



(51) International Patent Classification:

B60W1 0/20 (2006.01) G0SD 1/02 (2006.01)
G0SD 1/00 (2006.01) G08G 1/16 (2006.01)

(21) International Application Number:

PCT/US20 18/019047

(22) International Filing Date:

21 February 2018 (21.02.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/600,593 23 February 2017 (23.02.2017) US

(72) Inventor; and

(71) Applicant: BISHEL, Richard [US/US]; 16020 NW Ridgetop Lane, Beaverton, Oregon 97006 (US).

(74) Agent: BISHEL, Richard; 16020 NW Ridgetop Lane, Beaverton, Oregon 97006 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH,

GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

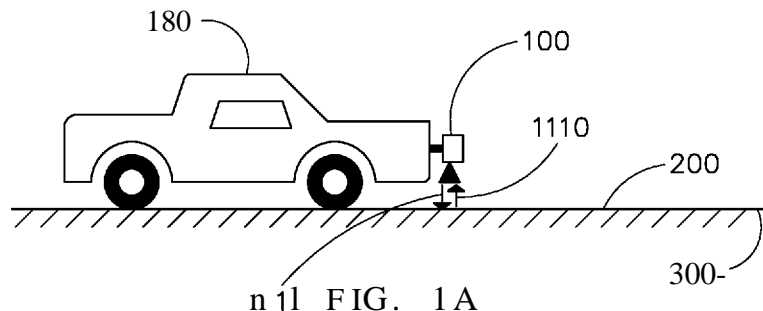
Declarations under Rule 4.17:

- as to the identity of the inventor (Rule 4.17(i))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(Hi))
- of inventorship (Rule 4.17(iv))

Published:

- with international search report (Art. 21(3))

(54) Title: VEHICLE GUIDANCE SYSTEM



(57) Abstract: A method and guidance system guides a land vehicle (180) along a pathway (300) using a downward-looking, lateral position-sensing, radar guidance apparatus on the vehicle and a microwave reflector (200) distributed along the pathway (300). A radar sensor (100) transmits radar signals (1111) downward towards the pathway (300) surface along which the vehicle (180) travels. The signals (1110) are reflected back to the vehicle by the microwave reflector (200) distributed along the pathway (300).



Patent Application

For

Richard Bishel

Titled: Vehicle Guidance System

RELATED APPLICATIONS

This patent application claims priority to Provisional Application No. 62/600,593, filed on Feb. 23, 2017. The content of the above-referenced application is expressly incorporated by reference herein in its entirety.

5

TECHNICAL FIELD

This disclosure relates generally to a method and apparatus for automated or semi-automated guidance of vehicles along a pathway and more particularly relates to a vehicle guidance or guidance-assist system using downward-looking radar that receives reflections
10 back from microwave reflectors along the pathway.

BACKGROUND

Using radar sensors to detect objects has been known and used for the last century. For example, radar has been used for the guidance of airborne ordnance delivery vehicles, such
15 as guided missiles and airplanes. Currently, radar sensors in automotive or land vehicles are aimed forward or sideways to detect objects for collision avoidance and automated cruise control. Forward-looking radar systems have been developed for highway motor vehicle guidance, *i.e.*, steering.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and additional features and advantages of example embodiments will become
5 more readily apparent from the following detailed description of example embodiments, made
with reference to the following drawings.

FIG. 1A is a side pictorial view of a vehicle guidance system showing a vehicle, a radar
10 sensor, a roadway, and a microwave reflector, according to one embodiment.

10

FIG. 1B is a top pictorial view of the system shown in FIG. 1A.

FIG. 2A is a top view of vehicles in a roadway intersection with different microwave
15 reflectors designating different paths of the vehicles, according to one embodiment.

15

FIG. 2B is a top view of two microwave reflectors separated by physical distance.

FIG. 2C is a top view of two microwave reflectors connected together.

