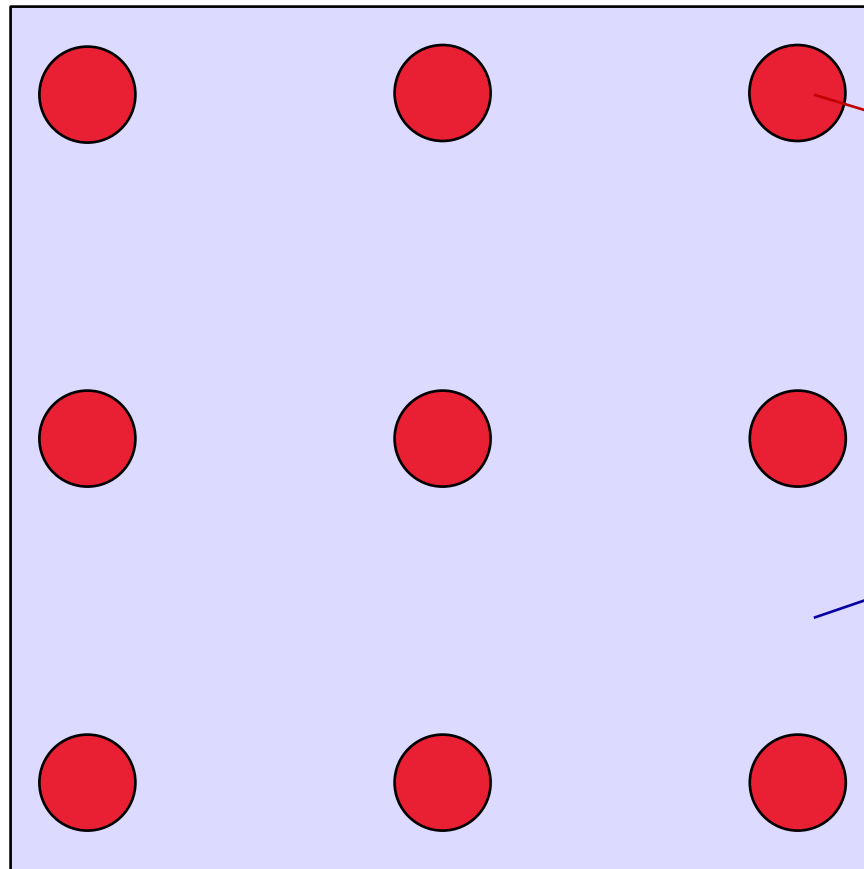
Borowski/Spector combination

filters, emitters, and detectors. *Id.* Hall's detector implementation is then improved by applying Borowski's teachings regarding the benefits and application of SPAD arrays, to improve Hall in a predictable manner. *Id.* Spector's aperture array is further incorporated to reduce cross-talk within the system. *Id.* The Hall-Borowski-

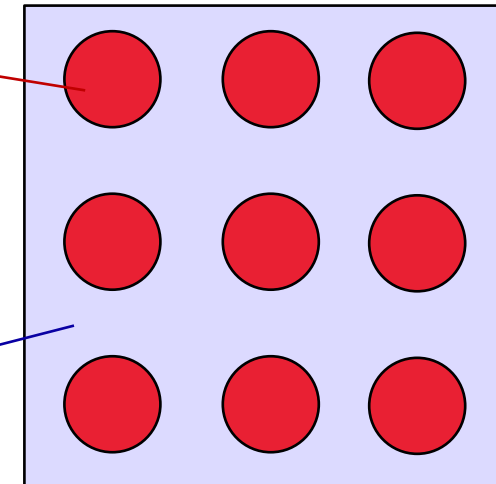
Petition at 55 (highlighting added)

Fill factor

Small fill factor



Large fill factor

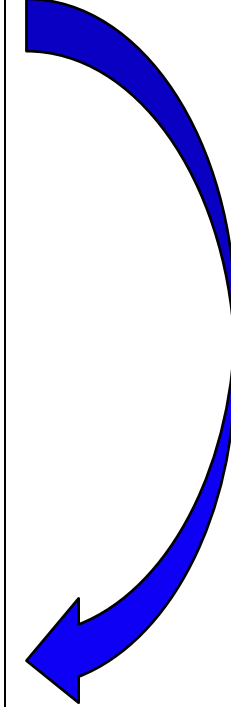
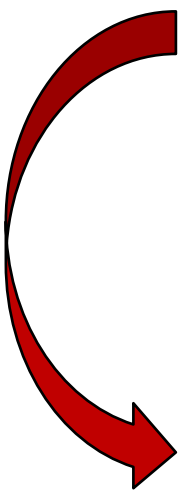


Sensor

Supporting
circuitry, etc

EX2010, ¶¶144-48, 168-70; POR at 56-57

Spector discloses that apertures are not used for small fill factor detectors



tion sites. A pixelated optical sensor array **20** may work alone or in conjunction with an aperture array **18** for defining the optical detection sites on the sensor array. For example, Princeton Lightwave, Inc. of Cranbury, N.J. makes a variety of pixelated optical sensor arrays, including for example the Merlin 32×32 free-running LiDAR camera, which may be used to perform the functions of the detector array **20**. For an optical sensor array in which the detectors are much smaller than the spacing between the detectors (fill factors less than 10%), such as in the Princeton Lightwave camera, the individual optical detection sites for correspondence with individual light spots are defined by the array itself. For detectors with a large fill factor, an aperture array may be beneficial to establish the individual optical detection sites.

EX1005, 3:45-56 (highlighting added); see also POR at 56; EX2010, ¶144; PO Sur-Reply at 21-23

Dr. Shanley testified that SPADs required special supporting circuitry

Q. So what happens with SPADs if you don't have a quenching circuit?

A. Okay, I have a lot of experience with that. Initially --

So you have this IV characteristic; okay? And if you start biasing here and you continue biasing --

So what you have is current and voltage characteristic here, and this is voltage here, and this is current on this axis.

So if you continue biasing -- and what happens is, when you operate down here, it's going to automatically increase to go to infinity. So what happens is this whips back to zero, and you may burn your diode out. You may just destroy it. I've seen things where they actually go into thermal runaway and all you have is a heated mess of semiconductor there. I've done many of those.

EX2011, 70:5-22 (highlighting added); see also POR at 65; EX2010, ¶169

Evidence of SPADs having low fill factor as of priority date



“Regretfully, even mature CMOS technology does not resolve a problem of a **low fill factor** (ratio of sensitive area to the total area occupied by electronics for active quenching of Geiger discharge) of the front-side **SPAD arrays**. For example, the recent development of MiSPIA (Microelectronic Single-Photon 3D Imaging Array) carried out by the world-recognized leaders in R&D of SPADs (Politecnico di Milano, Micro Photon Devices, Fraunhofer IMS) resulted in the **fill factor of 3.14%** for the 150 μm pitch 30 μm active area FrontSPAD array [20-21].”

EX2014 (published 2017) at 3 (emphasis added)

Grounds 3 and 4
A POSITA Would Not Have Been
Motivated to Combine
Hall and Borowski

Hall/Borowski combination

filters, emitters, and detectors. *Id.* Hall's detector implementation is then improved by applying Borowski's teachings regarding the benefits and application of SPAD arrays, to improve Hall in a predictable manner. *Id.* Spector's aperture array is further incorporated to reduce cross-talk within the system. *Id.* The Hall-Borowski-

Pet. at 55 (highlighting added)

Hall

ment at any given time. The detection of return signals includes significant sources of measurement noise that are exacerbated as measurement ranges are extended. In many applications, the signal to noise ratio of measured signals is improved by increasing laser pulse intensity.

EX1008, 2:27-33

SPADs, per Dr. Shanley

Noise and interference can affect the sensitivity of the system—for example, the ability of the LiDAR device to accurately detect objects at longer ranges, or in poor weather conditions. They may be **particularly problematic in systems that employ SPADs**, because even a single errant photon may cause a false positive detection, while also rendering the SPAD inoperable until it is quenched.

