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(54) Title: FLASH LADAR COLLISION AVOIDANCE SYSTEM

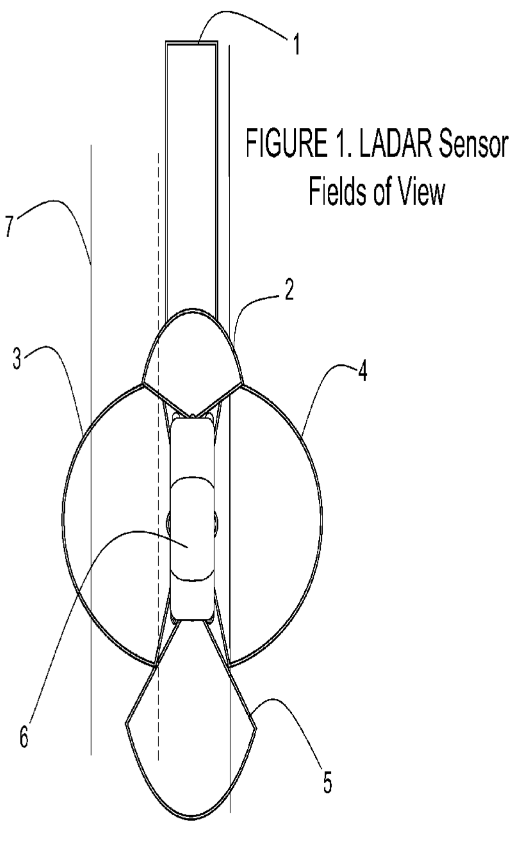

FIGURE 1. LADAR Sensor Fields of View

(57) Abstract: A vehicular collision avoidance system comprising a system controller, pulsed laser transmitter, a number of independent ladar sensor units, a cabling infrastructure, internal memory, a scene processor, and a data communications port is presented herein. The described invention is capable of developing a 3-D scene, and object data for targets within the scene, from multiple ladar sensor units coupled to centralized LADAR-based Collision Avoidance System (CAS). Key LADAR elements are embedded within standard headlamp and taillight assemblies. Articulating LADAR sensors cover terrain coming into view around a curve, at the crest of a hill, or at the bottom of a dip. A central laser transmitter may be split into multiple optical outputs and guided through fibers to illuminate portions of the 360 field of view surrounding the vehicle. These fibers may also serve as amplifiers to increase the optical intensity provided by a single master laser.

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FLASH LADAR COLLISION AVOIDANCE SYSTEM

FIELD OF THE INVENTION.

The present invention relates to the field of remote sensing of objects using LADAR and the application of LADAR to vehicular collision avoidance.

BACKGROUND OF THE INVENTION.

Many collision avoidance systems have been built which rely on microwave radars, scanning LADARs, and passive thermal and IR sensing. LADAR systems typically require the transmission of a high energy illuminating pulse. Historically, these systems rely on solid state lasers operating in the near infrared with a lasing media of Neodymium-YAG or Erbium doped glass. Many of these systems utilize multiple pulses over a period of time to detect remote objects and improve range accuracy. These systems are often based on a single detector optical receiver. To develop a complete picture of a scene, the laser and optical receiver must be scanned over the field of view, resulting in a shifting positional relationship between objects in motion within the scene. Flash ladar systems overcome this performance shortcoming by detecting the range to all objects in the scene simultaneously upon the event of the flash of the illuminating laser pulse.

U.S. patent number 4,403,220 awarded to Donovan describes a collision avoidance system based on a scanning microwave radar. U.S. patent number 5,5,29,138 issued to Shaw and Shaw details a vehicle collision avoidance system based on a scanning LADAR or sets of scanning LADARs. U.S. patent number 7,061,372 awarded to Gunderson, et. al. describes a modular collision avoidance sensor which may incorporate any number of sensor technologies, including LADAR, ultrasound, radar, and video or passive infrared sensing.

The present invention is a collision avoidance system enabled by a plurality of vehicle mounted flash ladar sensors incorporating elements of the flash ladar technology disclosed in Stettner et al, U.S. Patent Nos. 5,696,577, 6,133,989, 5,629,524, 6,414,746B1, 6,362,482, and U.S. patent application US 2002/0117340 A1, and which provides with a single pulse of light the range to every light reflecting pixel in the field of view of the flash ladar sensor as well as the intensity of the reflected light.

BRIEF DESCRIPTION OF THE INVENTION

Many attempts have been made to solve the problem of how to create the true 3-D imaging capability and integrate it with a vehicle which would enable a vehicle based collision avoidance. The instant invention makes use of a number of new and innovative discoveries and combinations of previously known technologies to realize the present embodiments which enable the vehicle operator to benefit from a collision avoidance technology with the capacity to provide nearly 360° target detection and monitoring. When integrated with the vehicle navigation and control systems, both collision avoidance and robotic driving are enabled. This ability to operate the LADAR enabled collision avoidance system is provided by practicing the invention as described herein.

This invention relies on the performance of a plurality of multiple pixel, infrared laser radar modules for capturing three-dimensional images of objects or scenes within the field of view with a single laser pulse, with high spatial and range resolution (Flash LADAR). The figures and text herein describe the electrical and mechanical innovations required to enable a cost effective LADAR based collision avoidance system which is particularly well adapted to the automotive environment, where low cost, reliability, and robust environmental performance are basic requirements.

The vehicular collision avoidance system utilizes a pulsed laser transmitter capable of illuminating an entire scene with a single high power flash of light. The vehicular collision avoidance system employs a system controller to trigger a pulse of high intensity light from the pulsed laser transmitter, and counts the time from the start of the transmitter light pulse. The light reflected from the illuminated scene impinges on a plurality of receiving optics and is detected by a number of focal plane array optical detectors housed in independent ladar sensor units. An interconnect system typically comprised of a fiber cable and wire harness connects the individual vehicle mounted ladar sensor units to a central LADAR-enabled collision avoidance system which supports the functions central to the described vehicular collision avoidance system.

The instant invention provides a nearly 360° coverage for a land or sea based vehicle with coverage above and below the plane of travel. While specifically adapted for ground based vehicles, the technology described may be easily applied to boats, hovercraft, and airborne platforms such as helicopters and airplanes. The collision avoidance system pioneers a number of new technical concepts, including the embedding of key LADAR elements within standard headlamp and taillight assemblies, and articulating LADAR sensors adapted to cover terrain coming into view around a curve, at the crest of a hill, and at the bottom of a dip. In one embodiment, a central laser transmitter is split into multiple optical outputs and guided through fibers to illuminate portions of the 360° field of view surrounding the vehicle. In a further embodiment, these fibers also serve as amplifiers to increase the optical intensity provided by a single master laser.

Therefore it is an object of this invention to provide a LADAR enabled collision avoidance system which has low initial cost, high availability, nearly 360° field of view coverage, ability to proactively adapt to variations in terrain, and can be easily integrated into existing ground based vehicles, watercraft, and airborne platforms.

The present invention comprises a vehicular collision avoidance system enabled by a flash ladar with a number of sensors specifically adapted for integration into a moving vehicle. The system described is designed to be manufactured economically, and to be integrated into a vehicle with minimum adaptation of the vehicle. Flash LADAR sensors are detailed which are integrated into a forward looking headlamp assembly which may be actuated on a motorized pivot mount. Side mounted flash ladar sensors are described which are integrated into turn signal indicator light assemblies, and rear view sensors are described which are integrated into taillight assemblies. Additionally, the flash ladar enabled collision avoidance system incorporates a central processing unit which incorporates object recognition software. Based on the objects in the field of view of the ladar sensors, the relative motion of these objects, and the vehicle dynamics, the collision avoidance system central processor produces audible, visible, or tactile warnings to the operator of the vehicle. In some cases posing extreme risk, the collision avoidance system takes active control of the vehicle in order to conduct evasive maneuvers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an overhead view of an automobile incorporating multiple flash ladar sensors and their overlapping fields of view.

FIG. 2 is a side view of three possible mounting points for the forward looking flash ladar sensors .

FIG. 3 is a side view of an automobile travelling along the crest of a hill and in the bottom of a dip in the road.

FIG. 4 is an overhead view of an automobile travelling along a section of a left-curving roadway.

FIG. 5 is a diagram of an integrated headlamp and flash ladar sensor.

FIG 6 is a diagram of an integrated headlamp and flash ladar sensor which illustrates an alternative arrangement of lensing elements for both illuminating the roadway with visible light and pulsed laser light, and collecting and directing reflected laser light to a detecting focal plane array, and shows washer and wiper hardware for keeping the forward surfaces clean.

FIG. 7 is a diagram of an integrated headlamp and flash ladar sensor which illustrates a rectangular arrangement of lighting elements as well as a reflecting lens apparatus for receiving laser light reflected from the scene, and features a laser external to the assembly.

FIG. 7A is a diagram of an integrated ladar sensor and headlamp which features a longer focal length reflecting lens and a remote external laser, with pulsed laser light delivered via an optical fiber.

FIG. 8 is a diagram showing pivot mechanisms attachment to the integrated headlamp and ladar sensor for facilitating two axis angle adjustment.

FIG. 9 is an overhead view of an alternative to FIG 1 showing overlapping fields of view of a ground vehicle employing the ladar sensor of FIGs 5, 6, 7, and 8, in which the collision avoidance system employs between four and six sensors, each at a corner of the vehicle.

FIG 10 is a block diagram of a collision avoidance system employing a plurality of independent flash ladar sensors.

FIG. 11 is a detailed system block diagram of an advanced adaptation of the collision avoidance system of FIG 10, which incorporates a number of digital and analog signal processing modules and a low power master pulsed laser transmitter with a distributed fiber amplifier and associated pump lasers.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

A preferred embodiment of the present invention, the Flash LADAR collision avoidance system (CAS), is depicted in block diagram form in FIGs. 10 and 11. These figures will be discussed in detail once foundational concepts of the LADAR enabled CAS are explained through the discussion of FIGs 1-9. FIG. 1 is an overhead diagram which shows one pattern of ladar sensor coverage which will enable a collision avoidance digital signal processor to determine which objects in the path of the vehicle, or travelling on an intercept path, necessitate evasive maneuvers by the host vehicle.

The host vehicle **6** may be an automobile, boat, ship, hovercraft, airplane or robotic crawler. FIGURE 1 illustrates several basic requirements for a vehicle mounted collision avoidance system. First, a field of view **1** in the direction of travel of the vehicle must extend furthest from the vehicle. The field of view may be rectangular as shown for field of view **1**, to project illuminating laser flashes directly in the path of the vehicle at long ranges while driving on a straight highway **7** at high speed, or in an arc, typically with shorter range and wider field of view **2** to detect nearby objects when maneuvering at low speeds, e.g.; parking.

Lateral sensor field of view patterns **3** and **4** monitor left and right sides of the vehicle respectively, and operate at medium ranges, providing input over a wide arc to facilitate low speed maneuvering, and to provide some level of early warning capability for potentially higher speed lateral impact events. A rear facing sensor field of view pattern **5** provides sensor coverage in a similar fashion to the side impact sensors **3** and **4**, by detecting stationary or slow moving objects near the rear of the vehicle in a wide arc, thus facilitating low speed maneuvers such as parking, while simultaneously enabling a rear impact sensor with a view of any vehicles approaching from the rear in an uncontrolled manner at higher speeds.

Figure 2 details one of the important design considerations regarding the ladar enabled collision avoidance system. A major issue is the question of where to mount the transmitter or transmitters on the vehicle as well as where the optical detectors should be mounted. In most of the previous work by the present inventors, these transmitters and receivers have been co-located as close as possible with parallel and overlapping fields of view along the same radial axis. By mounting the ladar sensor high on the vehicle, it might be possible to sweep an entire 360° field of view, thus keeping one aspect of system complexity to a minimum. However, as the diagram shows, a high mounted ladar sensor **8** co-located with the rear view mirror or dome light position, blind spots arise in the near field below the projection line **12** of the forward field of view **11** of the high mounted ladar sensor **8**. In a similar fashion, these blind spots will appear at the rear of the vehicle below a line of sight from the rear view mirror or dome light position **8** to where this line of sight is cut off by the trunk lid. To a lesser extent, additional blind spots will arise on the left and right side of the vehicle in the near field below a line of sight from the rear view mirror to the bottom of the driver's side window where it connects with the door panel, and likewise on the passenger's side where the window connects with the door panel. Other blind spots arise for a high mounted ladar sensor which are caused by the roof supports at either end of the front windshield, the front and rear doors, and the rear windshield. These are commonly referred to in industry parlance as the A, B, and C pillars, respectively. Additional optical transmission blockages may be caused by the vehicle occupants, seatbacks, headrests, and tissue boxes, stuffed animals, etc., stored on the rear windshield deck. The issues of optical transmission blockages are very similar for a high mounted ladar sensor **8** co-located with either the rear view mirror or the dome light.

As shown in Figure 2, the distance to where the lower line of sight limit **13** intersects the roadway surface **15** is greater in a dash mounted ladar sensor variant **9** than in the high mounted case shown by line **12**. This increase in the blind spots of the dash mounted variant **9** will be further exacerbated in the rear view and sides because of the much lower initial height of the dash mounted sensor **9**, creating a much lower angle as in the angle shown between line of sight **13** and roadway **15**. Additionally, optical transmission blockages in the passenger compartment such as occupants, seats, headrests, etc. will be exacerbated due to their being directly in the viewing path of a dash mounted ladar sensor **9**. These blindspots reduce the ability of the ladar sensor to perfom adequately in slow maneuvers such as backing up from a driveway or parking. Though the high mount **8** ladar sensor position is preferable to the dash mount variant **9**, both options have significant limitations. At the bottom of Figure 2, the preferred low level headlamp **18** mounting point or taillight/indicator light level mounting point **10** of the ladar sensor is depicted with a lower line of sight **14**. This mounting arrangement substantially reduces the blindspots in the search pattern identified above with respect to both the high mounted dome light or rear view mirror position **8**, and the mid-level dash mounted variant **9**. High mount **8** and mid-level mounting positions **9** for the ladar sensor would preclude the projection of a near field illumination and search pattern **16** if not mounted at the periphery of the vehicle. Near field illumination pattern **16** can be formed from the same light beam which produces far field illumination pattern **11** using a combination of refractive and diffractive optics. These refractive and diffractive optics may also serve as the collection mechanism for the light reflected from object in the field of view of the ladar sensor. Diffractive optics work on the principle of interference, not bending (refraction) of light. Diffractive optics, which are very thin and compact, are used to shape the laser beam so photons aren’t emitted out to the field of view of the receive optics.