20 FIG. 3A is a front pictorial view of the radar sensor with several antennas illuminating
microwave reflectors on a roadway, according to one embodiment.

FIG. 3B is graph of a return radar signal versus lateral distance from the microwave reflector
from FIG. 3A.

25

FIG. 3C is a graph of an output of a radar sensor versus lateral distance from the microwave
reflector from FIG. 3A.

30 FIG. 4A is a front pictorial view of another radar sensor with several antennas illuminating
two microwave reflectors on a roadway, according to another embodiment.

FIG. 4B is a graph of return radar signals versus lateral distance from two microwave reflectors as in FIG. 4A using a narrow antenna beam pattern.

5 FIG. 4C is a graph of return radar signals versus lateral distance from two microwave reflectors as in FIG. 4A using a wider antenna beam pattern.

FIG. 4D is a graph of an output of the radar sensor versus lateral distance from a first microwave reflector in FIG. 4A.

10 FIG. 4E is a graph of an output of the radar sensor versus lateral distance from a second microwave reflector in FIG. 4A.

FIG. 5 is a block diagram of a vehicle guidance system, according to one embodiment.

15 FIG. 6A is a top pictorial view of a microwave reflector as a flat reflector.

FIG. 6B is a top pictorial view of a microwave reflector as a metallic mesh.

FIG. 6C is a top pictorial view of a microwave reflector as a narrow flat reflector.

20

FIG. 6D is a top pictorial view of a microwave reflector as a small microwave corner reflectors.

25 FIG. 6E is a top pictorial view of a microwave reflector as a frequency-selective surface using Y dipoles.

FIG. 6F is a top pictorial view of a microwave reflector as a frequency-selective surface using rectangular loops.

30 FIG. 6G is a top pictorial view of a microwave reflector as a frequency-selective surface using cross dipoles.

FIG. 6H is a top pictorial view of a microwave reflector as a frequency-selective surface using round loops.

5 FIG. 6I is a top pictorial view of a microwave reflector as a frequency-selective surface using solid loops.

FIG. 6J is a top pictorial view of a microwave reflector as a frequency-selective surface using angle dipoles.

10 FIG. 6K is a top pictorial view of a microwave reflector as a frequency-selective surface using cross loops with end dipoles.

FIG. 6L is a top pictorial view of a microwave reflector as a frequency-selective surface using small and large cross dipoles.

15

FIG. 6M is a top pictorial view of a microwave reflector as a wire.

FIG. 6N is a top pictorial view of a microwave reflector as a pipe.

20 FIG. 7A is a top pictorial view of a microwave reflector, according to another embodiment.

FIG. 7B is front pictorial view of a microwave reflector on a roadway, according to one embodiment.

25 FIG. 8A is a top pictorial view of a microwave reflector as a frequency-selective surface, according to one embodiment.

FIG. 8B is side pictorial view of the microwave reflector in FIG. 8A.

30 FIG. 9A is a top pictorial view of a microwave reflector as another frequency-selective surface, according to another embodiment.

FIG. 9B is a side pictorial view of the microwave reflector in FIG. 9A.

FIG. 10A is a graph of a returned radar signal vs. frequency transmitted from a frequency-selective surface with reflective properties.

5

FIG. 10B is a graph of a returned radar signal vs. frequency transmitted from a different frequency-selective surface with absorption properties.

FIG. 11 is a block diagram of one type of radar sensor using Continuous Wave radar technology, according to one embodiment.

10

FIG. 12 is a block diagram of a radar sensor using multiple individual radars, according to one embodiment.

FIG. 13 is a block diagram of a radar sensor using multiple transmit/receive antennas, according to one embodiment.

15

FIG. 14 is a block diagram of a radar sensor using a single transmitting antenna and multiple received antennas, according to one embodiment.

20

FIG. 15A is a top pictorial view of a placement of antennas on the radar sensor within a single row, according to one embodiment.

FIG. 15B is a top pictorial view of a placement of antennas on the radar sensor with two rows, according to one embodiment.