EX1003, ¶50 (emphasis added)

Grounds 1 and 2

Pacala + Droz / Pacala + Droz + Villeneuve

“stop region” claim construction

Claims 21 & 26

“stop region” – Claim language

21. An optical system for performing distance measurements, the optical system comprising:

...

a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field,

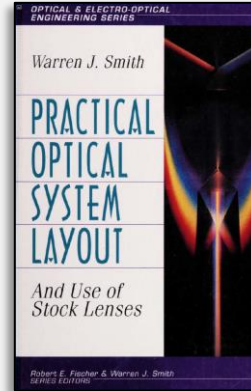
26. An optical system for performing distance measurements, the optical system comprising:

...

a light sensing module coupled to the platform and comprising a bulk receiver optic, an aperture layer comprising a plurality of apertures separated by a stop region, a plurality of photosensors operable to detect photons emitted from the plurality of optical emitters and received through the bulk receiver optic after being reflected from surfaces within the field,

EX1001, cl. 21, 26 (emphasis and highlighting added)

“stop region” – Plain and ordinary meaning

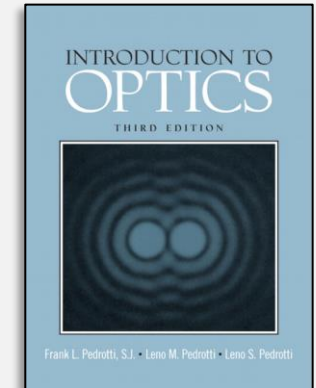


“In a typical camera lens the iris diaphragm is the aperture stop. In every optical system there is some feature, usually a diameter, which **limits the size or diameter of the beam of rays which can pass through the system**... Often the aperture stop is referred to simply as ‘**the stop**.’”

EX2013, p. 49 (emphasis added) (published 1997); EX2010, ¶108; POR at 30-32; PO Sur-Reply at 6

“The **aperture stop** of an optical system is the actual physical component that **limits the size of the maximum cone of rays** ... that can be processed by the entire system. ... The diaphragm of a camera and the iris of the human eye are examples of aperture stops.”

EX2007, p. 21 (emphasis added) (published 2006); EX2010, ¶107; POR at 30-32; PO Sur-Reply at 6



“stop region” – Expert support

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The use of the term “stop region” in the ’405 patent is consistent with how persons of ordinary skill in the art understood the term.

Decl. of Jason A. Janet, Ph.D. (EX2010), ¶107; *see also id.*, ¶¶98-106, 108-109

“stop region” – ’405 patent specification

An input aperture layer 1740 including an optically transparent aperture 1744 and optically non-transparent stop region 1746 configured to define a narrow field of view when placed at the focal plane of an imaging optic such as bulk receiver optic 202 or 1008 (shown in FIGS. 2 and 10, respectively; not shown in FIG. 17). Aperture layer 1740 is configured to receive the input marginal ray lines 1733. The term “optically transparent” herein

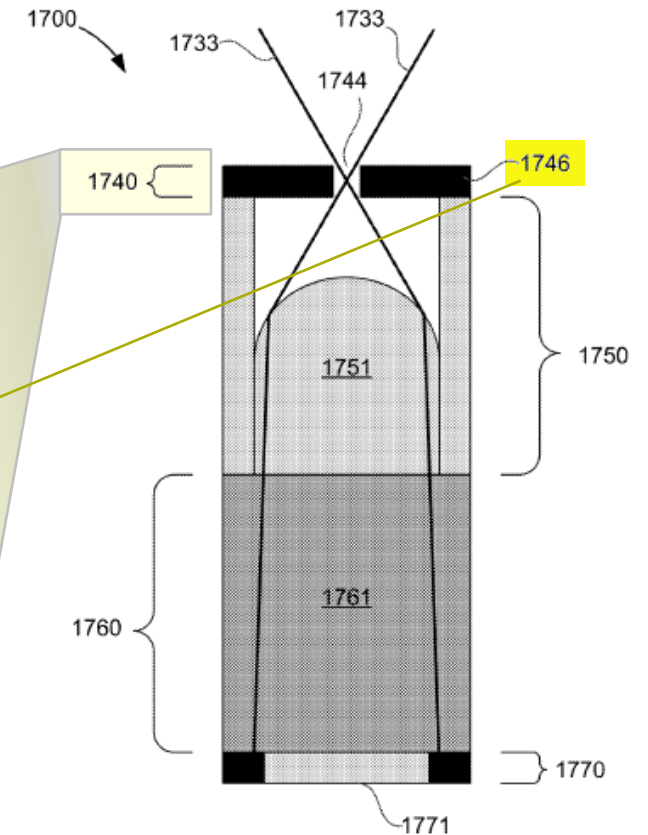


FIG. 17

EX1001, Fig. 17, 37:18-25 (highlighting added); POR at 26-27; EX2010, ¶102; PO Sur-Reply at 3-4

“stop region” – ’405 patent specification

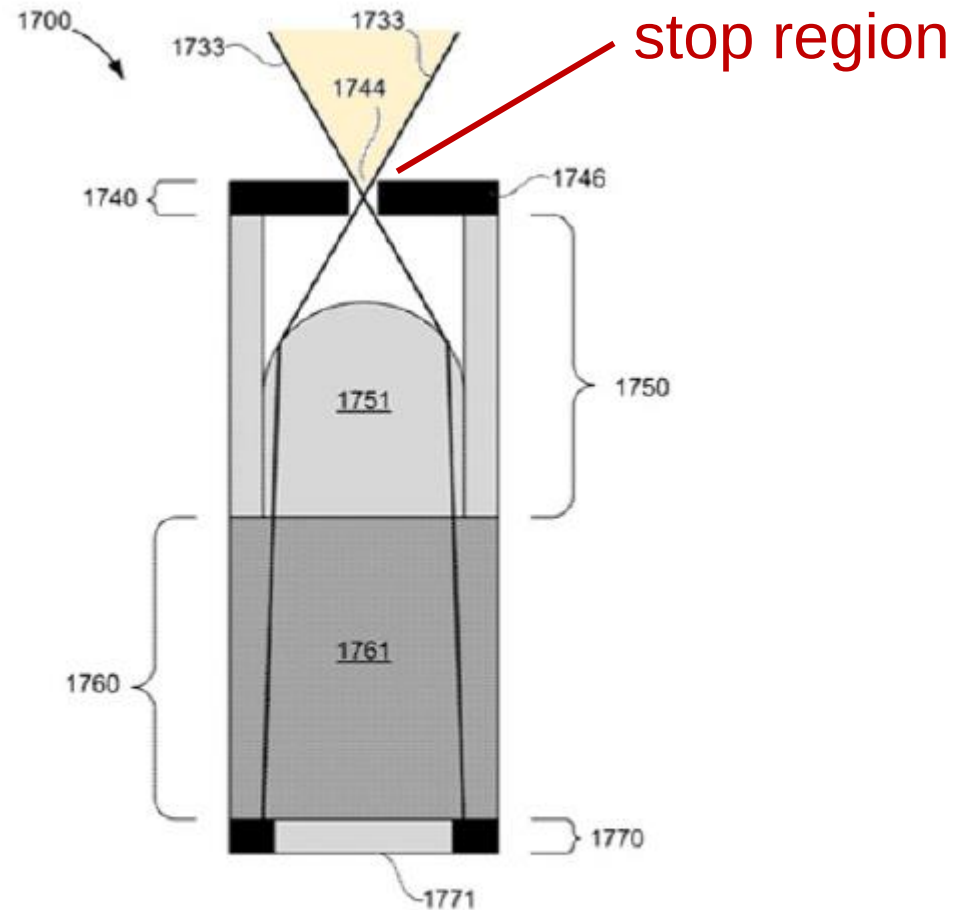
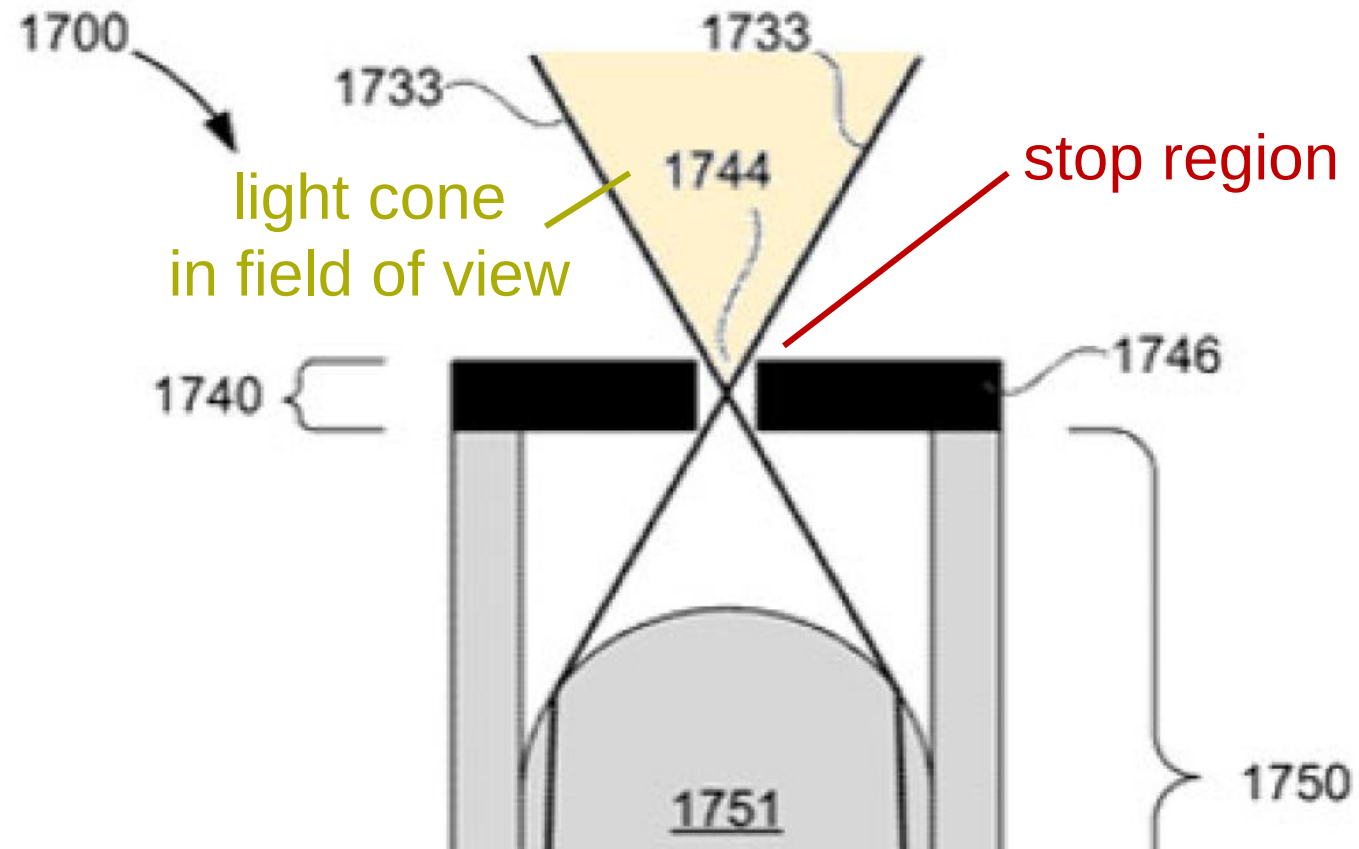