Returning to Figure 1, the coverage pattern in the horizontal plane could be achieved with four independent sensors. Patterns **1** and **2** can be formed from the same ladar sensor using a combination of refractive and diffractive optics for both the transmission of the illuminating light pulses and the collection of the light reflected from objects in the field of view. Patterns **3**, **4**, and **5** can be produced from an additional three independent sensors placed at strategic points on the vehicle for a total of four independent sensors. However, in an automobile design, the difficulty associated with finding four new points for mounting of ladar sensors should not be underestimated. Engineers tasked with designing an automobile chassis and body would need to accommodate the additional four openings in the body panels and provide electrical wiring harness interfaces and routing of the harness to the new points. There becomes the need to increase the number of parts used in the sub assemblies and the top assembly, and there would need to be additional stations on the assembly line to install each of the new independent ladar sensors.

A more sophisticated approach is to reuse the packaging of the headlamps, turn signals, and taillight/brakelight assemblies for the mounting of the ladar sensors. The advantages of this approach build on a significant body of knowledge gained over many years in the automotive industry. Headlamps and taillights have migrated to the periphery of the vehicle for issues of operation and visibility. Long gone are the days of single headlamps mounted at the forward center of the vehicle like a locomotive. Likewise, most headlamps and taillight/brakelight assemblies are mounted at the corners of the vehicle for reasons of illumination of the area of operation of the vehicle, and for visibility of the vehicle to operators of other vehicles in the vicinity. This great body of knowledge should be built on, rather than lightly disregarded when integrating a new function, the ladar sensor, into a moving vehicle such as an automobile. We expect a much easier path to adoption of this new functionality if it can be integrated with the present functions and hardware associated with the pathway illuminating systems of the vehicle rather than a fully independent approach with major accommodations made to the body and chassis and assembly lines if the ladar sensors are not incorporated into the existing pathway illuminating hardware. Therefore, the integrated headlamp and ladar sensor is developed herein as well as the integrated auxiliary lamp and ladar sensor assembly. By auxiliary lamp we mean any short range illuminating lamp or indicator light, to include at minimum, turn signals, brake lights, taillights, parking lights, or any similar lights commonly installed on moving vehicles.

This approach to integrating the ladar sensor into the headlamp assemblies and auxiliary lamp or indicator light assemblies will produce fields of view as shown in Figure 9, with identical overlapping far field illumination and viewing patterns **11** projected along roadway **7**. The overlapping horizontal projections of near field patterns **16** in Figure 9 are from ladar sensors integrated into indicator lights **10** as shown in Figure 2, or from integrated ladar sensor and headlamp assemblies **18** as discussed in Figures 3 and 4.

Referring to Figure 3, an important feature of the integrated headlamp and ladar sensor we describe is the ability to steer the field of view of the ladar illumination pulse **11** along with the headlamps mechanically in the vertical and horizontal axes. The diagram in Figure 3 shows a moving vehicle **6** travelling at the crest of a hill **87**, with articulating ladar sensor and headlamp **18** at a depressed angle, illuminating the trough at the bottom of the curvature of the hill **87**. Likewise, the bottom of Figure 3 shows a moving vehicle **6** travelling at the bottom of a dip in the road, prior to ascending a hill, **17**. In this view, the ladar sensor and headlamp assembly **18** is at an elevated angle, sweeping out the incline of the curvature of the hill, **17** rising in front of it.

Figure 4 further illustrates the advantages of the beam steering capability of the ladar sensor and headlamp assembly **18**. Pictured is a motor vehicle **6** approaching a bend to the left in the roadway **19**. Both headlamp and ladar sensor far field beam patterns **11** are steered to the left to sweep out the area in the path of the vehicle at the greatest distance from the vehicle, therefore giving the greatest possible amount of time for collision threat detection and avoidance.

Figure 5 illustrates a number of design and construction features of the integrated ladar sensor and headlamp assembly **18**. At the right of Figure 5 is shown a cross section showing details of the assembly taken along line SS. The assembly is contained within a glass or high impact plastic transparent envelope **20**. A double lens system for collecting and focusing the light returned from the scene in the field of view is formed by large diameter lens **21** at the front of the assembly, which works with a second lens **35** directly in front of receive sensor **28**.

Receive sensor **28** is comprised of an infrared focal plane array mounted atop a readout integrated circuit and thermal management interface. The ladar sensor is comprised of laser light source **31**, receive sensor **28,** and additional electronics contained in electronics housing **29**. Mounted between second lens **35** and receive sensor **28** is an optical bandpass filter **41** which blocks all wavelengths of light except the wavelength of the light from the laser light source **31**, typically 1.57 microns in the preferred embodiment. The laser light source **31** may be a solid-state laser, semiconductor laser, fiber laser, or an array of semiconductor lasers. In the preferred embodiment, laser light source **31** is a disc shaped solid state laser of erbium doped phosphate glass pumped by 976 nanometer semiconductor laser light. In an alternative embodiment, laser light source **31** is an array of vertical cavity surface emitting lasers (VCSELs). The operation of receive sensor **28** will be discussed in greater detail in connection with Figure 10, the system block diagram. Supporting the large diameter lens **21** are a number of lens supports **22** which may be thermosonically bonded to transparent envelope **20**, or formed/molded into transparent envelope **20**. Large diameter lens **21** may be of a material which has a different index of refraction at the transmission wavelength of 1.57 microns from the index of refraction it exhibits at the headlamp illumination wavelengths in the .45-.65 micron range. This dichroic behavior of the material of large diameter lens **21** may be put to good use, creating different illumination patterns for the 1.57 micron ladar sensor illuminating laser **31**, and the visible white light emitting diodes **33**. Visible white LEDs **33** supplant the incandescent or halogen bulbs of traditional headlamps in the instant invention, due to their much higher efficiency, and therefore lower heat production. Shown on the left side of Figure 5 is a radial arrangement of eight LED subassemblies (**33**, **25**, and **26**) for simplicity and clarity of the drawing, but the actual number of LED subassemblies is typically much greater, on the order of 32-128, depending on the power desired for the particular headlamp or indicator lamp application. An example of a benefit of a dichroic material for large diameter lens **21** is the ability to project an illuminating 1.57 micron laser pulse in a far field pattern **11** to match the far field pattern of the LED light sources **33**, while at the same time illuminating the near field of the vehicle **6** with 1.57 micron pulsed laser light in a near field pattern **16**, with little or no light from the LED light sources **33** being diverted into the near field. Because the near field of the vehicle is not directly visible from the driver's position, it makes sense to not divert optical flux from the LED visible light into the near field **16**. It is preferred to have as much of the visible light transmitted so as to illuminate the driver's line of sight in the far field.

As noted above, LED light sources **33** are chosen for this application because of their high efficiency. The high efficiency of LED light sources produces real benefits to the integrated ladar sensor and headlamp in three significant ways. First, it reduces heating of the adjacent receive sensor **28** of the ladar sensor. The detector array of receive sensor **28** is typically a two dimensional array of Avalanche PhotoDiodes (APDs), which are sensitive to shifts in operating temperature, and must be operated at a fixed temperature in the preferred embodiment of the invention. In order to keep the temperature of the receive sensor **28** comprised of APD array and readout IC constant, thermoelectric coolers are used as a heat pump to remove excess heat to an associated heatsink at the rear of the electronics housing **29**. Closed circuit control is then used to monitor and maintain the receive sensor **28** at a constant temperature by supplying a variable current to the thermoelectric coolers. Second, the ladar sensor may draw 30-40 watts of power from the vehicle electrical power systems. This additional power requirement can be offset by reducing the electrical power required to illuminate the roadway by substituting LEDs **33** for the traditional halogen or incandescent light sources, thus easing the burdens on the vehicle electrical system design, and facilitating the seamless integration of ladar sensing technology. Third, the dramatically increased life expectancy of the LED light sources reduces the probability the integrated ladar sensor and headlamp assembly **18** will have to be repaired during the life of the vehicle. Because the integrated ladar sensor and headlamp assembly **18** will of necessity be a subsystem with a higher value, the decision to repair or replace the integrated ladar sensor and headlamp **18**, should be based on the higher value component, the ladar sensor. This repair/replace decision is facilitated if the light sources chosen have an extremely low failure rate and very long lifetime as do the LED light sources **33**.

Each LED light source **33** typically has a molded aspherical lens **25** and reflector/director **26** to collect and project substantially all of the light emanating from LED light source **33** into the far field pattern **11**. Additionally, an optional intermediate lens **23** may be positioned between the molded lens **25** and the large diameter lens **21** to provide additional conditioning of the visible light beam emanating from the LED light source **33**. Intermediate lens **23** may be held in place by support features **24** molded into, formed in, or thermosonically welded to transparent envelope **20**. The intermediate lens **23** may be made of a polymer, or a glass with flexibility and formed in a split ring, with split **36** designed to allow the ring to be compressed in diameter prior to inserting into transparent envelope **20**. Once the intermediate lens **23** with split ring design is compressed, it may be engaged with the detent in support feature **24**, and then released, allowing it to spring out to its full diameter, thereby retained and supported within transparent envelope **20** by support features **24**. Visible LEDs **33** are mechanically supported and electrically connected via printed wiring board **27** which may be a printed circuit board made of fiberglass, alumina, aluminum nitride, or other insulator/conductor printed wiring system.

To complete the functionality of the integrated ladar sensor and headlamp **18**, a laser light source is necessary and is shown located on a parallel axis with receive sensor **28**. The laser light source has an eye safe filter **32** which limits the wavelength of light emitted through diffuser **34** to only those inherently eye-safe wavelengths of light. Diffuser **34** may be an ordinary refracting lens, an array of diffraction gratings, a series of ground or molded prisms, or a holographic diffuser. In the preferred embodiment, the wavelength of choice is in the range of 1.54-1.57 microns, though many other wavelengths may be useful as a source of illuminating laser light. A zero time reference is established by retro-reflector post **39** attached to transparent envelope **20** which indicates the leading edge of an outgoing laser pulse by feeding back a portion of the outgoing laser pulse energy to the receive sensor **28**, which detects it and processes the pulse in the same manner as all succeeding reflections from the scene in the field of view of integrated ladar sensor and headlamp assembly **18**. This reflected zero time reference optical signal is referred to locally as an Automatic Range Correction (ARC) signal, and the several pixels on receive sensor **28** illuminated by the ARC signal are referred to as ARC pixels, and are the zero time references for all range measurements made by integrated ladar sensor and headlamp assembly **18**. Retro-reflector post **39** may be formed of a plastic or glass and may be integrally molded with transparent envelope **20** or bonded to transparent envelope **20** thermosonically. The preferred method is to have retro reflector post **39** integrally molded into transparent envelope **20** and to apply a white epoxy paint or metallic coating as a reflective coating **40** to the exterior of transparent envelope **20** in line with retro-reflector post **39**. A metallic reflective coating **40** may be applied by any number of methods, including flame spraying, electroplating, or physical vapor deposition. Metallic coating may also be a thin film of metal applied under heat and pressure which causes the base material of transparent envelope **20** to reflow and permanently capture a metallic strip functioning as a metallic reflective coating **40**. The metal chosen for a metallic retro-reflective coating or layer **40** should be impervious to the effects of corrosion as it is an outside, exposed surface. Materials such as stainless steel, nickel, gold, and platinum are appropriate for this function. Finally, a sealant, or passivation layer may be applied over a metallic reflective coating **40** to further reduce the potential effects of a corrosive environment by using any of the above mentioned processes. The preferred method is to use physical vapor deposition in which a target of glass is heated in a crucible within a vacuum chamber to deposit a thin layer of passivating glass over the corrosion resistant metallic reflective coating **40**. Alternatively, if the transparent envelope **20** is plastic, any number of epoxy resins or plastic overmoldings may be applied as a passivating layer over reflective coating **40**.

Forming the retro-reflecting post **40** within the transparent envelope **20** serves a dual purpose with respect to the ARC signal and ARC pixels. It is expected there will be some non-negligible and undesirable retroreflections from an outgoing laser illuminating pulse from laser light source **31** when the light pulse encounters scratches, dirt, dead bugs, ice, snow, or other light reflecting obstructions which may be adhered to the front surface of transparent envelope **20**. It is important to have the ability to "gate out", or ignore, these signals by having an ARC signal which occurs later in time than these undesirable retro-reflections from the exterior surface of transparent envelope **20**. The additional delay occasioned by the height of retro-reflector post **39** and its non-unity index of refraction, creates additional delay over the thin sections of transparent envelope **20**, thus making the retro-reflected optical signal from a white or metallic reflective coating **40** occur slightly later in time than the undesired retroreflections from any materials adhered to the exterior surface of transparent envelope **20**. At the far right of Figure 5 is the interface connector **30** which carries bidirectional electrical signals, power, ground, and any necessary optical signals to and from the integrated ladar sensor and headlamp **18** and provides connections to the vehicle electrical and optical systems. Resident within electronics housing **29** are a serial communications port for bidirectional communications with a central ladar system controller (**71** in Figure 10), power conditioning electronics, and interface electronics including analog to digital converters for reporting the status of the integrated ladar sensor and headlamp **18**, and its associated analog parameters such as temperature, voltage, power consumption, etc. The serial communications port also sends ordered pairs of range and intensity detected by the ladar sensor to the central ladar system controller (**71** in Figure 10) and receives commands therefrom to control the direction of the sensor, the intensity of the laser illuminating pulse and the intensity of the LED light sources **33**. Electronics housing **29** also contains circuitry to convert digital signals and commands received from a central ladar system controller to analog values as required to point the integrated ladar sensor and headlamp **18**, to brighten or dim LED light sources **33**, or to run wiper/washer operations described in association with Figure 6.

Shown at the left of Figure 5 is a view looking into the integrated ladar sensor and headlamp **18** along the optical axis OA, showing a number of details of the design including the preferred rectangular shape **38** of receive sensor detector **28** as well as the rectangular shape **37** of the laser light source **31** of the preferred embodiment. Figure 5 is not a scale drawing; rather it is intended to illustrate the various design concepts incorporated in the preferred embodiment. Other lensing options with multiple convex surfaces, with concave surfaces, and alternatively, with some prismatic or diffractive surfaces may be employed to achieve the desired effects described herein. A shorter range, wider field of view integrated ladar sensor and auxiliary lamp **10** as anticipated in FIGs. 2 and 4, is an adaptation of the design described in association with Figure 5. The integrated ladar sensor and auxiliary lamp **10** uses a wide field of view lens with a short focal length such as a fisheye lens, or an array of diffractive gratings or prismatic elements to survey a field of view in excess of 90 degrees, and up to approximately 180 degrees. The term auxiliary lamp includes taillights, brake lights, parking lights, turn signal indicator lights, fog lights, etc., commonly found on the exterior of an automobile.