25

FIG. 15C is a top pictorial view of a placement of antennas on the radar sensor with multiple rows, according to one embodiment.

FIG. 15D is a front pictorial view of a placement of antennas on the radar sensor with two rows in different vertical placement, according to one embodiment.

30

FIG. 15E is a front pictorial view of a placement of antennas on the radar sensor with angular placement, according to one embodiment.

5 FIG. 15F is a top pictorial view of a placement of antennas on the radar sensor with front and back angular placement, according to one embodiment.

FIG. 16 is a block diagram of one type of radar sensor using Continuous Wave radar technology, according to one embodiment.

10 FIG. 17 is a block diagram of another type of radar sensor using Frequency Modulated Continuous Wave radar technology, according to one embodiment.

FIG. 18 is a block diagram of another type of radar sensor using Ultra-Wide Band radar technology, according to one embodiment.

15

FIG. 19 is a block diagram of a multiple-input, multiple-output impulse radar system, according to one embodiment.

20 FIG. 20 is a front pictorial view of the radar sensor in FIG. 19 tracking the microwave reflector.

FIG. 21 is a front pictorial view of a radar sensor on a vehicle tracking a side microwave reflector, according to one embodiment.

25 FIG. 22A is a top pictorial view of a microwave reflector with frequency-selective properties, according to one embodiment.

FIG. 22B is a top pictorial view of a vehicle with a radar sensor following the microwave reflector in FIG. 22A installed on a straight section of a roadway.

30

FIG. 22C is a top pictorial view of a vehicle with a radar sensor following the microwave reflector in FIG. 22A installed at an intersection of roadways.

FIG. 23A is a top pictorial view of two microwave reflectors with different frequency-selective properties, according to one embodiment.

5 FIG. 23B is a top pictorial view of a vehicle with a radar sensor following the microwave reflector in FIG. 23A installed on a straight section of a roadway.

FIG. 23C is a top pictorial view of a vehicle with a radar sensor following the microwave reflector in FIG. 23A installed at an intersection of roadways.

10

FIG. 24 is a top pictorial view of a lawnmower with a radar sensor following microwave reflectors buried in a lawn, according to one embodiment.

FIG. 25A is a top pictorial view of a radar sensor with mechanical movement capabilities
15 mounted on a front of a vehicle, according to one embodiment.

FIG. 25B is a front pictorial view of the radar sensor in FIG. 25A.

FIG. 26A is a side pictorial view of a tractor with a radar sensor following a microwave
20 reflector buried under the ground surface, according to one embodiment.

FIG. 26B is a top pictorial view of the tractor in FIG. 26A.

FIG. 27 is a top pictorial view of an indoor mobile appliance with a radar sensor tracking a
25 microwave reflector installed in a room, according to one embodiment.

FIG. 28 is a top pictorial view of a vehicle with a radar sensor following a microwave reflector and discrete location microwave reflectors, according to one embodiment.

30 FIG. 29 is a block diagram of a radar sensor integrated with other location sensors, according to one embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS**Preface**

5 With reference to the above-listed drawings, this section describes particular embodiments and their detailed construction and operation. The embodiments described herein are merely examples, set forth by way of illustration only and not limitation. Those skilled in the art will recognize in light of the teachings herein that there are alternatives, variations and equivalents to the example embodiments described herein. For example, other
10 embodiments are readily possible, variations can be made to the embodiments described herein, and there may be equivalents to the components, parts, or steps that make up the described embodiments.

For the sake of clarity and conciseness, certain aspects of components or steps of certain
15 embodiments are presented without undue detail where such detail would be apparent to those skilled in the art in light of the teachings herein and/or where such detail would obfuscate an understanding of more pertinent aspects of the embodiments.

Overview

20 This overview is provided to introduce a selection of concepts in a simplified form that are further described later in greater detail. This overview is not intended to identify key or essential inventive concepts of the claimed subject matter, nor is it intended for determining the scope of the claimed subject matter.