FIG. 17

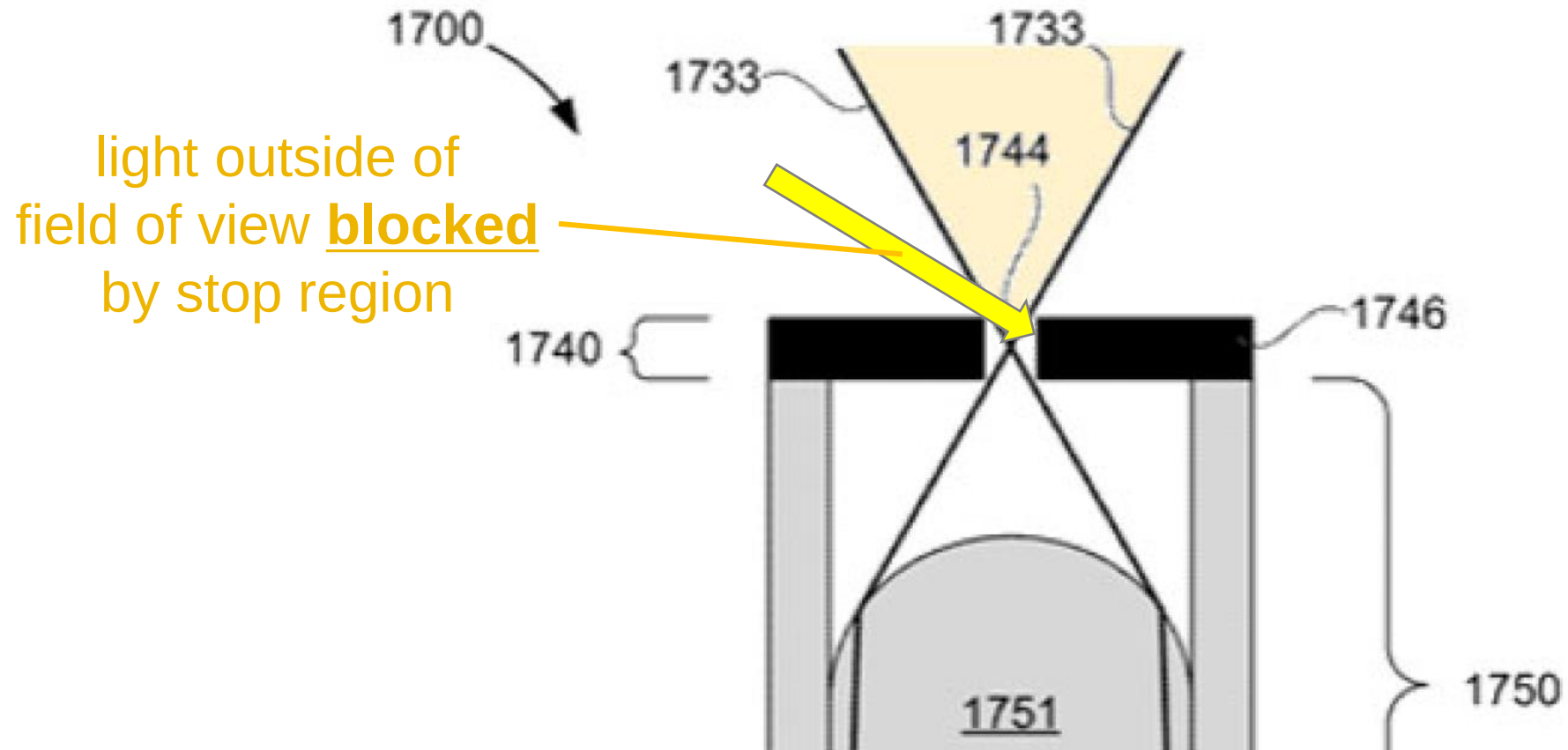
EX1001, Fig. 17 (colored annotations added); POR at 26-28; EX2010, ¶¶102, 103, 107, 109; PO Sur-Reply at 3-4