Figure 6 shows a number of optional features and alternative embodiments of integrated ladar sensor and headlamp assembly **18**. The right half of Figure 6 shows a cutaway view of integrated ladar sensor and headlamp **18** along section line DD. As noted with respect to the discussion of Figure 5 above, there is a distinct possibility of non-negligible retro-reflections from a variety of materials which could be adhered to the exterior of transparent envelope **20**. A wiper system comprised of electric motor **42**, rotating shaft **43**, and wiper blade **44** works together with washer fluid pumping tube **45** and washer fluid spray nozzle **46** to keep the exterior surface of integrated ladar sensor and headlamp assembly **18** free of bugs, dirt, snow, hail, etc. as much as possible in order to facilitate better 3-dimensional ladar sensor capability. Washer fluid pumping tube **45** has a hose fitting **47** extending towards the rear to engage with a hose from the vehicle windshield fluid reservoir and pump. A different optical design and layout are shown, with a greater number of visible LED subassemblies arranged in a radial pattern. Each LED subassembly in this case features a concave lens **25** together with a parabolic reflector of different shape for a different far field lighting effect. Circuit board support **48** is attached to transparent envelope **20** and creates a mounting point for the LED circuit board **27** assembly which is in a slightly more forward location in this embodiment of the design.

Connected to circuit board support **48** is lens mount **49** which is shown with two large diameter plano-convex lenses **21** and **50** mounted back to back to provide for a wide field of view for receive sensor **28**, though a number of other lensing arrangements are anticipated, including convex, concave, and aspherical shapes as well as arrays of prismatic and diffractive surfaces. Electrical connections **51** carry power and ground, brightness control, and other bidirectional signals through circuit board support **48** and electronics housing **29** to interface connector **30** for connection to the vehicle electrical systems. A further benefit of using a washer fluid spray system is the location of washer fluid spray nozzle **46**, which is positioned ideally to create a retro-reflected ARC signal suitable for illumination of the ARC pixels of receive sensor **28**. To function reliably in this manner, washer fluid spray nozzle **46** should be made of a corrosion resistant metal alloy such as stainless steel, nickel, gold, or platinum, or be powder coated white. The location of washer fluid spray nozzle **46** well outside the exterior surface of transparent envelope **20**, means the retro-reflected optical signals therefrom will be well delayed past any retro-reflected optical signals caused by bugs, mud, dirt, snow, or ice adhered to the exterior surfaces of transparent envelope **20**, making for an excellent solution to the question of where to locate and how to provide for an appropriate retro-reflected ARC signal suitable for illuminating the ARC pixels of receive sensor **28**.

A common design trade-off for a ladar sensor is the range versus transmitted power consideration. Greater transmitted power yields additional range, at the expense of more complex laser designs, greater electrical power requirements, and therefore cost and weight of the system. Figure 7 addresses this range problem in a new and unique manner with respect to ladar sensor design. Instead of arbitrarily increasing power to yield range enhancement, a much larger optical gain is realized in the ladar sensor optical receiver of this alternative embodiment by increasing the effective aperture of the ladar sensor optical receiver through beneficial use of a parabolic reflector **53** instead of the traditional glass or polymer lens elements of Figure 5. Moreover, the aspect ratio of the optical aperture created by reflecting mirror **53** may be adjusted to be rectangular **52**, circular, square, or any other desired geometry. Figure 7 illustrates a number of features not found in FIGs. 5 and 6. At the left of Figure 7 is a front view of the integrated ladar sensor and headlamp assembly **18**. At the right of Figure 7, a section of the front view along line FF looking to the left is shown. The parabolic reflector **53** captures light passing through the transparent envelope **20** and converges the captured incoming light at focus element **61** which is shown here as a secondary converging mirror, but may be a diverging mirror, or a convex or concave refracting lens, or a lens with an aspherical geometry. Focus element **61** conditions the light to pass through mirror aperture **60** so as to fall on the active area of receive sensor **28**. Focus element **61** is positioned and held in place by support beam **54** which is permanently affixed to, or integrally molded into, parabolic reflecting mirror **53**. Reflecting mirror **53** has a parabolic profile in the preferred embodiment and may be molded or formed out of metal, glass, or a fiber reinforced polymer, or another material suited to a particular application. Reflecting mirror **53** may alternatively be created in a characteristic shape which is spherical, hyperbolic, exponential, or another geometry which suits a particular application. The refractive lens designs as in FIGs 5 and 6 do not scale easily to large apertures and higher optical gains. A circular headlamp assembly may typically be 7 inches in diameter, thus leaving 6 inches for a large diameter lens **21** of FIGs 5, 6. Such a large diameter lens **21** manufactured out of a solid glass blank will be expensive and heavy, and require a more substantial mechanical mounting system, with the additional associated weight and cost. Because the parabolic reflector **53** may be cast, molded, or formed out of a thin walled glass, powder metal, or fiber reinforced polymer, it will be much lighter for a given aperture and optical gain than an equivalent solid glass lens. This resultant lower weight has many benefits for man-portable and flight systems, and has a much lower cost of fabrication.

The laser illuminating source **31** in the design embodiment of Figure 7 is positioned outside the transparent envelope **20** of the integrated ladar sensor and headlamp **18**, and is coupled through a fiber coupler **59** and flexible optical fiber **58** and rigid lightguide **57** to corner cube **55.** Corner cube **55** rotates the transmission axis of the illuminating laser light 90 degrees into alignment with the optical axis shown as dashed line OA of the integrated ladar sensor and headlamp assembly **18**. Corner cube **55** may be a high quality device made of ground glass coated with a reflecting mirror surface and mounted to support beam **54** using epoxy, adhesive or mechanical means such as C-clips, U-clips or other friction or compression fasteners, or assembled to diffuser **56** and then attached as a compound unit to support beam **54** using any of the aforementioned attachment methods. Corner cube **55** may alternatively be integrally formed with support beam **54** and coated with a reflective metallic surface, with diffuser **56** attached thereto. Diffuser **56** acts to distribute the illuminating laser light in any of the desired patterns discussed herein, and may be an arrayed waveguide grating, interference filter, holographic diffuser, or other diffractive optic construction. Diffuser **56** may be bonded to corner cube **55** by any number of methods including glass bonding, epoxy or adhesive bonding, or mechanical mounting using sheet metal C-clips, U-clips, or other compression and friction fasteners. Shown at the left of Figure 7 is the rectangular aspect of secondary lens **23** which is optionally included in the various embodiments shown herein. Also visible is the rectangular aspect of mirror aperture **60**, though other shapes are anticipated depending on particular applications of the invention as described herein.

Figure 7A illustrates a number of refinements to the integrated ladar sensor and headlamp assembly **18** incorporating a reflecting mirror **53**. At the left of Figure 7A is a front view of the integrated ladar sensor and headlamp assembly **18**. At the right of Figure 7A, a section of the front view along line FF looking to the left is shown. First, support beam **54** has been angled so focus element **61** can be above, or in this case, in advance of reflecting mirror **53**, thus increasing the focal length of reflecting mirror **53**, which is desirable in some cases to allow for an increased optical aperture without penalizing the optical performance. Increase of the optical aperture is desirable to produce a positive effect on optical gain. In this drawing it can be seen the proximity of diffuser **56**, corner cube **55**, and focus element **61** to the interior surface of transparent envelope **20** allows for them to be bonded directly to the transparent envelope **20** and for support beam **54** to be eliminated in low cost applications. An automobile might have two of this type of integrated ladar sensor and headlamp assembly **18**, plus four wide field of view ladar sensors integrated with auxiliary lighting assemblies **18**, resulting in the need for up to six laser light illuminating sources **31.** A further cost reduction mechanism anticipated is the concentration of all six laser illuminating sources into one central laser unit with a six-way power split output. This system architecture will be discussed in association with Figure 11. Shown in Figure 7A is flexible optical fiber **58** connecting within transparent envelope **20** through to interface connector **30** which in this embodiment connects to the vehicle optical and electrical harness (not shown in this Figure). The optical transmission lines within the optical and electrical wiring harness then connect to a central illuminating laser source which will be discussed in association with Figure 11.

Figure 8 illustrates details of the mechanism which provides the ability to point the integrated ladar sensor and headlamp assembly **18** both left and right, and up and down and responds to electrical positioning signals received over sub-assembly wiring harness **65**. Attached to transparent envelope **20** are two motorized horizontal pivots **62** positioned at the top and bottom of transparent envelope **20** which can rotate transparent envelope **20** both left (counter-clockwise) and right (clockwise) around vertical axis line VA. The second horizontal pivot **62** at the bottom of Figure 8 may be motorized, or may be a passive pivot consisting primarily of a rotary bearing. Motorized horizontal pivot **62** has electrical connections **66** which provide power, ground, and motor control to the motorized horizontal pivot **62**, and return motor status and rotational position status signals from the motorized horizontal pivot **62**. An outer housing **68** provides an attachment point for motorized horizontal pivots **62**, and may be in the shape of a full shell adapted to the contours of transparent envelope **20**, with adequate clearance to allow for a full range of horizontal and vertical angular displacement of transparent envelope **20**. Outer housing **68** is typically a full shell when the integrated ladar sensor and headlamp **18** is mounted on external hard points such as might be found on a military or utility vehicle. Alternatively, if the integrated ladar sensor and headlamp **18** is housed in a recessed opening in the body of a vehicle, as is typical in an automotive application, the full shell design for outer housing **68** can be replaced with a very simple open yoke which has a flattened toroid shape and only has sufficient depth to provide attachment to both motorized horizontal pivots **62** and motorized vertical pivots **63.** Horizontal pivots **62** and vertical pivots **63** and their respective rotational axes typically lie in the same plane. Motorized vertical pivots **63** attach to outer housing **68** and act to point the subassembly consisting of the outer housing **68**, motorized horizontal pivots **62**, and transparent envelope **20** up or down depending on electrical control signals received over electrical connections **67**. The second vertical pivot at the left of Figure 8 need not be motorized, and may be a simple passive pivot with rotary bearing. Electrical connections **67** provide power ground, and motor control signals to motorized vertical pivots **63,** and return motor status and angular position to a central controller. Both sets of electrical signal wires **66** and **67** pass through a vehicle mount **64** which may be a recess in a body panel in an automotive application, or a mounting bracket on an exterior surface of a utility or military vehicle. These two independent sets of electrical connections **66** and **67** then merge in a sub-assembly wiring harness **65** before terminating in an electrical connector **69** which is adapted to connect to the vehicle electrical systems.

Figure 9 shows an overhead view of an automobile **6** equipped with two of the integrated ladar sensor and headlamp assemblies **18** described in the text and in FIGs 5-8 above. The automobile is also equipped with short range integrated ladar and auxiliary lamp assemblies **10** at the four corners of the vehicle. The long range integrated ladar sensor and headlamp assemblies **18** provide a narrow and long distance field of view **11** along the length of straight roadway **7**, while the short range integrated ladar sensor and auxiliary lamp assemblies **10** provide an overlapping and much wider and shorter range field of view **16**. Typically the shorter range integrated ladar sensor and auxiliary lamp assemblies **10** are not capable of traversing, but operate in a staring mode, to reduce complexity and costs associated with the auxiliary lighting functions. In staring mode short range sensors are not capable of traversing in either a lateral angle or vertical angle like the headlamp assemblies. The overlapping region **70** between short range fields of view **16** at the rear of the vehicle is an area where object identification can be enhanced by post processing and comparing the 3-D images from the left and right short range integrated ladar and auxiliary light assemblies **10**. Object identification can be enhanced by the object rotating or moving through the field of view, or by the motion of the observing platform, or by simultaneous capture of 3-D information from two or more surfaces on the object not directly viewable from the same point of view, necessitating two independent ladar sensors with fields of view converging on the object in question as in overlapping region **70**.

Figure 10 shows a simplified system block diagram of a typical installation on a vehicle as anticipated herein and described in the preceding Figures 1-9. A ladar based collision avoidance system consisting of a central ladar system controller **71** connects to six independent ladar sensors through bidirectional connections **72** and **73**. Two long range units, each comprising an integrated ladar sensor and headlamp **18,** connect to system controller **71** through a set of bidirectional electrical and optical connections **72**. Connections **72** are comprised of electrical wires, optical fibers, and hybrid electrical/optical connectors in the preferred embodiment. Four short range units, each comprising an integrated ladar sensor and auxiliary lamp **10** connect to the system controller **71** through a set of bidirectional optical/electrical connections **73**. Connections **73** are comprised of electrical wires, optical fibers, and hybrid electrical/optical connectors in the preferred embodiment. Each integrated ladar sensor and headlamp **18** and integrated ladar sensor and auxiliary light **10** have at their core a receive sensor **28** first referenced herein in connection with the discussion of Figure 5. Receive sensor **28** is comprised of a two-dimensional focal plane array of avalanche photodetectors mounted atop a readout integrated circuit in the preferred embodiment. A square array of 128X128 avalanche photodetectors on an indium phosphide substrate comprises the focal plane array of the preferred embodiment. The focal plane array is bonded to and electrically connected to a readout integrated circuit via a square array of 128X128 indium bumps formed on the circuit side of the focal plane array. Each detector of the array is individually connected to a unit cell of the readout integrated circuit. The unit cell contains an input low noise amplifier, bandpass filter, threshold detecting circuit, analog sampler, and analog sample shift register, as well as a timing circuit referenced to a global input indicating the start of a laser illuminating pulse. Other signal conditioning circuitry resides on the readout integrated circuit which enable high fidelity reception and detection of low level optical signals reflected from objects and features in the field of view of the ladar sensor. Additional support circuitry resides on printed circuit boards within electronics housing **29** of Figure 5 which provide global timing references, buffer the readout integrated circuit outputs, convert analog signals to digital signals, convert digital signals to analog signals, provide necessary bias voltages, and set or adjust variables used within receive sensor **28**. Each ladar sensor of the preferred embodiment is of the flash ladar type. As used herein, a flash ladar is capable of illuminating a field of view with a single pulse of laser light, detecting the reflections from the field of view incident upon a two-dimensional array of light sensitive pixels, and measuring both the intensity and range to each feature in the field of view identifiable by an optical return incident upon a pixel in the two-dimensional array. Further details of the operation of receive sensor **28** are given in the citations of the present inventors previous work in the prior art references which are incorporated herein by reference

Figure 11 details the inner workings of ladar system controller **71** and amplifies on the nature of its interoperation with a variety of external integrated ladar sensor and vehicle headlamp and signal lamp modules. Ladar system controller **71** is comprised of seven basic elements, each connected and operating as follows in this preferred embodiment. A digital processor/controller **81** supervises the operations of the ladar system controller internal components, as well as controlling communications with the host vehicle through bidirectional connections **85**. Processor/controller **81** is a general purpose microcomputer integrated circuit in the preferred embodiment, but may be a specialized automotive processor adapted specifically to a vehicle manufacturer requirement, or a state machine such as a field programmable gate array or other programmable logic device. If the processor/controller **81** is a state machine type of device, non-volatile memory **80** is not required and can be eliminated. Typically, upon power-up of the ladar system controller **71**, processor/controller **81** initiates a boot-up sequence wherein the non-volatile memory **80** is accessed for the operating firmware which is loaded into a memory resident within processor/controller **81**. The memory resident within processor/controller **81** is typically volatile memory such as DRAM. Non-volatile memory **80** may also be resident on some processor/controller **81** integrated circuit designs in the form of ROM or PROM. If sufficient non-volatile memory is available within processor/controller **81**, external non-volatile memory **80** may be eliminated to reduce cost and simplify design. Normally, non-volatile memory **80** is comprised of ROM, PROM, Flash memory, or optical or magnetic storage media.