25 A radar vehicle guidance system can be used in guiding a land vehicle along a pathway. One embodiment has a downward-looking, lateral position-sensing, tracking radar guidance apparatus, such as an inexpensive radar system with an antenna array. A microwave reflector, such as metallic paint, is distributed along the roadway path in the direction of
30 vehicle travel similar to painting the side lines, preferably longitudinally along the center of a vehicle lane. The vehicle may be automatically steered to follow the metallic paint. A downward-looking radar allows for tight turns to be negotiated without any concern for

false targets. Since the distance to the surface is short, low-power radar can be used without any interference to other systems. A painted line with metal particles provides an inexpensive and robust guideline without environment concerns of ground moisture, mapping capabilities, frost or subsurface movement. The guidance system control can be similar to well-known embedded wire systems without any active roadway infrastructure.

Another embodiment has a downward-looking, lateral position-sensing UWB (Ultra Wide Band) impulse radar system with a multiple-antenna array. A microwave reflector, such as a metallic paint, tape, strip, metallic mesh, corner reflectors, frequency-selective surfaces, round wire, flat conductor, or pipe can be distributed along the roadway path in the direction of vehicle travel on the pathway surface or slightly below the surface, preferably longitudinally along the center of a vehicle lane. The vehicle can be automatically steered to follow the microwave reflector.

Another embodiment has a downward-looking impulse radar sensor mounted to the vehicle for use in guiding a land vehicle along a pathway, wherein the radar sensor consists of a plurality of receive/transmitter antennas and a signal processor coupled to receive signals received by the antennas to determine path lengths from each antenna to the microwave reflector to guide the vehicle along the pathway. A microwave reflector has different reflective properties than the pathway and is distributed along the pathway in the direction of vehicle travel.

Another embodiment is a method for guiding a vehicle along a pathway by directing radar waves downward toward the ground and an installed elongated microwave reflector distributed along the pathway, receiving radar waves from the ground and the microwave reflector, processing the received radar waves with the transmitted radar waves to determine the position of the elongated microwave reflector respect to the vehicle, and guiding the vehicle to follow the elongated microwave reflector.

The radar systems described herein have, in certain cases, the advantage that it is an active system giving all-weather and day-or-night performance and has the inherent capability of sensing distance and direction to targets.

Example Embodiments

Figs. 1A and 1B show the side view and top view, respectively, of a preferred embodiment of a vehicle guidance system. A vehicle 180 traveling down a roadway or pathway 300 following a microwave reflector 200 using a downward looking radar sensor 100. The pathway 300 where the microwave reflector 200 can be installed is not limited to roads, streets, and highways, but could include lawns, fields, terrain, rooms in a building, parking lots, warehouses, depots, and manufacturing floors. The microwave reflector 200 could be implemented on the surface or slightly below the surface. The vehicle 180 can be any mobile platform such as, for example, a car, truck, tractor-trailer, motorcycle, lawnmower, motorized wheelchair, utility vehicle, mining equipment, golf cart, or tractor. In Fig. 1A, the radar sensor 100 sends signals 1111 to the road surface 300 and the microwave reflector 200 and receives signals 1110 from the road surface 300 and the microwave reflector 200. The received signals 1110 are processed to determine an approximate position of the microwave reflector 200 relative to the radar sensor 100, which is attached to the front of the vehicle 180, and therefore, the position of the front of the vehicle 180 relative to the microwave reflector 200. The position of the vehicle 180 relative to the microwave reflector 200 is used to guide the vehicle 180 along the path of the microwave reflector 200.