“stop region” – ’405 patent specification



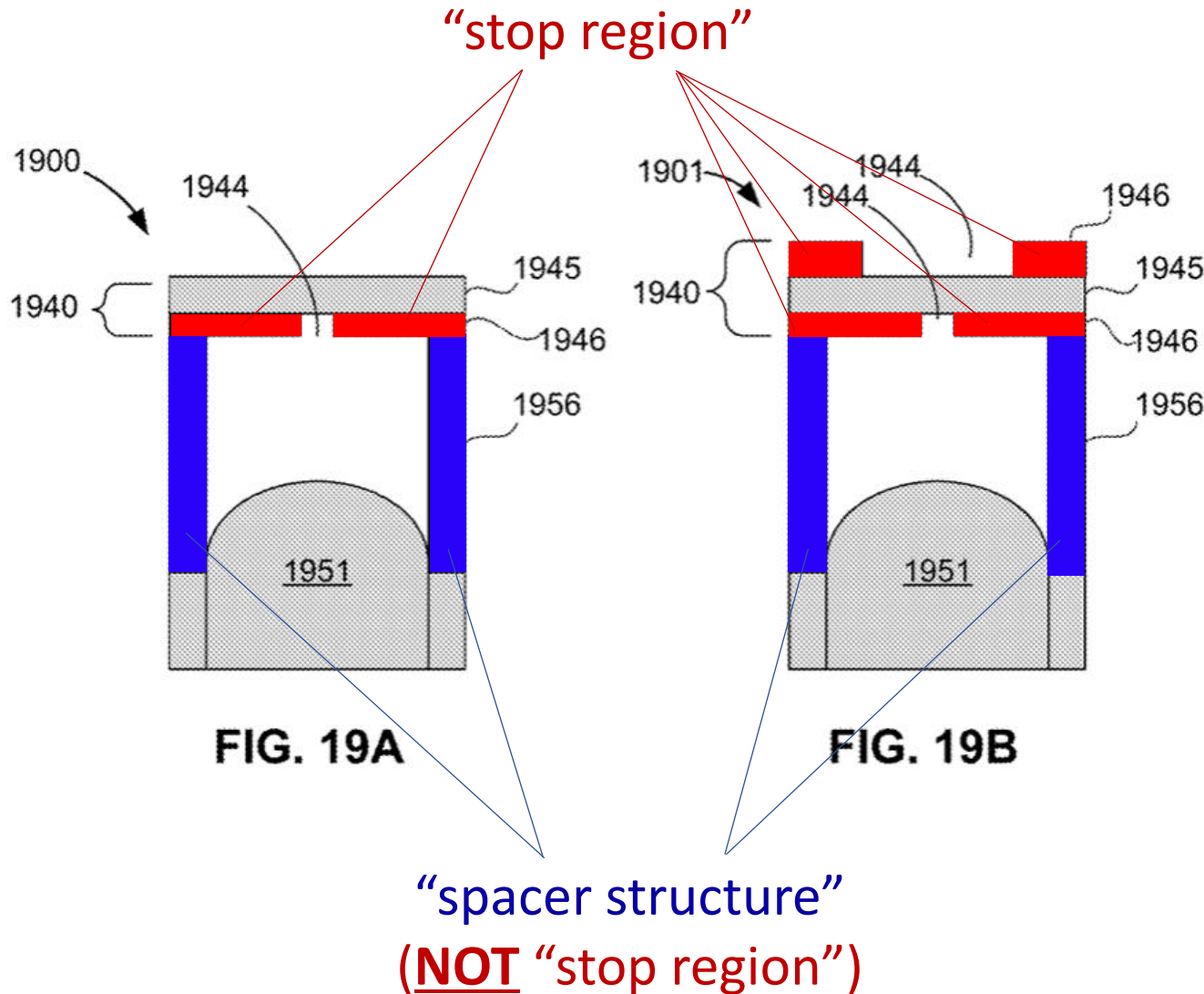
EX1001, Fig. 17 (colored annotations added); POR at 26-28; EX2010, ¶¶102, 103, 107, 109; PO Sur-Reply at 3-4

“stop region” – ’405 patent specification



EX1001, Fig. 17 (colored annotations added); POR at 26-28; EX2010, ¶¶102, 103, 107, 109; PO Sur-Reply at 3-4

“stop region” – ’405 patent specification



channel. Optically non-transparent spacer structure 1956 forms a tube of substantially similar or larger diameter to collimating lens 1951 and prevents any light from traveling outside the receiver channel in the region between aperture 1944 and collimating lens 1951. Optically non-transparent

EX1001, 39:32-36 (highlighting added)

Grounds 1 and 2
Droz does not disclose
a “stop region”

Droz embodiment relied upon for “stop region”

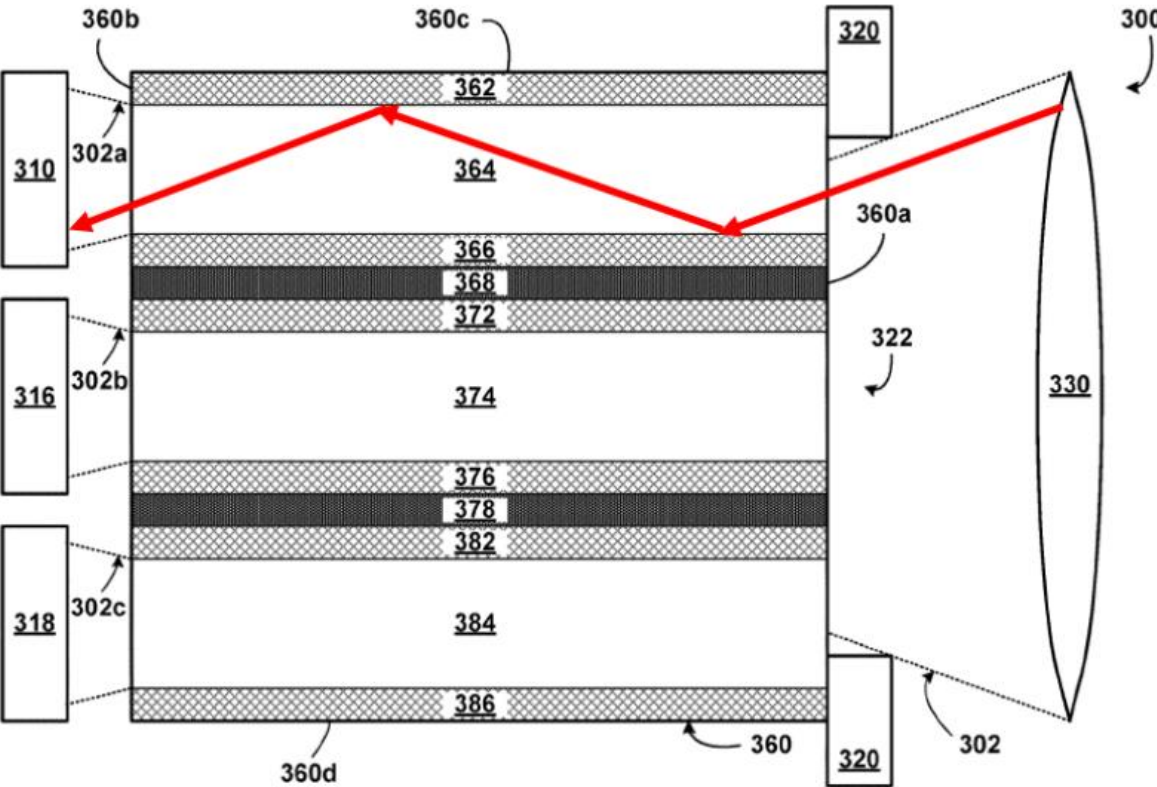


FIG. 3B

EX1006, Fig. 3B (colored annotations added), 14:23-33; POR at 32-33; EX2010, ¶100; PO Sur-Reply at 7-12

Alleged “stop region[s]”

waveguides). Ex. 1003 ¶¶150-151. Droz also teaches that a layer of light-absorbing material (*e.g.*, absorbing layers 368 and 378) is provided between waveguides to absorb leakage from one waveguide to an adjacent waveguide. Ex. 1006, 13:39-43, 14:47-60. The light-absorbing material comprises a stop region separating the apertures. Ex. 1003 ¶151.