Processor/controller **81** supervises the data communications port **82**, which is a general purpose Ethernet port in the preferred embodiment. Data communications port **82** may also be of a type specifically adapted to the vehicle market such as a CAN bus interface port, IDB-1394, SAE J1708 interface, or any of a multiplicity of other choices. Data communications port **82** may also be resident on processor/controller **81**, and is often included on many commercially available general purpose and automotive digital controller integrated circuit designs. The host vehicle **6** may also provide through bidirectional connections **85** and data communications port **82** periodic updates to the firmware resident on the non-volatile memory **80**, which would typically occur during scheduled maintenance visits or vehicle recalls. The host vehicle may also provide through data communications port **82** a number of important data to the ladar system controller **71** during normal operation, such as current time and date, vehicle position, speed, acceleration, turning rate, angle of incline/decline, weather data, or other vehicle or global data useful in managing and controlling the vehicle ladar sensors and headlamps and auxiliary lamps.

Processor/controller **81** determines the timing and initiates the pulsing of illuminating pulsed laser transmitter **79** in the embodiment detailed in Figure 11. The pulsed laser transmitter **79** is a low power or medium power semiconductor laser in this alternative embodiment, with output in the 1.54-1.57 micron wavelength. The optical output of pulsed laser transmitter **79** is passed through a length of erbium doped optical fiber which is simultaneously optically pumped by a number of semiconductor laser diodes at a nominal wavelength of 976 nanometers, though other wavelengths of pump light may be used. The amplifier/pump diodes module **78**, comprised of a coil of erbium doped fiber and several pump laser diodes create an amplified and intensified optical illuminating pulse with sufficient power to illuminate all of the required fields of view (**1**,**2**,**3**,**4**,**5**,**11** or **16**) of the various and several ladar sensors positioned on the vehicle **6**. Pulsed laser transmitter **79** and amplifier/pump diodes **78** are typically housed together in laser transmitter module **86**, but other arrangements are anticipated. The output of laser transmitter module **86** is then split into six output fibers **76** by optical power divider **77**. Optical power divider **77** typically splits the optical signal from laser transmitter **79** into six fiber outputs **76** with unequal power ratios. Optical power divider **77** may be an optical fiber coupler, or may be comprised of a series of neutral density filters, or may be a spatial optical power divider using a lens to condition the optical propagating mode appropriately to be divided amongst a number of optical outputs. Two high power laser light signals are provided for use by long range units LRU1 and LRU2, which are typically of the type of integrated ladar sensor and headlamp **18** described in FIGS. 5-8. Four lower power laser light signals are provided for use by short range units SRU1-SRU4, which are typically of the type of integrated ladar sensor and auxiliary lamp **10** described in FIGS 5-8. The six fiber outputs **76** are connected to the remote ladar sensor units SRU1-SRU4 and LRU1 and LRU2 through a fiber cable and wire harness **74** which may be routed throughout the vehicle in parallel with the host vehicle **6** wiring harness.

Connections to each long range integrated ladar sensor and headlamp unit **18** at the terminus of the fiber cable and wire harness **74** are made through bidirectional connections **72** as described with respect to Figure 10. Connections to each short range integrated ladar sensor and auxiliary lamp unit **10** at the terminus of fiber cable and wire harness **74** are made through bidirectional connections **73** as described with respect to Figure 10. In an alternative to the embodiment of laser transmitter **86** described above, the coil of erbium-doped fiber is removed from amplifier/pump diode module **78**, and a length of erbium doped fiber is connected between output fibers **76** and each ladar sensor unit **10** or **18** positioned on the vehicle **6** periphery. The fiber cable and wire harness **74** is in this alternative embodiment an active optical system, with six separate optically amplifying erbium doped fibers routed through the harness **74**. Fiber cable and wire harness **74** may be partially comprised of steel or metallic wire, Kevlar®, or other fiber strength members. Fiber cable and wire harness **74** is typically also comprised of conductive wires of copper, aluminum, German silver, or other electrically conductive material. Fiber cable and wire harness **74** also comprises a number of optical waveguides suitable for optical communications or transfer of high power optical pulses, and fabricated from any number of glass or polymer compounds characterized for these purposes. Finally, the individual strength members and electrical conductors and optical waveguides of fiber cable and wire harness **74** are typically bound together by tape wound around the bundle, plastic tubing slipped over the bundle, or a plastic jacket overmolded onto the outside of the bundle.

Processor/controller **81** also connects to sensor interface **84** which serves to condition the digital signals from processor/controller **81** appropriately for transmission to any one of two long range sensor units **18** or four short range sensor units **10**. Sensor Interface **84** has six bidirectional connection ports **75** which carry signals to ladar sensor units **10** and **18**, and return signals therefrom. These six bidirectional connection ports **75** connect with electrical conductors and optical waveguides embedded within fiber cable and wire harness **74**. The bidirectional connection ports **75** may be parallel electrical bus, serial electrical interface, serial or parallel optical interface, or some combination of electrical and optical interfaces, and also provide electrical power and ground return signals in the preferred embodiment. Sensor interface **84** also receives status signals and data signals from each of the long range sensor units **18** and short range sensor units **10** through connections **72** and **73**, fiber cable and wire harness **74**, and bidirectional connection ports **75**. The data signals consist of range and intensity pairs for each pixel in a two-dimensional focal plane array, which provide a complete 3-D image of an object or scene in the field of view of the sensor, from a single point of view. Sensor interface **84** passes status data to processor controller **81** and object and scene data in the form of ordered range and intensity pairs to scene processor **83**. Sensor interface **84** may contain analog to digital converters, digital to analog converters, pulse width modulation circuits, or any of a variety of other interface type circuits useful for controlling and monitoring a remote peripheral ladar and lighting subsystem. Sensor interface **84** may be an integrated circuit, and in some cases, may be resident on processor/controller **81**.

Scene processor **83** makes use of the data received from all six ladar sensors of the short range type **10** and long range type **18** to synthesize a composite view of the area in front of, behind, and surrounding the vehicle **6** and objects within these fields of view (**1**,**2**,**3**,**4**,**5**,**11**, and **16**). Scene processor **83** also identifies and tracks objects both static and moving within the composited scene and features in the scene posing a risk, and may also compute the relative risk and timing of a potential impact with any of these objects or features in the composited scene. Alternatively, scene processor **83** may be resident outside of ladar system controller **71** and be associated with the host vehicle **6** central computing function, in which case ordered pairs of scene data are merely passed from sensor interface **84** directly to data communications port **82** and thence to the host vehicle **6** for further processing. It is also envisioned ladar system controller **71** may be entirely encompassed within the vehicle **6** central electronics and computing function, and may even be largely realized as a software/firmware function executable on the vehicle **6** standard computing platform. Several modes of operation for the overall collision avoidance function are envisioned. A first mode, enabled by the several described embodiments, consists of simply displaying a 3-D graphics image showing the various details of stationary features in the scene and objects in motion which may be in the path of the vehicle **6** or on a collision course with the host vehicle **6**. This first described mode relies on the vehicle **6** operator to make judgements and apply vehicle controls appropriately to maneuver the vehicle **6**. This first described mode is fully supported by the specification herein minus the details of the display. A second mode, in which warnings of an impending collision are communicated to the vehicle operator, relies on a collision threat computation made by scene processor **83** or by the host vehicle **6** systems based on the 3-D range and intensity data provided by the various embodiments described herein. In this second mode, the specification of the Flash LADAR Collision Avoidance System as described herein may require the host vehicle to make computations of risk based on the 3-D data provided, and warn the vehicle **6** operator by visual, tactile, or auditory means. In a third operational mode, host vehicle **6** makes computations of risk or threat of collision based on 3-D data provided by the invention described herein, and applies control to vehicle **6** steering, braking, and engine systems to effect collision avoidance and/or steer and guide the vehicle autonomously. All three of the described collision avoidance modes are supported and enhanced by the presence and operation of the Flash LADAR Collision Avoidance System comprised of the various embodiments described herein in association with the numbered drawings.

Although the invention of the Flash LADAR Collision Avoidance System and the integrated ladar sensor and headlamp/auxiliary lamp and associated systems have been specified in terms of preferred and alternative embodiments, it is intended the invention shall be described by the following claims and their equivalents.

What is claimed is:

1. A ladar sensor with a field of view and headlamp with forward illuminating pattern housed within a common envelope and mounted to a vehicle, said envelope with at least one transparent face capable of transmitting visible wavelengths of light and infrared laser light;

said ladar sensor further comprising

a pulsed laser light output and diffusing optic for illuminating a scene in the field of view of said ladar sensor, and

a two dimensional array of light sensitive detectors positioned at a focal point of a light collecting and focusing lens, said light sensitive detectors for producing an electrical pulse from a reflected portion of the said pulsed laser light output,

an electrical circuit connected to each light sensitive detector output for amplifying and detecting said electrical pulse with a detected pulse output, and

a timing circuit connected to each detected pulse output, and

said timing circuit further connected to a reference signal indicating the start time of said pulsed laser light output, and

said timing circuit producing an elapsed time signal indicating the time delay between the start time of the said pulsed laser light output and an electrical pulse indicated by said detected pulse output from said electrical circuit,

said headlamp further comprising

at least one visible light source with a visible light output beam and

at least one visible light transmitting optical element for conditioning said visible light output beam to create said headlamp forward illuminating pattern.

2. The ladar sensor of claim 1 wherein the said ladar sensor is a flash ladar.

3. The ladar sensor of claim 1 wherein the said common envelope is made of glass.

4. The ladar sensor of claim 1 wherein the said common envelope is made of a polymer.

5. The ladar sensor of claim 1 wherein the said laser light output is from a solid state laser.

6. The ladar sensor of claim 5 wherein the said solid state laser is made of erbium doped phosphate glass.

7. The ladar sensor of claim 5 wherein the said solid state laser is in the shape of a disc.

8. The ladar sensor of claim 1 wherein the said diffusing optic is an array of diffractive elements.

9. The ladar sensor of claim 1 wherein the said diffusing optic is a holographic diffuser.

10. The ladar sensor of claim 1 wherein the said common envelope is mounted on a bracket to an exterior surface of a host vehicle.

11. The ladar sensor of claim 1 wherein the said common envelope is mounted to an interior surface of a host vehicle.

12. The ladar sensor of claim 1 wherein the said common envelope is mounted within a recess in a body panel of a host vehicle.

13. The ladar sensor of claim 1 wherein the said common envelope is mounted on a host vehicle within the space normally used for a headlamp assembly.

14. The ladar sensor of claim 1 wherein the said common envelope is mounted on a host vehicle within a space normally used for an auxiliary light.

15. The ladar sensor of claim 1 wherein the said common envelope is mounted on a vertical pivot .

16. The ladar sensor of claim 15 wherein the said vertical pivot is a motorized pivot.

17. The ladar sensor of claim 1 wherein the said common envelope is mounted on a horizontal pivot.

18. The ladar sensor of claim 17 wherein the said horizontal pivot is a motorized pivot.

19. The ladar sensor of claim 1 wherein the said two dimensional focal plane array of infrared light sensitive detectors is comprised of light sensitive avalanche photodiodes.

20. The ladar sensor of claim 1 wherein the said at least one visible light source is a light emitting diode.

21. The ladar sensor of claim 1 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is an aspherical lens.

22. The ladar sensor of claim 1 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is lens with spherical contour.

23. The ladar sensor of claim 1 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is a reflector.

24. The ladar sensor of claim 1 wherein the said envelope with at least one transparent face is provided with a motorized wiper, and said wiper is positioned and held in place so a substantial portion of said at least one transparent face is wiped when the motor is actuated by an electrical signal.

25. The ladar sensor of claim 1 wherein the said envelope with at least one transparent face is provided with a washer fluid pumping tube and washer fluid spray nozzle, and said washer fluid spray nozzle is positioned and held in place so a substantial portion of said at least one transparent face is washed when a washer fluid is forced through said washer fluid pumping tube.

26. The ladar sensor of claim 1 wherein a small retro-reflecting surface is formed on the said at least one transparent face of said common envelope which causes a sample of said laser light output to fall on at least one of said infrared light sensitive detectors.

27. The ladar sensor of claim 1 wherein the said common envelope has a connector mounted thereon which provides electrical connectivity to the host vehicle.

28. The ladar sensor of claim 1 wherein the said common envelope has a connector mounted thereon which provides optical connectivity to the host vehicle.

29. The ladar sensor of claim 1 wherein the said laser light output is from a semiconductor laser.

30. The ladar sensor of claim 1 wherein the said laser light output is from a vertical cavity surface emitting laser.

31. The ladar sensor of claim 1 wherein the said laser light output is from a remote laser delivered through an optical waveguide.

32. The ladar sensor of claim 31 wherein the said optical waveguide is an optical fiber.

33. The ladar sensor of claim 1 wherein the said laser light output is from an output of an optical amplifier.

34. The ladar sensor of claim 1 wherein the said light collecting and focusing lens is a dichroic lens.

35. The ladar sensor of claim 1 wherein the said light collecting and focusing lens comprises a reflecting mirror.

36. The ladar sensor of claim 35 wherein the said reflecting mirror is of a parabolic shape.

37. A ladar sensor with a field of view and auxiliary lamp with lateral illuminating pattern housed within a common envelope and mounted to a vehicle, said envelope with at least one transparent face capable of transmitting visible wavelengths of light and infrared laser light;

said ladar sensor further comprising

a pulsed laser light output and diffusing optic for illuminating a scene in the field of view of said ladar sensor, and

a two dimensional array of light sensitive detectors positioned at a focal point of a light collecting and focusing lens, said light sensitive detector for producing an electrical pulse from a reflected portion of the said pulsed laser light output,

an electrical circuit connected to each light sensitive detector output for amplifying and detecting said electrical pulse with a detected pulse output,

a timing circuit connected to each detected pulse output, and

said timing circuit further connected to a reference signal indicating the start time of said pulsed laser light output, and said timing circuit producing an elapsed time signal indicating the time delay between the start time of the said pulsed laser light output and an electrical pulse indicated by said detected pulse output from said electrical circuit,

said auxillary lamp further comprising

at least one visible light source with a visible light output beam and

at least one visible light transmitting optical element for conditioning said visible light output beam to create said auxiliary lamp lateral illuminating pattern.