Figs. 2A, 2B, and 2C show how several vehicles 180, 181, and 182 attached with the radar sensor 100 are guided through an intersection using a preferred embodiment. As shown in Fig. 2A, the vehicle 180 uses the radar sensor 100 to detect the path of the microwave reflector 200 to follow the roadway until the vehicle 180 moves into the intersection where it encounters a Y in the microwave reflectors materials 200 and 210. Figs. 2B and 2C illustrates in more detail two examples of the Y section in the microwave reflector 200. Fig. 2B shows that the microwave reflector 200 follows a straight path, whereas the microwave reflector 210 veers off to the right. Since the radar is looking downward, rather than forward, the radar sensor 100 detects the two microwave reflectors 200 and 210, and the vehicle's computer (not shown in this figure) directs the vehicle 180 to follow either microwave reflector 200 or 210. As an example of operation in Fig. 2A, the vehicle 180 tracking the microwave reflectors 200 and 210 would like to turn right at the intersection. As the vehicle 180 enters the intersection, the vehicle computer would select to follow

microwave reflector 210. Once the right turn is made, the radar sensor 100 would detect microwave reflectors 210 and 208, and the vehicle computer would select the microwave reflector 208 to follow. The microwave reflectors 200 and 210 can either be made of the same microwave reflective materials or two different types of microwave reflective materials.

5

Fig. 2B shows that there is physical separation between the microwave reflector 200 and 210 by distance x_d , whereas Fig. 2C shows no separation prior to the γ feature. There may be other configurations where two or more microwave reflectors might be necessary or desirable. The vehicle 180 is assumed to be a car or pickup truck, but there are situations where articulated vehicles, such as tractor-trailers, need to make a left turn prior to turning right to prevent the trailer from running over the sidewalk. In a similar manner as shown in Fig. 2A, vehicles 181 and 182 can follow the different microwave reflectors 200, 206, 208, and 210 using the radar sensor 100 to travel to the desired destination. Fig. 2A does not show all the possible turns and configurations the vehicles could make in or near an intersection.

10

15

Figs. 3A, 3B, and 3C illustrate one embodiment of the downward looking radar sensor 100 in operation. Fig. 3A shows one embodiment of the radar sensor 100 with three transmitting and receiving antennas 1101, 1102, and 1103 perpendicular to vehicle travel and spaced by distance x_{io} between adjacent antennas, at distance of γ above the roadway 300 and the microwave reflector 200. The spacing of the antennas can be equal distances as shown in Fig. 3A for equal resolution or at different distances to provide more resolution near the center of the radar sensor 100 than towards the end sections. The radar sensor 100 transmits signals and receives signals via a beam pattern 1125. The microwave reflector 200 in this embodiment provides a different return signal than the roadway 300, as illustrated in Fig. 3B, which is the graph of the return signal amplitude over the microwave reflector 200. When the radar antenna 1102 is directly above position x_0 , the amplitude of the returned signal 810 is at its maximum value. If the antenna 1102 is slightly to the left or right of this position, the amplitude would be a level 814. Further to the left or right, the signal amplitude 810 would be at levels 816 or 812. If the radar antenna 1102 is over the roadway 300 and not close to the microwave reflector 200, then the returned signal

20

25

30

amplitude 810 would at level 818. If the received signals are processed from all three antennas, then the output 704 can be derived for the displacement of the radar sensor 100 in the lateral direction, x . Fig. 3C shows the output 704 of the radar sensor 100 vs. the distance x from the microwave reflector 200. At the center position 804, x_0 , the radar sensor 100 is directly centered with the microwave reflector 200. Therefore, the output 704 is zero and no steering correction is needed. If the radar sensor 100 were mounted on the center of the front of the bumper, the vehicle would be following the microwave reflector precisely along the microwave reflector 200. If the radar sensor 100 moves slightly to the right or left to positions 805 or 803, the radar output 704 would be a +L1 level or -L1 level, respectively. The vehicle computer receiving this information from the radar sensor 100 would steer the vehicle to minimize this error. Likewise, at positions 806 and 807, the radar sensor 100 has moved too far to the right, and therefore, the output 704 would be greater, at levels +L2 and +L3, respectively. Similarly, at positions 802 and 801, the radar sensor 100 has moved too far to the left, and therefore, the output 704 would be negative and at greater amplitude, at levels -L2 and -L3, respectively. The output 704 can be used as a guidance signal for the vehicle to direct the steering mechanism to alter the vehicle lateral direction so that the vehicle follows the microwave reflector 200. Alternatively, the output 704 can be used as a prompting signal to alert the driver that a steering correction is recommended to better follow the microwave reflector 200.