Pet. at 28

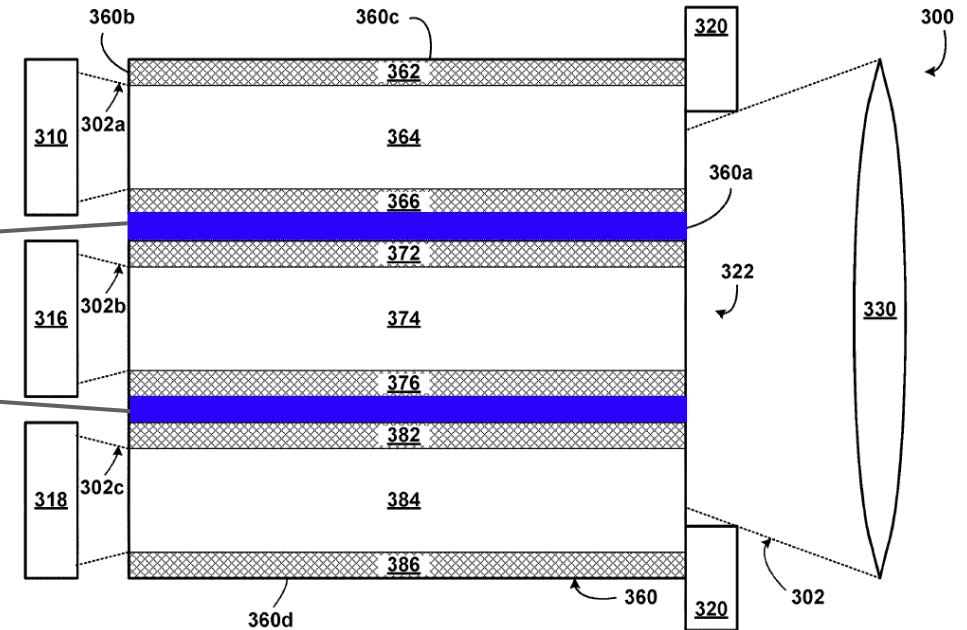
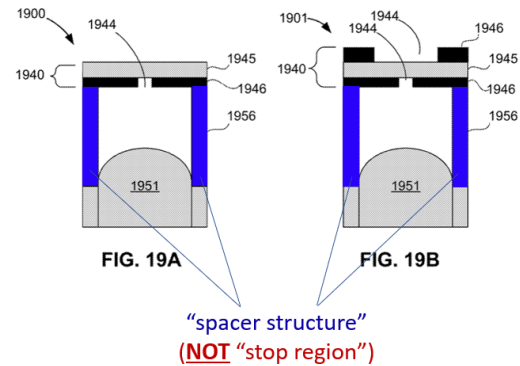
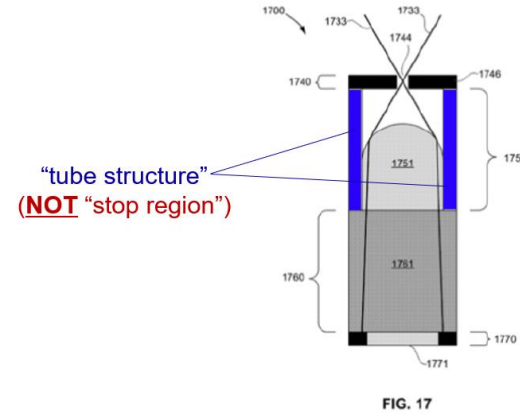


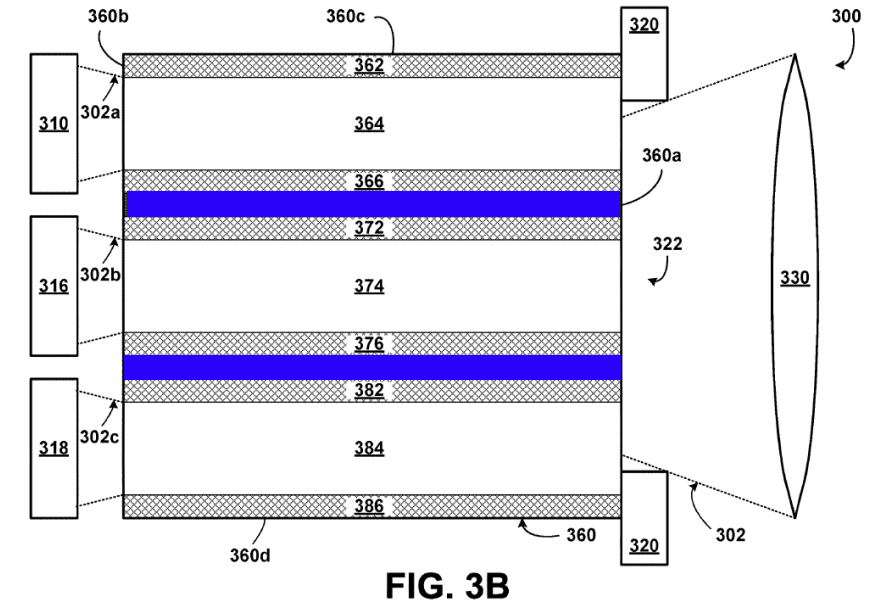
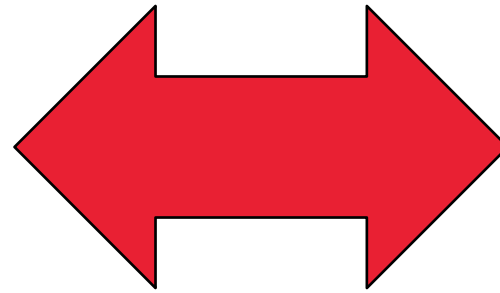
FIG. 3B

EX1006, Fig. 3B (colored annotations added)

Alleged “stop region[s]”



Petitioner's alleged “stop region[s]”
in Droz are analogous to the
non-“stop region” elements
in the '405 patent



'405 patent

Droz

POR at 33-35; EX2010, ¶¶103-104; PO Sur-Reply at 4-5

Petitioner's original “stop region” theory

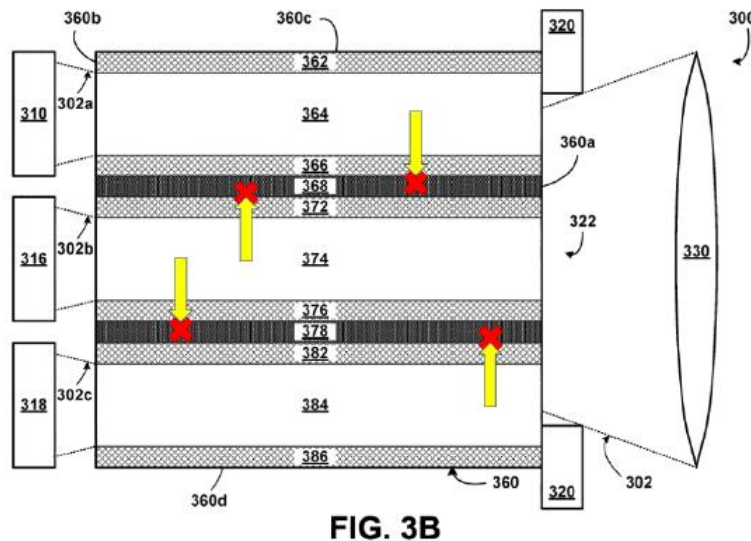


FIG. 3B
EX1006, Fig. 3B (colored annotations added); POR at 33-37; EX2010, ¶97

As a result, guided light in the first waveguide may potentially leak through cladding 366 as an evanescent field evanescent toward the second waveguide. **To mitigate this leakage**, as shown, absorbing layer 368 includes an absorber (e.g., carbon black) that has a suitable thickness to absorb the evanescent field evanescent from the first waveguide and/or the second waveguide. Similarly, absorbing layer 378 may be configured **to absorb evanescent light between the second and third waveguides**.