38. The ladar sensor of claim 37 wherein the said ladar sensor is a flash ladar.

39. The ladar sensor of claim 37 wherein the said common envelope is made of glass.

40. The ladar sensor of claim 37 wherein the said common envelope is made of a polymer.

41. The ladar sensor of claim 37 wherein the said diffusing optic is an array of diffractive elements.

42. The ladar sensor of claim 37 wherein the said diffusing optic is a holographic diffuser.

43. The ladar sensor of claim 37 wherein the said common envelope is mounted to an interior surface of a host vehicle.

44. The ladar sensor of claim 37 wherein the said common envelope is mounted within a recess in a body panel of a host vehicle.

45. The ladar sensor of claim 37 wherein the said common envelope is mounted on a host vehicle within the space normally used for an auxiliary lamp assembly.

46. The ladar sensor of claim 37 wherein the said two dimensional focal plane array of infrared light sensitive detectors is comprised of light sensitive avalanche photodiodes.

47. The ladar sensor of claim 37 wherein the said at least one visible light source is a light emitting diode.

48. The ladar sensor of claim 37 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is an aspherical lens.

49. The ladar sensor of claim 37 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is a lens with spherical contour.

50. The ladar sensor of claim 37 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is a reflector.

51. The ladar sensor of claim 37 wherein a small retro-reflecting surface is formed on the said at least one transparent face of said common envelope which causes a sample of said laser light output to fall on at least one of said infrared light sensitive detectors.

52. The ladar sensor of claim 37 wherein the said common envelope has a connector mounted thereon which provides electrical connectivity to the host vehicle.

53. The ladar sensor of claim 37 wherein the said common envelope has a connector mounted thereon which provides optical connectivity to the host vehicle.

54. The ladar sensor of claim 37 wherein the said laser light output is from a semiconductor laser.

55. The ladar sensor of claim 37 wherein the said laser light output is from a vertical cavity surface emitting laser.

56. The ladar sensor of claim 37 wherein the said laser light output is from a remote laser delivered through an optical waveguide.

57. The ladar sensor of claim 37 wherein the said optical waveguide is an optical fiber.

58. The ladar sensor of claim 37 wherein the said laser light output is from an output of an optical amplifier.

59. The ladar sensor of claim 37 wherein the said light collecting and focusing lens is a dichroic lens.

60. The ladar sensor of claim 37 wherein the said light collecting and focusing lens comprises a reflecting mirror.

61. The ladar sensor of claim 37 wherein the said reflecting mirror is of a parabolic shape.

62. A ladar sensor with a field of view and auxiliary lamp with rearward illuminating pattern housed within a common envelope and mounted to a vehicle, said envelope with at least one transparent face capable of transmitting visible wavelengths of light and infrared laser light;

said ladar sensor further comprising

a pulsed laser light output and diffusing optic for illuminating a scene in the field of view of said ladar sensor, and

a two dimensional array of light sensitive detectors positioned at a focal point of a light collecting and focusing lens, said light sensitive detector for producing an electrical pulse from a reflected portion of the said pulsed laser light output,

an electrical circuit connected to each light sensitive detector output for amplifying and detecting said electrical pulse with a detected pulse output, and

a timing circuit connected to each detected pulse output,

said timing circuit further connected to a reference signal indicating the start time of said pulsed laser light output, and said timing circuit producing an elapsed time signal indicating the time delay between the start time of the said pulsed laser light output and an electrical pulse indicated by said detected pulse output from said electrical circuit,

said auxiliary lamp further comprising

at least one visible light source with a visible light output beam and

at least one visible light transmitting optical element for conditioning said visible light output beam to create said auxiliary lamp rearward illuminating pattern.

63. The ladar sensor of claim 62 wherein the said ladar sensor is a flash ladar.

64. The ladar sensor of claim 62 wherein the said common envelope is made of glass.

65. The ladar sensor of claim 62 wherein the said common envelope is made of a polymer.

66. The ladar sensor of claim 62 wherein the said diffusing optic is an array of diffractive elements.

67. The ladar sensor of claim 62 wherein the said diffusing optic is a holographic diffuser.

68. The ladar sensor of claim 62 wherein the said common envelope is mounted to an interior surface of a host vehicle.

69. The ladar sensor of claim 62 wherein the said common envelope is mounted within a recess in a body panel of a host vehicle.

70. The ladar sensor of claim 62 wherein the said common envelope is mounted on a host vehicle within the space normally used for an auxiliary lamp assembly.

71. The ladar sensor of claim 62 wherein the said two dimensional focal plane array of infrared light sensitive detectors is comprised of light sensitive avalanche photodiodes.

72. The ladar sensor of claim 62 wherein the said at least one visible light source is a light emitting diode.

73. The ladar sensor of claim 62 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is an aspherical lens.

74. The ladar sensor of claim 62 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is a lens with spherical contour.

75. The ladar sensor of claim 62 wherein the said at least one visible light transmitting optical element for conditioning said visible light output beam is a reflector.

76. The ladar sensor of claim 62 wherein a small retro-reflecting surface is formed on the said at least one transparent face of said common envelope which causes a sample of said laser light output to fall on at least one of said infrared light sensitive detectors.

77. The ladar sensor of claim 62 wherein the said common envelope has a connector mounted thereon which provides electrical connectivity to the host vehicle.

78. The ladar sensor of claim 62 wherein the said common envelope has a connector mounted thereon which provides optical connectivity to the host vehicle.

79. The ladar sensor of claim 62 wherein the said laser light output is from a semiconductor laser.

80. The ladar sensor of claim 62 wherein the said laser light output is from a vertical cavity surface emitting laser.

81. The ladar sensor of claim 62 wherein the said laser light output is from a remote laser delivered through an optical waveguide.

82. The ladar sensor of claim 62 wherein the said optical waveguide is an optical fiber.

83. The ladar sensor of claim 62 wherein the said laser light output is from an output of an optical amplifier.

84. The ladar sensor of claim 62 wherein the said light collecting and focusing lens is a dichroic lens.

85. The ladar sensor of claim 62 wherein the said light collecting and focusing lens comprises a reflecting mirror.

86. The ladar sensor of claim 62 wherein the said reflecting mirror is of a parabolic shape.

87. A ladar headlight module comprising

a ladar sensor with a field of view and a headlight housed together in the same package and mounted to a vehicle, said ladar further comprising;

a pulsed infrared laser light output,

a ladar receive sensor further comprising

a two dimensional array of infrared light sensitive detectors, and a timing circuit connected to each pixel of said two dimensional array of infrared light sensitive detectors, said timing circuit providing a range measurement to features in the field of view reflecting a portion of said pulsed infrared laser light.

88. The ladar headlight module of claim 87 wherein the said ladar headlight module is mounted to an interior surface of a host vehicle.

89. The ladar headlight module of claim 87 wherein the said ladar headlight module is mounted within a recess in a body panel of a host vehicle.

90. The ladar hedlight module of claim 87 wherein the said ladar headlight module is mounted on a host vehicle within the space normally used for a headlight assembly.

91. The ladar headlight module of claim 87 wherein the said ladar headlight module is mounted on a vertical pivot.

92. The ladar headlight module of claim 91 wherein the said vertical pivot is a motorized pivot.

93. The ladar headlight module of claim 87 wherein the said ladar headlight module is mounted on a horizontal pivot.

94. The ladar headlight module of claim 93 wherein the said horizontal pivot is a motorized pivot.

95. The ladar headlight module of claim 87 wherein the said two dimensional array of infrared light sensitive detectors is comprised of infrared light sensitive avalanche photodiodes.

96. The ladar headlight module of claim 87 wherein the said ladar headlight module is provided with a motorized wiper, and said wiper is positioned and held in place so a substantial portion of said headlight is wiped when the motor is actuated by an electrical signal.

97. The ladar headlight module of claim 87 wherein the said ladar headlight module is provided with a washer fluid pumping tube and washer fluid spray nozzle, and said washer fluid spray nozzle is positioned and held in place so a substantial portion of said headlight is washed when a washer fluid is forced through said washer fluid pumping tube.

98. The ladar headlight module of claim 87 wherein a small retro-reflecting surface is formed on said same package housing both ladar and headlight and which causes an optical sample of said laser light output to fall on at least one of said infrared light sensitive detectors.

99. The ladar headlight module of claim 87 wherein the said ladar headlight module has a connector mounted thereon which provides electrical connectivity to a host vehicle.

100. The ladar headlight module of claim 87 wherein the said ladar headlight module has a connector mounted thereon which provides optical connectivity to the host vehicle.

101. The ladar headlight module of claim 87 wherein the said laser light output is from a semiconductor laser.

102. The ladar headlight module of claim 87 wherein the said laser light output is from a vertical cavity surface emitting laser.

103. The ladar headlight module of claim 87 wherein the said laser light output is from a remote laser delivered through an optical waveguide.

104. The ladar headlight module of claim 103 wherein the said optical waveguide is an optical fiber.

105. The ladar headlight module of claim 87 wherein the said laser light output is from an output of an optical amplifier.

106. A ladar auxiliary light comprising

a ladar sensor with a field of view and an auxiliary light housed together in the same package and mounted to a vehicle and said ladar further comprising;

a pulsed infrared laser light output,

a ladar receive sensor comprising

a two dimensional array of infrared light sensitive detectors, and

a timing circuit connected to each pixel of said two dimensional array of infrared light sensitive detectors, said timing circuit providing a range measurement to features in the field of view reflecting a portion of said pulsed infrared laser light.

107. A collision avoidance system comprising

a plurality of ladar sensor modules mounted on a vehicle and

a central ladar system controller,

each of said ladar sensor modules connected to said ladar system controller via bidirectional connections, and each of said bidirectional connections comprising

a cable assembly routed through the vehicle, said cable assembly further comprising

a connector at a first end for connecting to a ladar system controller,

a plurality of electrically conductive signal wires, and

a connector at a second end for connecting to a remote ladar sensor module.

108. The collision avoidance system of claim 107 wherein at least one of the said ladar sensor modules shares a common housing with a vehicle headlamp.

109. The collision avoidance system of claim 107 wherein at least one of the said ladar sensor modules shares a common housing with a vehicle auxiliary lamp.

110. The collision avoidance system of claim 107 wherein at least one of the said ladar sensor modules is a flash ladar.

111. The collision avoidance system of claim 107 wherein the said ladar system controller has at least one serial communications port.

112. The collision avoidance system of claim 107 wherein the said ladar system controller has at least one parallel communications port.

113. The collision avoidance system of claim 107 wherein the said cable assembly further comprises

a first hybrid connector at a first end of said cable assembly,
said first hybrid connector having
a plurality of electrical contacts and
at least one optical connecting interface,
said first hybrid connector terminating a first end of a bundle of connecting members,
said connecting members comprising
a plurality of electrically conductive signal wires and
at least one optical fiber, and
a second hybrid connector at a second end of said cable assembly,
said second hybrid connector comprising a plurality of electrical contacts and at least one optical connecting interface,
said second hybrid connector terminating a second end of said bundle of connecting members.

114. A collision avoidance system comprising

a plurality of ladar sensor modules mounted on a vehicle and
a central ladar system controller, each of said ladar sensor modules connected to said ladar system controller via bidirectional connections,
each of said bidirectional connections comprising
a cable assembly routed through the vehicle, said cable assembly further comprising
a first connector terminating a first end of a cable comprised of a plurality of electrically conductive signal wires, and

a second connector terminating a second end of said cable for connecting to a remote ladar sensor module.

115. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a master laser with an output connected to an optical amplifier input, and said optical amplifier is optically pumped by a plurality of laser diodes, and said optical amplifier output is connected to an input of an optical power divider, and said optical power divider further having a plurality of optical outputs.

116. The collision avoidance system of claim 115 wherein the said master laser is a laser diode.

117. The collision avoidance system of claim 115 wherein the said master laser is a vertical cavity surface emitting laser diode.

118. The collision avoidance system of claim 115 wherein the said optical amplifier has a gain region comprised of an erbium doped optical fiber.

119. The collision avoidance system of claim 115 wherein the said optical power divider is a fused fiber coupler.

120. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a microprocessor integrated circuit.

121. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a microcontroller integrated circuit.

122. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a data communications port

123. The collision avoidance system of claim 122 wherein the said data communications port is comprised of an Ethernet network interface port.

124. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a volatile memory.

125. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a non-volatile memory.

126. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a plurality of digital to analog signal converters.

127. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises a plurality of analog to digital signal converters.

128. The collision avoidance system of claim 114 wherein the said ladar system controller further comprises

a scene processor, said scene processor capable of accepting range and intensity data from a plurality of ladar sensor modules, and said scene processor further capable of synthesizing the range and intensity data received from said plurality of ladar sensor modules into a composite three dimensional model of the scene surrounding the said vehicle.

129. The collision avoidance system of claim 114 wherein at least one of the said ladar sensor modules shares a common housing with a vehicle headlamp.

130. The collision avoidance system of claim 114 wherein at least one of the said ladar sensor modules shares a common housing with a vehicle auxiliary lamp.

131. The collision avoidance system of claim 114 wherein at least one of the said ladar sensor modules is a flash ladar.

132. The collision avoidance system of claim 114 wherein the said ladar system controller has at least one serial communications port.

133. The collision avoidance system of claim 114 wherein the said ladar system controller has at least one parallel communications port.