20

Figs. 4A-4E illustrate another embodiment of a system with two different microwave reflectors. Fig. 4A shows two different microwave reflectors 200 and 210 with different microwave reflective properties or with the same reflective properties but separated by a physical distance. The microwave reflector 200 reflects frequencies in a first frequency region such as a region around 10 GHz, and the other microwave reflector 210 reflects frequencies in a second frequency region such as a region around 24 GHz. The radar sensor 102 transmits and receives both frequency regions via a plurality of the antennas 1104. Each antenna 1104 transmits both frequencies via signals 1113 and receives both signals 1112 from the roadway surface 300 and the two microwave reflectors 200 and 210. The radar sensor 102 can process the signals at the two different frequencies from the different surfaces similarly to what is illustrated in Fig. 4B. In Fig. 4B, the signal 820 is a return amplitude from the antenna for the first frequency region moving in the x direction, which is

30

lateral to the direction travelled. x_1 is the position where the antenna 1104 is over the microwave reflector 200. Similarly, the signal 821 is a return amplitude from the antenna for the second frequency region moving in the x direction, which is lateral to the direction travelled. x_2 is the position where the antenna 1104 is over the microwave reflector 210.

5 The radar sensor 102 outputs a signal 704 for tracking the microwave reflector 200 and a signal 705 for tracking the microwave reflector 210 relative to the movement over the radar sensor 102 in the lateral direction x . A guidance computer on the vehicle can select between either microwave reflectors to follow and, therefore, the path the vehicle take on the roadway. The microwave frequencies selected for the various microwave reflectors, one or more, to reflect or absorb can be close in frequency, e.g., 10.0 and 10.5 GHz, or far
10 apart, e.g., 10 GHz and 122 GHz. In some configurations, two or more microwave reflectors will have multiple selective frequency surfaces and the radar sensor can process the multiple microwave reflectors and provide the guidance computer with multiple paths to follow.

15

Fig. 4B shows narrow beamwidths of the antenna 1104. Therefore, a single detection level 825 suffices to indicate that the antenna 1104 is over the microwave reflector 200. Fig. 4C shows broader beamwidths of the antenna 1104, and, therefore, several detection levels such as 825 and 829 may be utilized. The roadway return signal is shown to be at level 823
20 for both antenna beamwidths. Narrow antenna beamwidths provide a more defining signal when over the microwave reflector 200 and, therefore, fewer false detections, but more antennas may be required to provide similar resolution to that of broader beamwidth antennas. Higher microwave frequencies, such as 122 GHz, require smaller antennas than lower microwave frequencies, such as 5 GHz, for similar antenna beamwidths. Figs. 4D and
25 4E show the outputs 704 and 705, respectively, of the radar sensor 102 of the error level versus the x direction.

Fig. 5 shows a block diagram of one embodiment of the vehicle guidance system which includes the radar sensor 100, a vehicle controller or guidance computer 500, a vehicle
30 steering system 510, a speed control system 520, and a vehicle location system 530. The output 704 of the radar sensor 100, which detects the position of the microwave reflector 200 relative to the radar sensor 100, is sent to the vehicle controller 500. The vehicle

controller 500 sends signals based on information from the radar sensor 100 and possibly other sensors (not shown) to the steering system 510, speed control system 520, and the vehicle location system 530. The vehicle controller 500 is programmed to steer the vehicle in an appropriate direction to follow the microwave reflector 200 in this embodiment.