EX1006, 14:51-60; POR at 33-37; EX2010, ¶97-101, 109

Petitioner's reply “stop region” theory

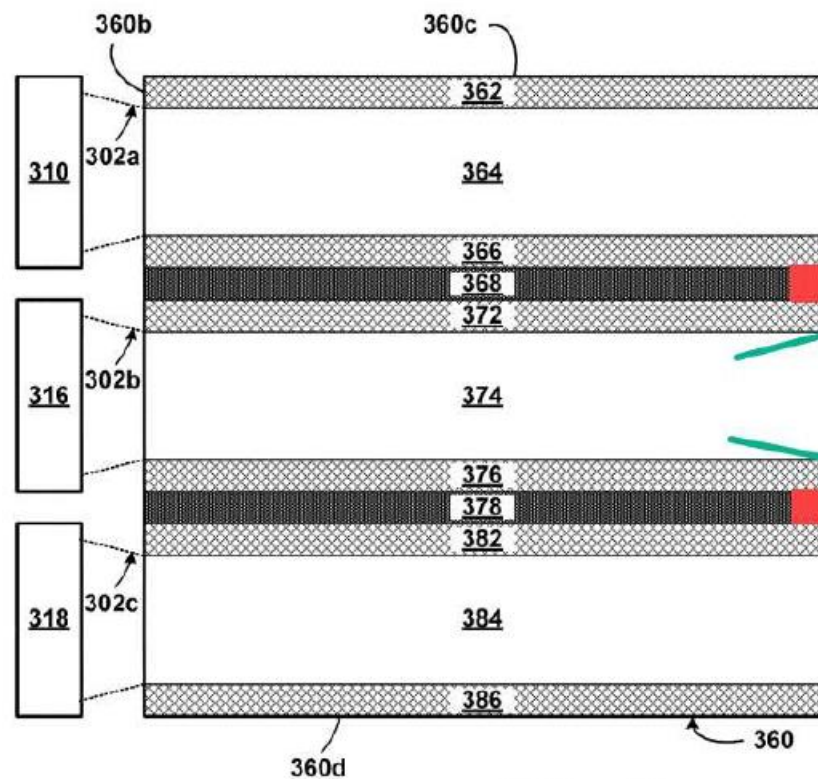


FIG. 3B

Reply at 8-9; EX1033, ¶25

Deficiencies with reply “stop region” theory

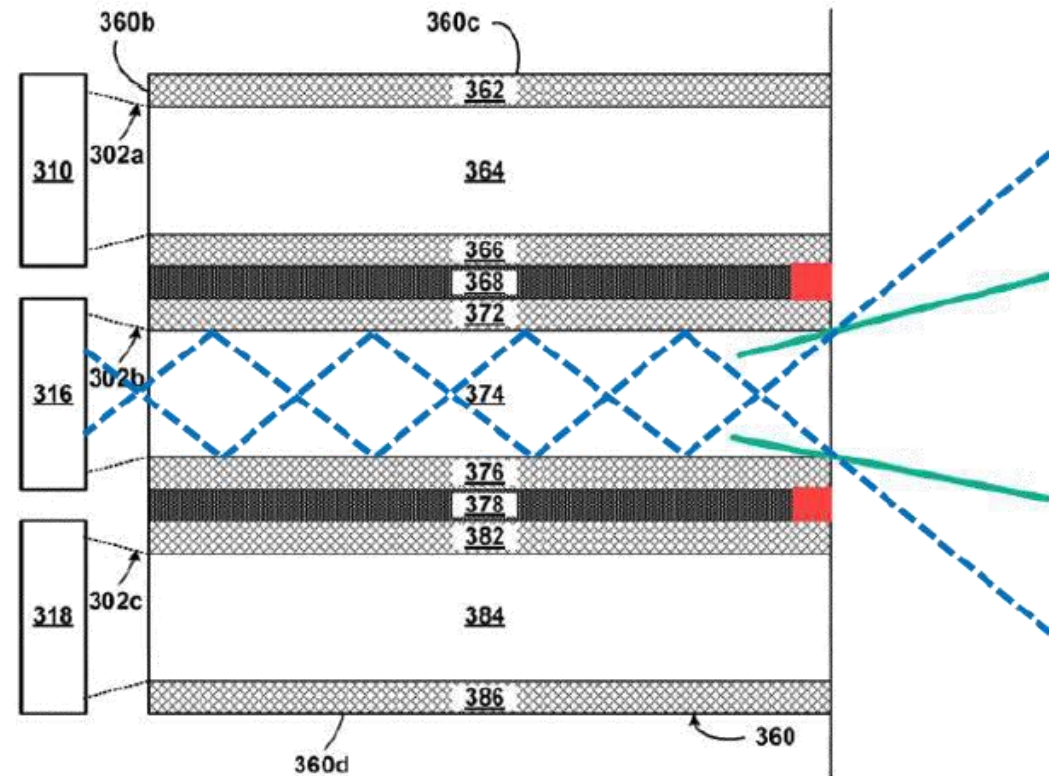


FIG. 3B

Light outside
Petitioner's green lines
can reach the
photosensor

EX1006, Fig. 3B (colored annotations added), 14:23-33; PO Sur-Reply at 8-10; POR at 32-36; EX2010, ¶¶100, 109

Deficiencies with reply “stop region” theory

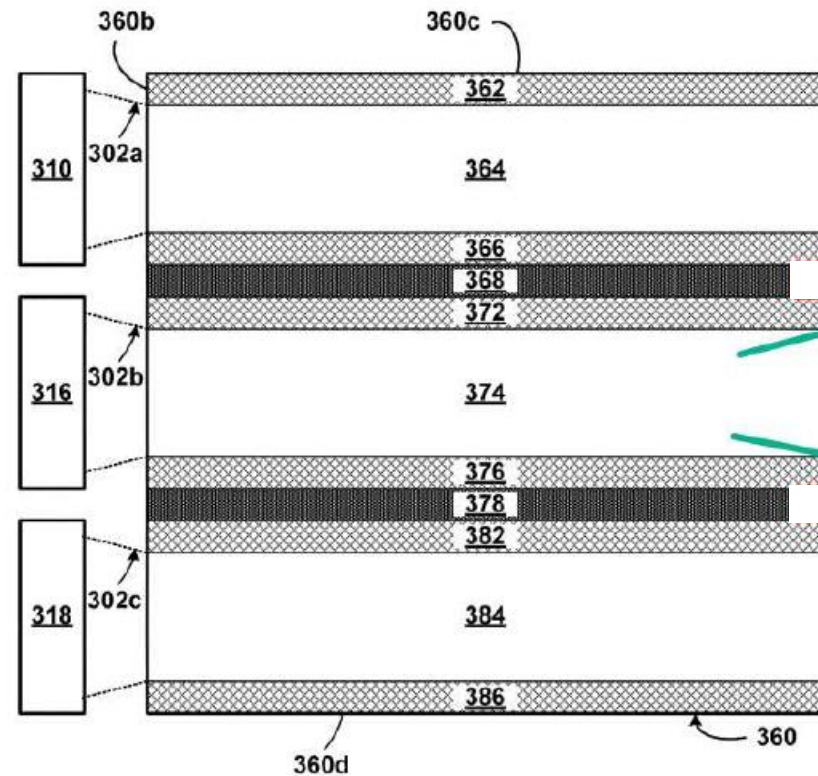


FIG. 3B

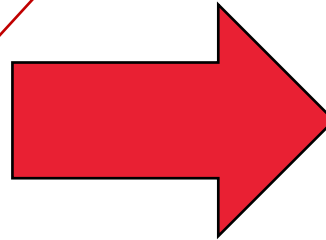
If ends of absorbing
layers are removed,
nothing
happens to
Petitioner's green lines