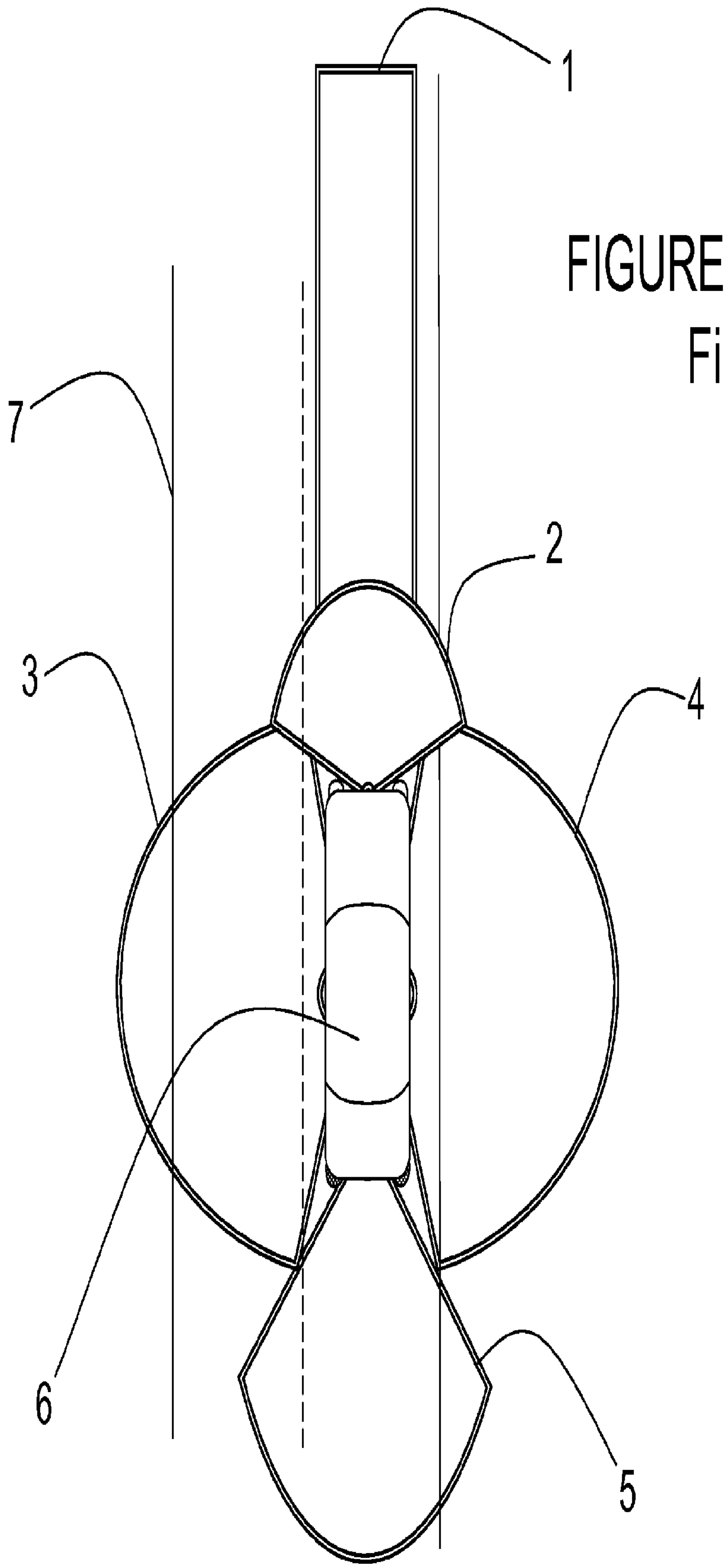


FIGURE 1. LADAR Sensor Fields of View

FIGURE 2. Mounting Location Analysis

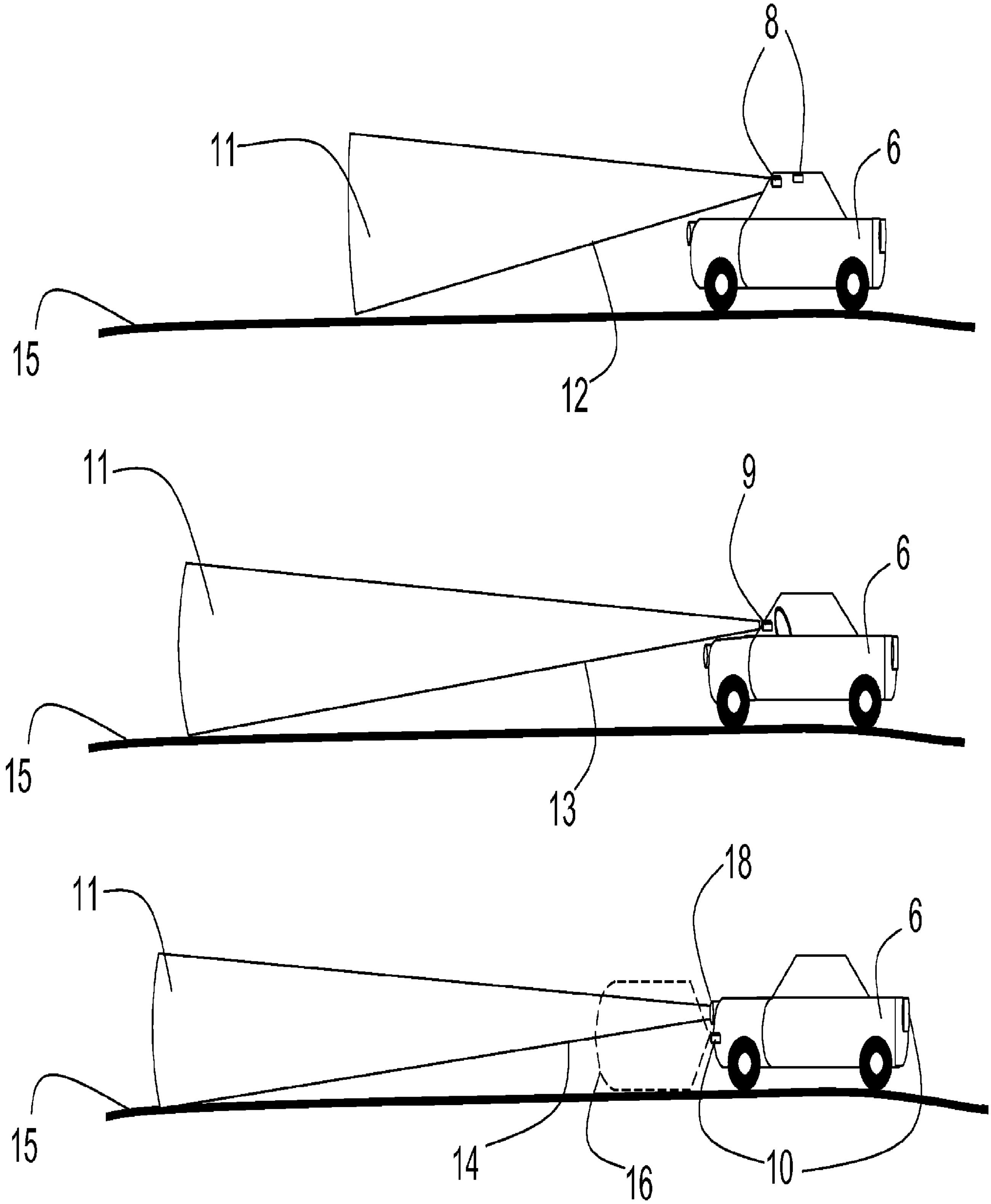


Figure 3. Articulating LADAR Headlamp

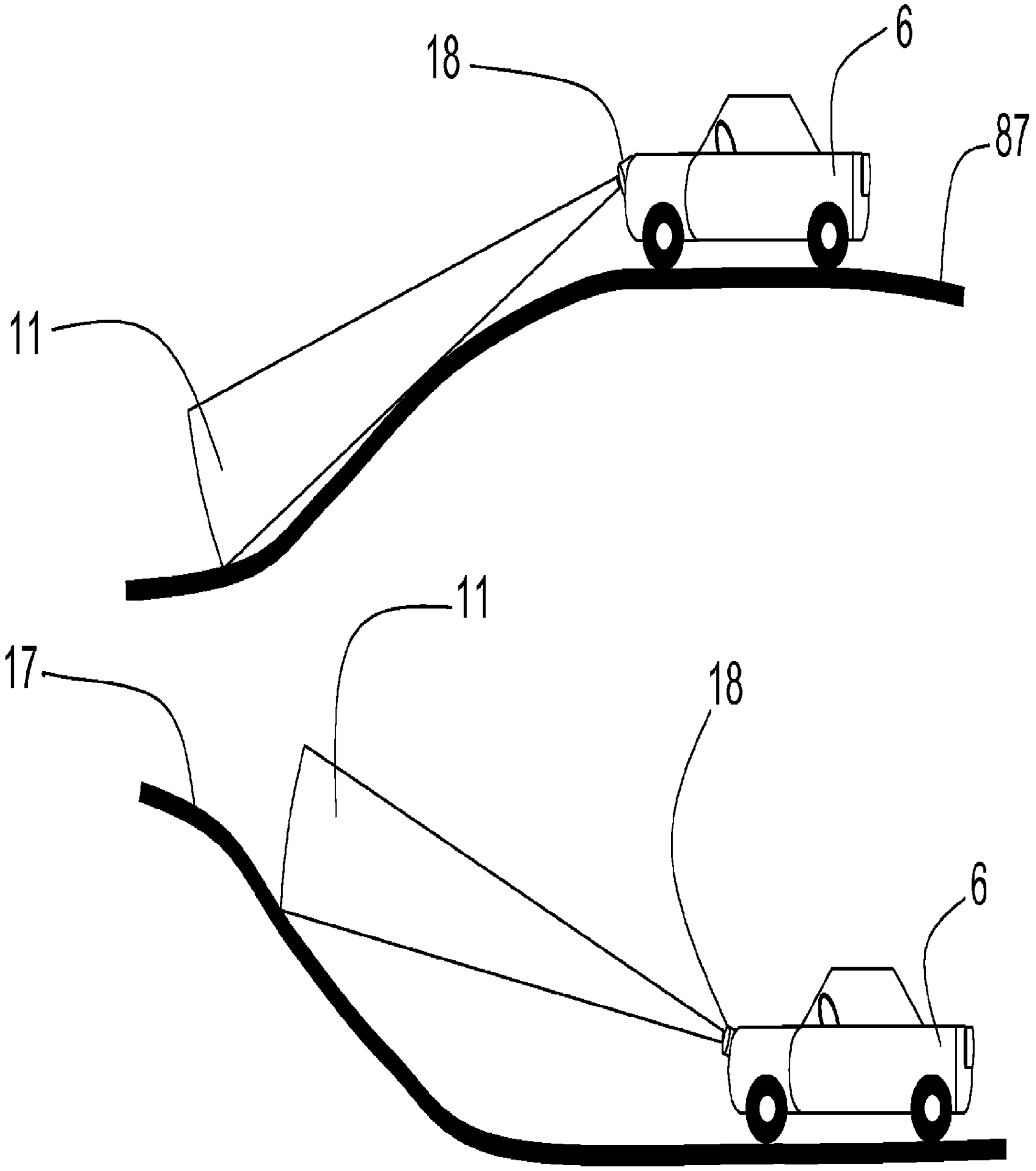


FIGURE 4. Articulating LADAR Sensor

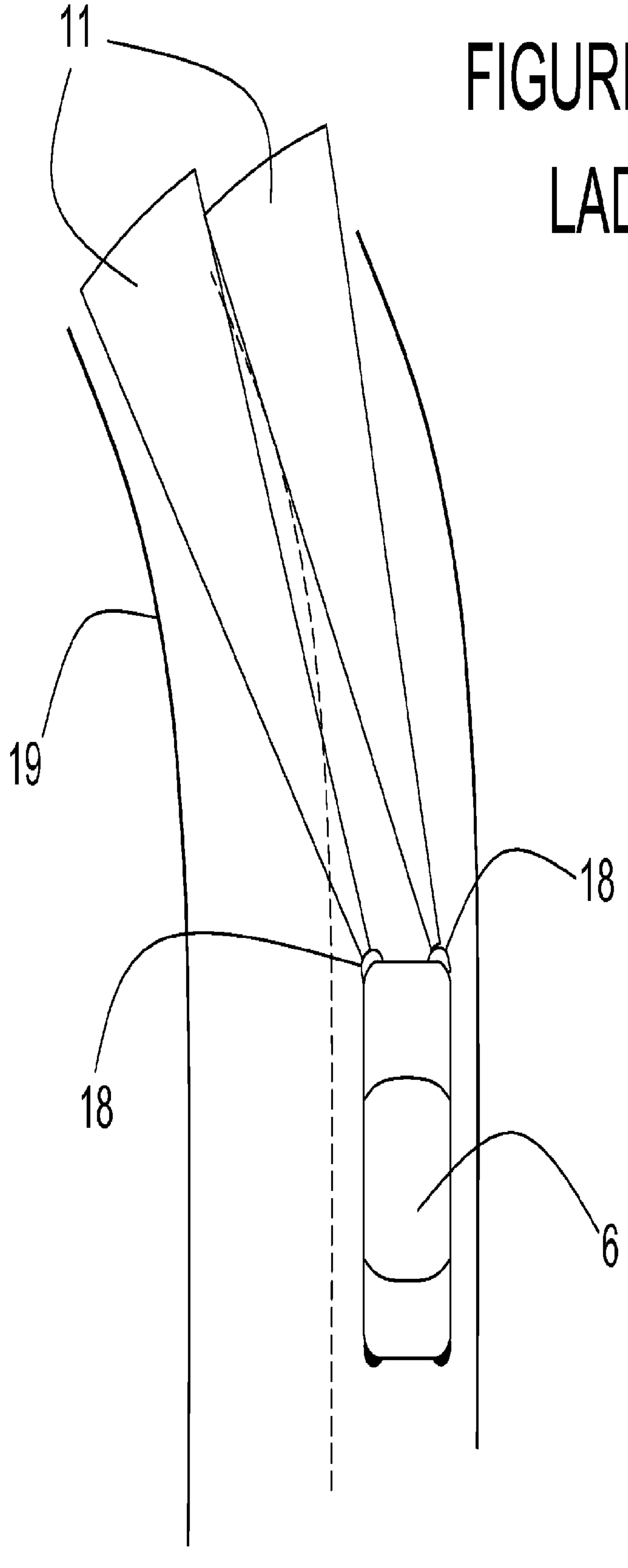