5

The microwave reflectors that are illustrated in various embodiments are made out of materials to either absorb or reflect microwave frequencies compared to the ground or roadway surfaces. Figs. 6A-6N show some of the configurations, but there are many combinations. Fig. 6A shows microwave reflector 220, which is a metallic paint, tape, or strip and, typically, provides a reflected return signal that is significantly different than the roadway surfaces 300. And the return signal would be similar over the transmitting frequency. Fig. 6B shows a microwave reflector 222 made of a metallic mesh such as aluminum or metal screen wire. The return signal depends on the mesh size and/or spacing and can be made to be a frequency-selective surface by the pattern and size of the pattern.

10

15

The metallic mesh would be easier to install in soil near the surface without affecting plants and water runoff. Fig. 6C shows a microwave reflector 224, which can be applied as a metallic paint, tape, or strip, but the width of the reflector is narrow. Fig. 6D shows a microwave reflector 226, which contains small metallic corner reflectors attached to a tape, strip, or roadway. These corner reflectors provide a high returned signal regardless of

20

whether the antenna angle is aligned relative to the microwave reflector. Figs. 6E-6K show microwave reflectors that are frequency-selective surfaces that can be attached to the roadway with tape, paint, or strips. These frequency-selective surfaces may be made up of many small dipoles, loops, or combination of both in a repeatable pattern. Fig. 6E shows a microwave reflector 228 with Y dipoles. Fig. 6F shows a microwave reflector 230 made up

25

of rectangular loops. Fig. 6G shows a microwave reflector 232 with cross dipoles. Fig. 6H shows a microwave reflector 234 with round loops. Fig. 6I shows a microwave reflector 236 with solid loops. Fig. 6J shows a microwave reflector 238 with angle dipoles. Fig. 6K shows a microwave reflector 240 with a combination of cross loops with end dipoles. Many configurations are possible. Each configuration of a microwave reflector with frequency-

30

selective surfaces will have certain amplitude, phase, and frequency response characteristics. Fig. 6L shows a microwave reflector 242 with small and large cross dipoles. The reflector 242 can have dual frequency characteristics. With a radar sensor transmitting

and receiving both frequencies, the vehicle guidance computer will have two signals to track the same reflector, creating system redundancy. Fig. 6M shows a microwave reflector 241 made up a conductor, which can be either a round wire or a flat wire. Higher resolution radars can track a narrow reflector, such as an appropriately sized reflector 241. Fig. 6N shows a microwave reflector 243 made of a metallic tube.

Figs 7A and 7B show top and front views of the microwave reflector 220. Fig. 7A shows the top view of the reflector 220, and Fig. 7B shows front view of the reflector 220 either painted, taped on, or installed as strip on the roadway 300. Painting a metallic material on the roadway can be done in a manner similar to current highway painting procedures except the paint is metallic and highly reflective to microwaves, whereas current highway systems use specialized paint that is highly visible to light or headlights. Thus, the procedure for painting a microwave-reflective paint involves little or no additional expense compared to current roadway line painting.

15

Figs. 8A and 8B show the top and side views of the microwave reflector 232. Fig. 8A shows the top view of the reflector 232 with a crossed dipole pattern making this surface microwave frequency selective. Fig. 8B shows the pattern painted on a specialized substrate 233 which enhances its frequency properties. The microwave reflector 232 can be created by painting a metallic pattern on the roadway with a specialized painting wheel having a cross-dipole pattern. This procedure may be more expensive than painting just the metallic paint as in Figs. 7A and 7, but creates a frequency-selective surface.

Figs. 9A and 9B show another embodiment of the microwave reflector 232. Fig. 9A shows a top microwave reflector 232 with cross dipoles. Fig. 9B shows a side view of the microwave reflector 233, which acts as a microwave frequency absorber over certain frequencies. In this embodiment, the microwave reflector is a tape with the metallic cross dipole pattern 232, sandwiched between two dielectric materials 252 and 254 over a metallic ground plane 250. The tape can be applied to the roadway surface.