EX1006, Fig. 3B (modified); PO Sur-Reply at 8-11; POR at 35-36; EX2010, ¶109

Droz



Petitioner
removed
element **320**
from patent

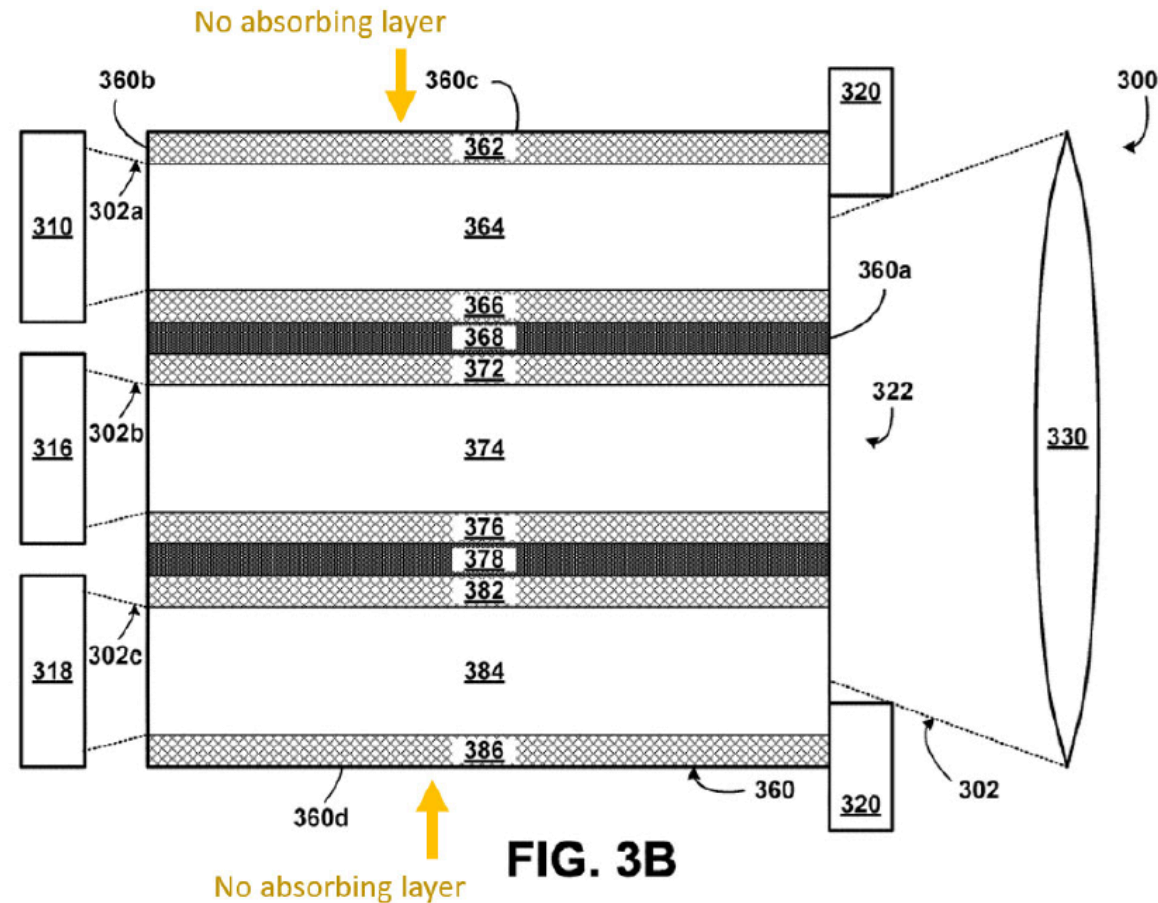


Hesai's Reply



41

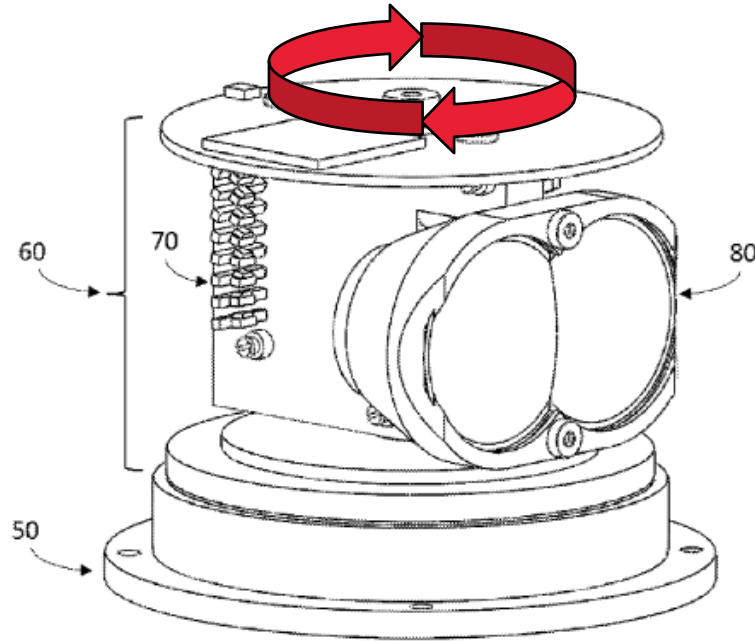
Deficiencies with reply “stop region” theory



EX1006, Fig. 3B (modified); PO Sur-Reply at 8-11; POR at 35-36; EX2010, ¶109

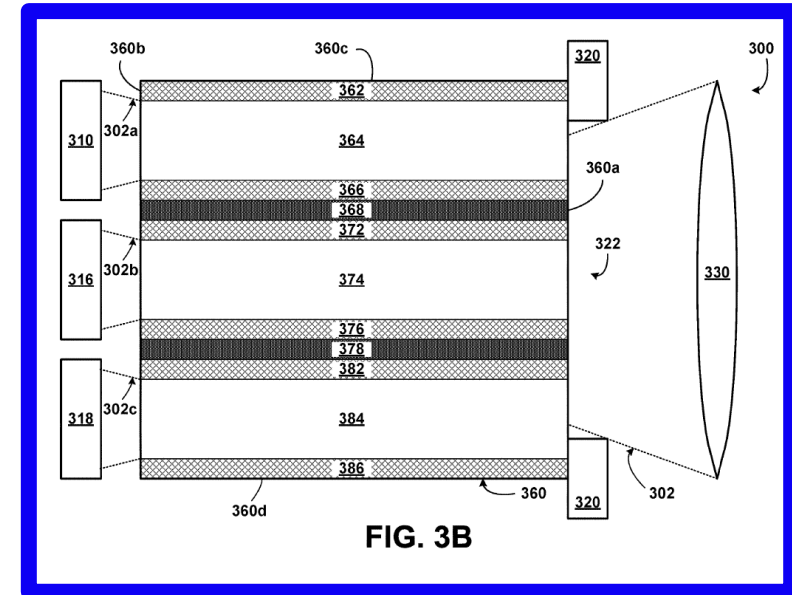
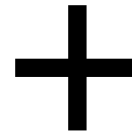
Grounds 1 and 2
No Reasonable Expectation of Success
for the Pacala-Droz Combination

Pacala-Droz combination



Pacala's
spinning system

EX1004, Fig. 2, [0013]; POR at 38-39



Droz's
stationary system

EX1006, Fig. 3B; POR at 14-15; EX2010, ¶76

Pacala-Droz combination would have required a team

56

1 Q. Would a POSITA have had that information?

2 A. Would who?

3 MR. HAGIZ: Objection to form.

4 A. Oh. Yeah. Oh, yeah. I mean, myself, today,

5 I myself can run the CAD programs and top-level. But

6 a mechanical engineer out of school or an optical

7 engineer or an electrical engineer, they all can run

8 these programs that does it.

9 And basically, between the optical CAD and

10 the mechanical CAD, it talks about how you wrap metal

11 around these objects once you've done your optical

12 design. It gives you the whole list of materials and

13 all the parameters associated with the materials and

14 the optics. And then the same thing happens with the

15 CAD programs. And then there's interfaces that marry

16 the two. And you can get all this information, just

17 drops out.

18 So you'll get the form, fit, and function,

19 including weight and all this right out of those

20 systems.

21 Q. But you didn't do that analysis for the

22 Pacala-Droz combination; correct?

57

1 MR. HAGIZ: Objection to form.

2 A. I don't have any of the data to do it.

3 Q. Would a person of ordinary skill in the art

4 have had the data to do that analysis?

5 MR. HAGIZ: Objection to form.

6 A. They could do that analysis –

7 Let me caveat that by saying: If they

8 came to me and said design this system, then the

9 answer is yes, I could do that analysis. Okay? And a

10 POSITA could do that, also.

11 But you have to remember that usually the

12 way these things are done is that there's a team of

13 people, and there's the system guy who sets all the

14 requirements, and he sort of runs the whole program.

15 And then there's the optics guy saying, "Well, you've

16 got to design optics for such-and-such a thing." And

17 the electrical engineering guy says, "Okay, this is

18 going to be my focal plane. This is going to be my

19 laser. These are my electronic requirements." And

20 then there's the mechanical guy, that says, "Okay, you

21 guys, give me all that stuff and then I'll wrap my

22 metal around it and design all the housing and stuff

58

1 like that."

2 So each of these areas in the team would

3 understand the overall systems part of it and then how

4 to craft this into a unique operating, functioning

5 system.

6 Q. So is it your understanding that a POSITA

7 would be a team here?

8 MR. HAGIZ: Objection to form.

9 A. Most definitely. But I might remark that the

10 team possesses overlapping skills. And so there are

11 certain members of the team who could run all of those

12 programs and do all of that analysis. But in -- what

13 happens in a practical purpose is that you have this

14 team because you want to run things in parallel. And

15 if you had one person doing all these things, they

16 would have to do it sequentially. I do my optics

17 design. Then I would have to run my optomechanical

18 design, and I would have to do my electronics design

19 and all of that.

20 So you have to have a team to put all

21 these pieces together.

22 Q. How many manhours would you estimate would be

EX2011 at 56-58 (highlighting added)

Pacala-Droz combination would have required a team

But neither party proposes a team POSITA:

Petitioner

A POSITA as of May 15, 2017 would have had an undergraduate degree in mechanical or electrical engineering or physics and two to three years of experience in LiDAR design. Less work experience may be compensated by a higher level of education or vice versa. Ex. 1003 ¶¶75-80.

Pet. at 12

Patent Owner

Patent Owner submits that a POSITA would have had an undergraduate degree in mechanical or electrical engineering and two to three years of work experience with electro-optical and electro-mechanical devices or systems, with, at a minimum, at least one year of work experience was with LIDAR designs, where less work experience may be compensated by a higher level of education or vice versa. (EX2010, ¶¶60-62.)