FIGURE 5. Integrated LADAR Sensor and Headlamp

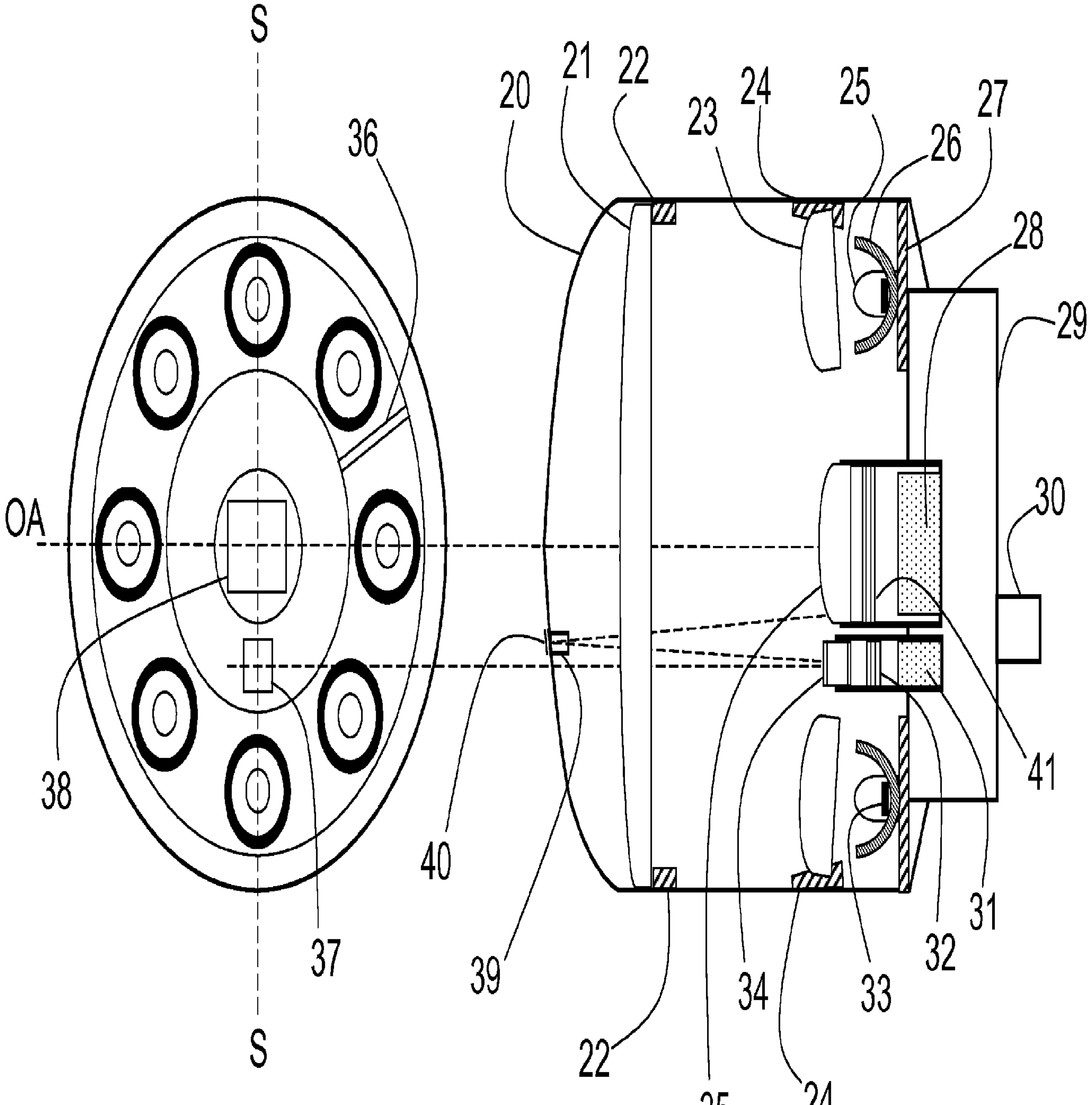


Figure 6. LADAR Sensor and Headlamp with Washer and Wiper

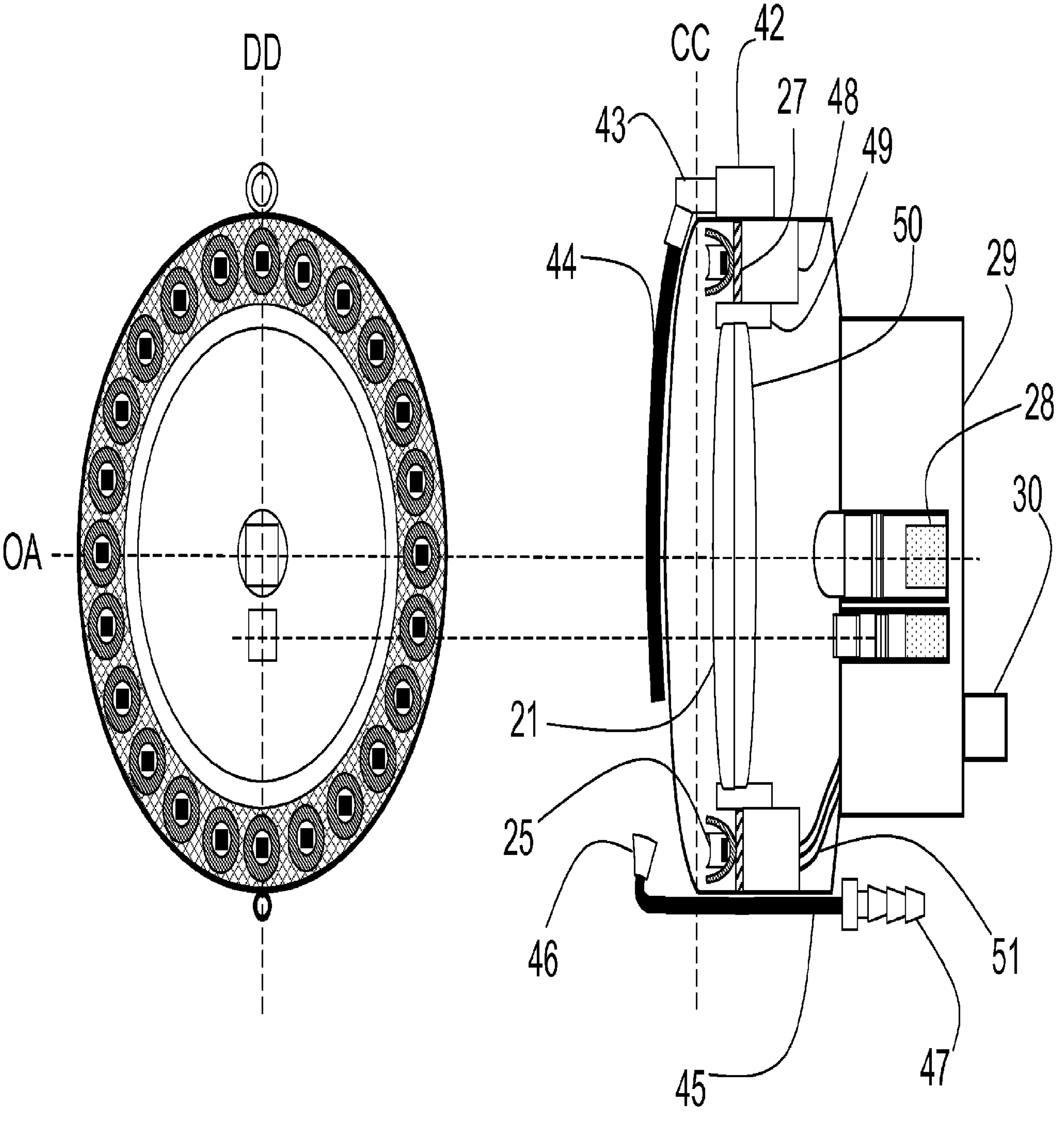


Figure 7. Rectangular Illumination and Reflecting Lens Apparatus

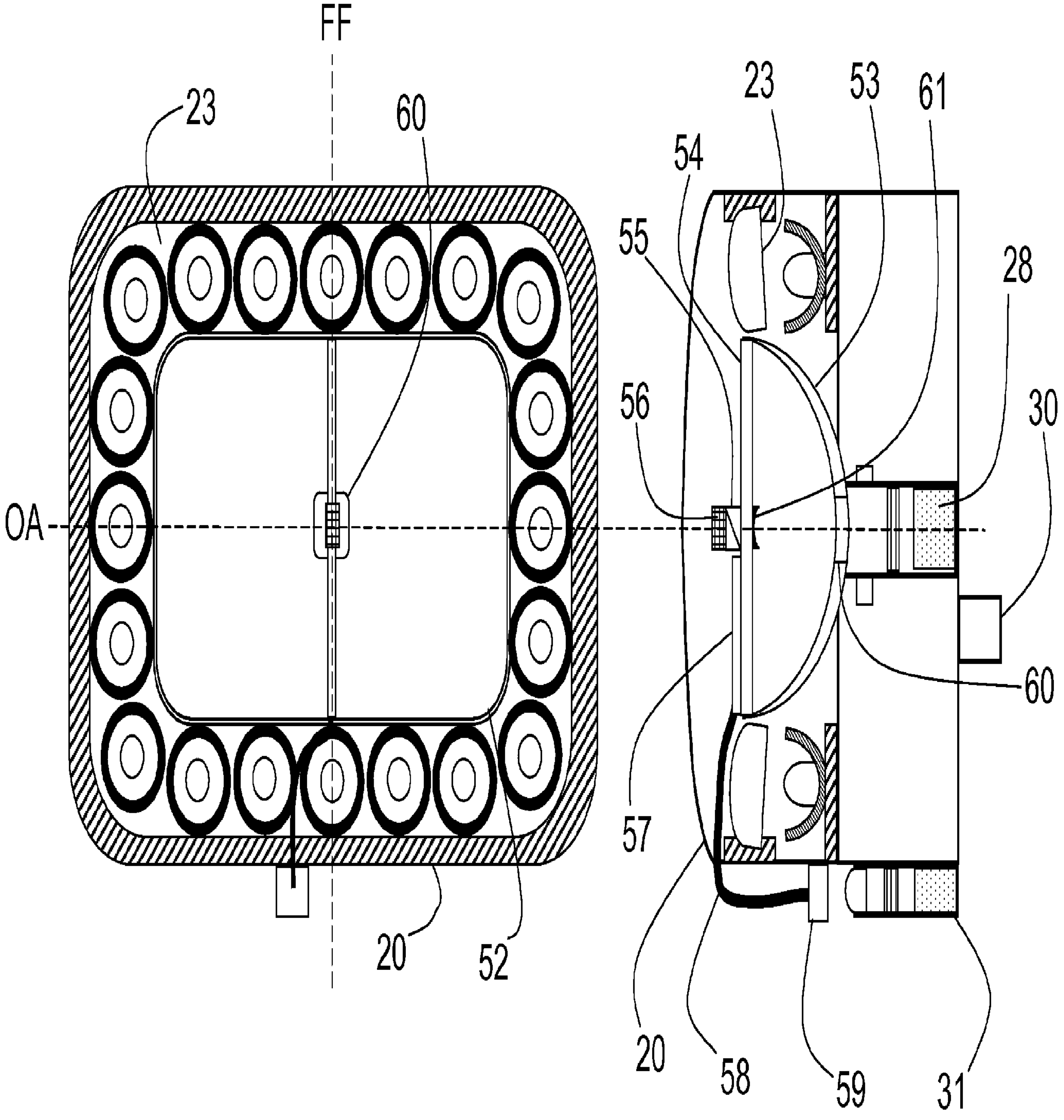


Figure 7A. Long Focal Length Reflecting Lens

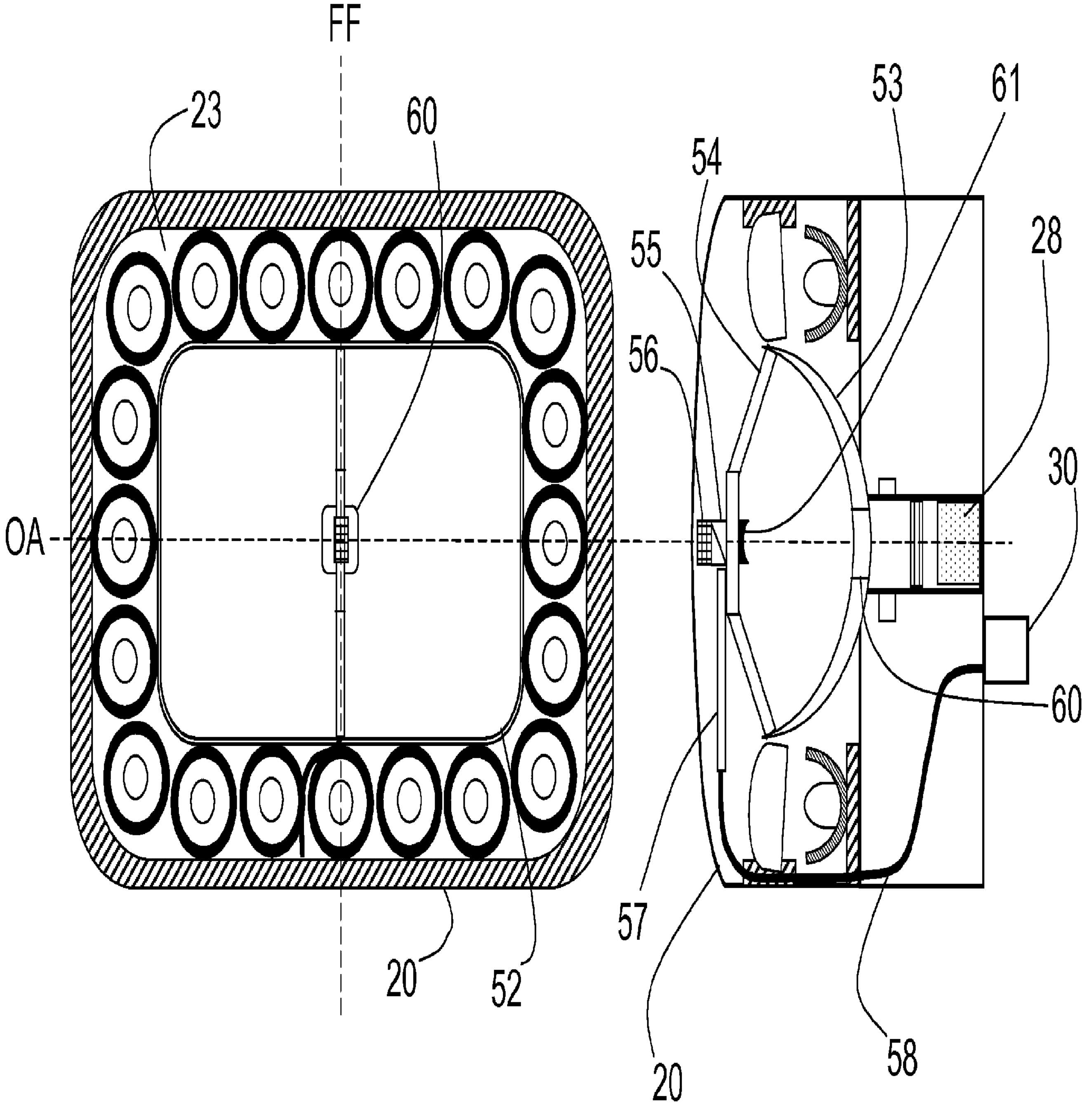
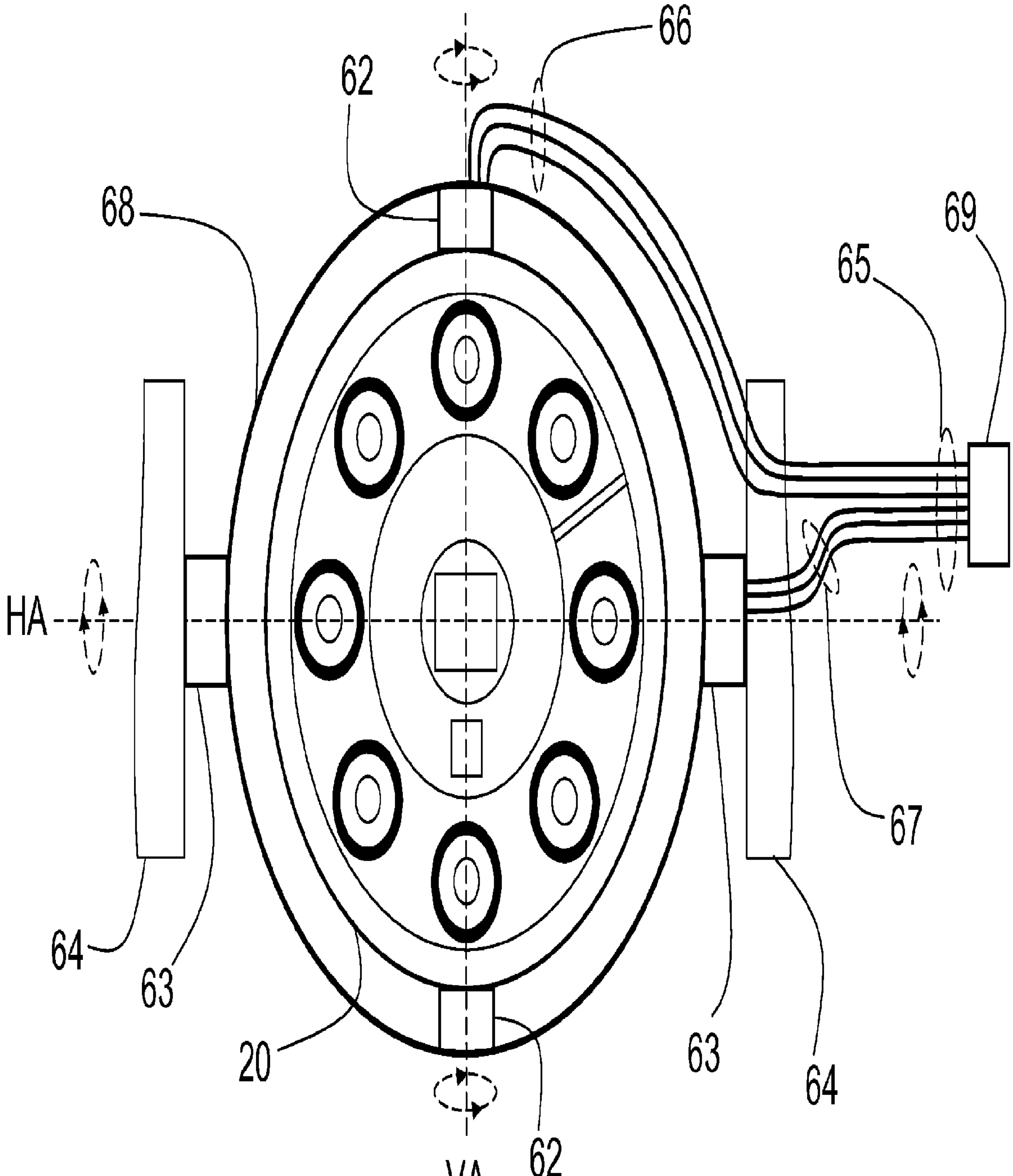


Figure 8. Pivot Mechanisms



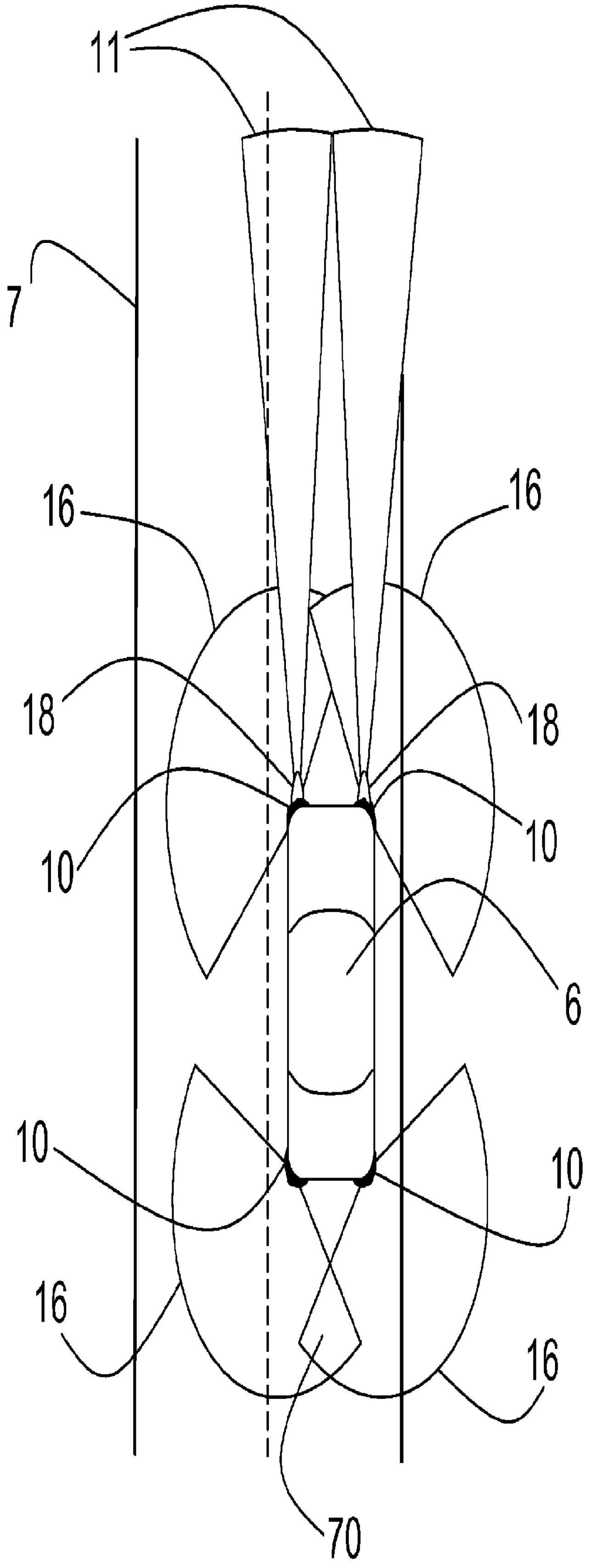


Figure 9. Alternative Fields of View

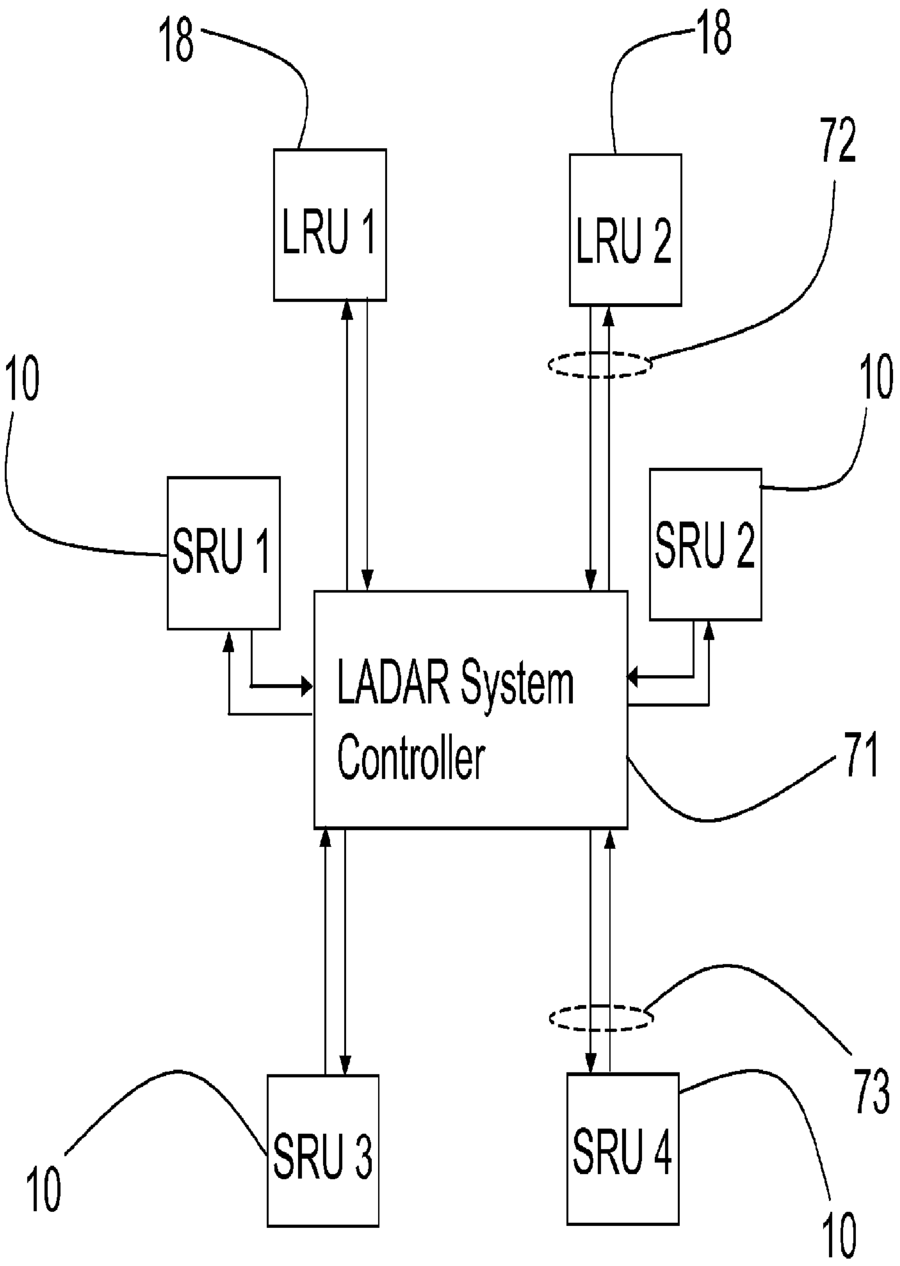


FIGURE 10 LADAR CA System Block Diagram

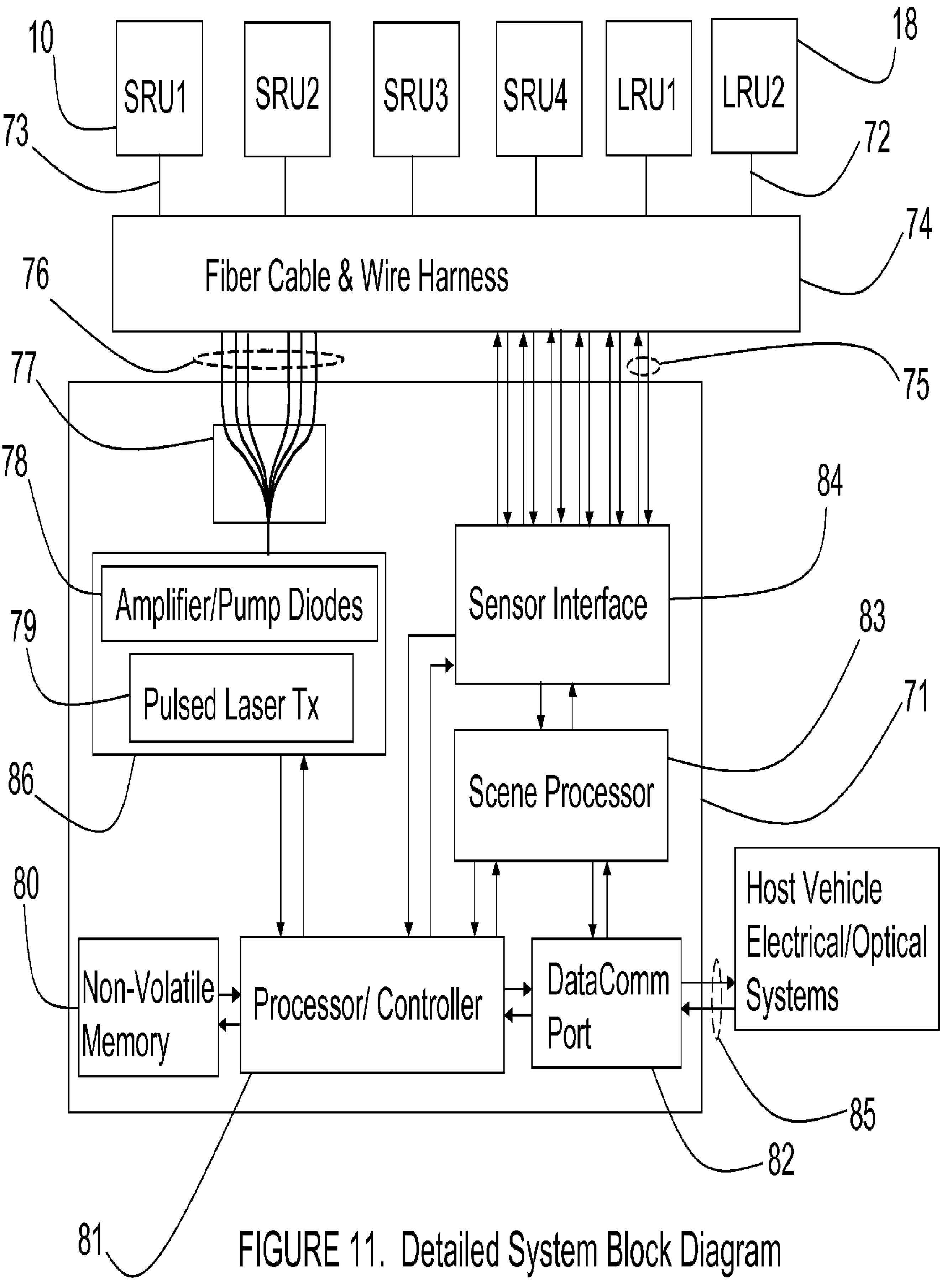


FIGURE 11. Detailed System Block Diagram