POR at 8

No analysis for how to combine Pacala and Droz

POR at 38-44; Sur-Reply at 12-15

Size

14 Q. How large would the Pacala-Droz system
15 combination be?
16 MR. HAGIZ: Objection to form and scope.
17 A. Again, I really can't answer that. I don't
18 know dimensions of objects and the system requirements
19 and things like that.

EX2011, 54:14-19 (highlighting added)

Mass Distribution

20 Q. What would the mass distribution be for the
21 combined Pacala-Droz system?
22 MR. HAGIZ: Objection to form and scope.
1 A. I can't -- I haven't calculated mass
2 distribution in many, many years. So, you know -- and
3 not knowing the form and the materials and all of that
4 involved, I couldn't venture a guess.

EX2011, 54:20-55:4 (highlighting added)

Weight

6 Q. How much would the combined Pacala-Droz
7 system weigh?
8 MR. HAGIZ: Objection to form, scope.
9 A. I can't answer that because I don't know -- I
10 mean, it's --
11 I can't answer that because I'd have to do
12 a whole system analysis to look at the weight of the
13 thing, including bias circuits and the whole thing.

EX2011, 54:6-13 (highlighting added)

Manhours

22 Q. How many manhours would you estimate would be
1 required to construct the Pacala-Droz combination
2 system?
3 MR. HAGIZ: Objection to form and scope.
4 A. To answer -- I really can't comment on that.
...
2 Q. Ballpark, do you think it would require more
3 than a man-year or less than a man-year?
4 MR. HAGIZ: Objection to form.
5 A. I really can't answer that. I mean, that's
6 hard.

EX2011, 58:22-60:19 (highlighting added)

Dr. Shanley testified that Pacala's system is compact

POR at 38-44; Sur-Reply at 12-15

Size

14 Q. How large would the Pacala-Droz system
15 combination be?
16 MR. HAGIZ: Objection to form and scope.
17 A. Again, I really can't answer that. I don't
18 know dimensions of objects and the system requirements
19 and things like that.

EX2011, 54:14-19 (highlighting added)

Weight

6 Q. How much would the combined Pacala-Droz
7 system weigh?
8 MR. HAGIZ: Objection to form, scope.
9 A. I can't answer that because I don't know – I
10 mean, it's –
11 I can't answer that because I'd have to do
12 a whole system analysis to look at the weight of the
13 thing, including bias circuits and the whole thing.

EX2011, 54:6-13 (highlighting added)

6 Q. Dr. Shanley, can you show me what
7 in Pacala suggests LiDAR construction that is
8 overall compact in size and provided low-cost
9 optical layout?

10 A. Looking at Figure 2 in Pacala.

11 Q. So what about Figure 2 in Pacala
12 indicates that it's a compact device?

13 A. Yeah, the way the arrangement of
14 the swivel device is, the two optical elements,
15 the transmit and receive areas, and his
16 electrical layout on the side, just the drawing
17 looks very, very compact, and the description
18 that he provides in the text basically leads
19 one to assume that it's a nice compact device.

EX2018, 78:6-19 (highlighting added)

Conclusory, factually unsupported combinations must fail



ActiveVideo Networks v. Verizon Commc'ns,
694 F.3d 1312, 1327 (Fed. Cir. 2012)

“We agree with the district court that the obviousness testimony by Verizon’s expert was conclusory and factually unsupported. ... **The expert failed to explain** how specific references could be combined, which combination(s) of elements in specific references would yield a predictable result, or **how any specific combination would operate** or read on the asserted claims.”

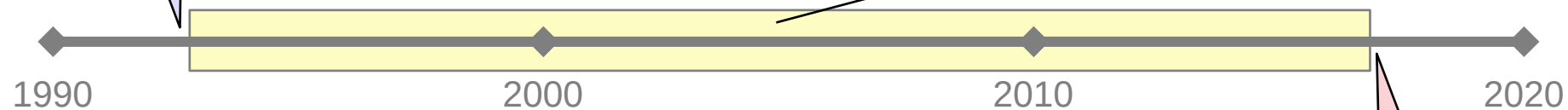
Secondary Considerations of Nonobviousness

Industry skepticism

Early 1990s
Dr. Shanley learned about SPADs

- Dr. Shanley declined to use SPADs in any LIDAR system prior to the '405 patent
- Dr. Shanley unaware of any commercial or noncommercial LIDAR system that used SPADs prior to the '405 patent

EX2011, 12:18-22, 14:10-15:4, 79:2-5, 79:11-14



May 15, 2017
Priority date of '405 patent

Failure by others

Evaluation of performance of silicon photomultipliers in LIDAR applications

Sergey L. Vinogradov^{a,b,c}
^aP.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, 119991, Russia
^bNational Research Nuclear University "MEPhI", Moscow, 115409, Russia
^cUniversity of Liverpool, Sci-Tech Daresbury, Warrington WA4 4AD, UK

ABSTRACT

Silicon Photomultipliers (SiPMs) are a well-recognized new generation of photon number resolving avalanche photodetectors. Many advantages – a high gain with an ultra-low excess noise of multiplication, multi-panel architecture, relatively low operating voltage – make SiPMs very competitive in a growing number of applications. Challenging demands of LIDAR applications for a receiver having high sensitivity starting from single photons, superior time-of-flight resolution, robustness including surviving at bright light flashes, solid-state compactness and more, are expected to be feasible for the SiPMs. Despite some known drawbacks, namely crosstalk, afterpulsing, dark noise, limited dynamic range, SiPMs are already considered as promising substitutes for conventional APDs and PMTs in LIDAR applications. However, these initial considerations are based on a rather simplified representation of the SiPM as a generic LIDAR receiver described by generic expressions.

This study is focused on a comprehensive evaluation of a SiPM potential considering essential features of this new technology, which could affect applicability and performance of SiPMs as LIDAR receivers. Namely, an excess noise due to correlated processes of crosstalk and afterpulsing, are included into account utilizing the well-established framework of analytical probabilistic models. The analysis of SiPM performance in terms of a photon number and time resolution clarifies their competitiveness over conventional APD and PMT and anticipates the development of next SiPM generations.

Keywords: silicon photomultiplier, SiPM, LIDAR, SNR, time resolution, analytical model

1. INTRODUCTION

Nowadays a SiPM is a well-established new generation of photodetectors widely recognized due to their unique advantages with respect to conventional PMT, linear mode APD, and Geiger mode APD in photon number resolving detection of low-level light pulses. An initial SiPM generation has been developed in Russia starting from basic research of an avalanche breakdown with negative feedback in Metal-Insulator-Semiconductor structures in 1970s-1980s [1-3]. R&D of Metal-Resistor-Semiconductor structures as operational SiPM prototypes in 1980s-1990s [4-5], and development of the most feasible, reliable, efficient and thus popular design of a modern conventional SiPM as a matrix of independent GM APD cells with polysilicon quenching resistors with common output in 2000s [6-7]. Some more details on the R&D of SiPMs could be found elsewhere, for example, the author's point of view is expressed in [8].

Most of the SiPM application studies during the 2000s were focused on a detection of scintillation and Cherenkov light pulses in high energy particle physics, astrophysics, and nuclear medicine, especially positron emission tomography, as discussed in [6-7] and [9]. However, the feasibility of a LIDAR receiver based on SiPM technology has been undisclosed till the 2010s, even if some SiPM developers (Semul, Amplification Technologies) mentioned LIDAR as a target application for their SiPMs on the corporate web pages much earlier. So, this application area is rather new, and just a few papers reported on studies in it as discussed below.

To the best of author's knowledge, first experimental studies on SiPM feasibility as a LIDAR receiver have been started

*vin@lebedev.ru; phone +7 499 132-4236; www.lebedev.ru

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“Therefore, to the best of the author’s knowledge, there are **no attempts either to implement SPAD arrays** or dSiPMs as a single photon number resolving LIDAR receiver or to combine an array of SPAD arrays or dSiPMs as a focal plane array of photon number resolving detectors **in 3D imaging LIDARs**. In this situation, detailed analysis of the SPAD-based receivers is out of the scope of this paper.”

EX2014 at 4 (emphasis added) (published 2017)