30

Figs. 10A and 10B show returned signal amplitude vs. frequency transmitted for different types of microwave reflectors. Fig. 10A shows the frequency bandpass response from the

reflected signals with a frequency-selective surface that reflects the band of frequencies. Fig. 10B shows the frequency bandstop response from the reflected signals with a frequency-selective surface such as the one in Fig. 9B. In some embodiments, the radar sensor is designed to track a null for the microwave reflector instead of high amplitude
5 signal.

The downward-looking radar sensor 100 in Fig. 1 can utilize a variety of types of radar such as, for example, CW (Continuous Wave), monopulse, dual-frequency, FMCW (Frequency Modulated Continuous Wave), UWB, UWB impulse radar, or a combination of various types.
10 The radar preferably operates at microwave frequencies from 0.3 to 1000 GHz. The following sections illustrates embodiments of the different radar sensors.

Fig. 11 shows one embodiment of a radar unit in a radar sensor assembly. One or more such radars may be needed to create the radar sensors referenced previously. In this
15 embodiment, the radar is a CW radar that operates at microwave frequencies from 0.3 to 1000 GHz. The signal 1116 is generated by a oscillator 400 and sent out of the transmitting antenna 402. In this embodiment, the transmitting and receiving antennas are separate, but in other embodiments, a single antenna could be used both transmission and reception. The returned signal 1114 is received by a receiving antenna 404 and converted via a mixer
20 408 with the transmitted signal via a path 406. The converted signal outputs a baseband signal, which is the DC amplitude of the returned signal 1114. The baseband signal is amplified by an amplifier 410 and filtered by a low-pass filter 412. The output of the filter 412 is compared to two different detection levels 416 and 417 via comparators 414 and 415, respectively. In this embodiment, the output 420 will be high if the processed signal
25 amplitude is greater than the detection level 416. Likewise, the output 421 will be high if the processed signal amplitude is greater than the detection level 417. This embodiment shows two detection levels, but there can be a single detection level or many detection levels for each radar unit incorporated in a radar sensor system. This embodiment down-converts the microwave signals directly to baseband, but it is also possible to use a
30 superheterodyne-type radar receiver and/or to do processing at an intermediate band.

Figs. 12-15 show some other embodiments of different radar configurations. Fig. 12 shows an embodiment of radar sensor 106 with seven individual radars units 150-156. Each radar unit transmits, via an antenna 1106, a signal 1121 and receives a signal 1120. The received signal 1120 is processed for detecting the surface (not labeled) or the microwave reflector 202. The radar units 150-156 each has several detection levels, and the output of each radar unit 150-156 is sent to a processor 434 via signaling lines 1504, 1514, 1524, 1534, 1534, 1544, 1554, and 1564, respectively for the radar units 150-156. The processor 434 can assign weights to each input from each radar unit and generate an outputs signal 704 similar to Fig. 3C, which shows different amplitude levels as the radar sensor 106 transverses in the lateral direction from the microwave reflector 202.

Fig. 13 shows another embodiment for a radar sensor 108. The radar sensor 108 uses a single transmitter/receiver unit 435 and switches each antenna 1135 via a switch 1130. Each antenna 1135 is switched to be connected for a period of time sufficient for a signal to be sent and received from the roadway surface 300 and the microwave reflector 202 via that particular antenna. The unit 435 processes each signal from the multiple antennas and derives an output 704, which represents the position of the antennas 1135 relative to the microwave reflector 202.

Fig. 14 shows another embodiment for a radar sensor 110. The radar sensor 110 uses a single transmitting antenna 1402 placed higher than the individual received antennas and having a wider beam antenna pattern signals 1117. The received signals 1115 are received via individual antennas 1403 and processed by a processing and RF circuitry unit 436 to provide an output 704. The output 704 represents the lateral distance of the received antennas 1403 from the microwave reflector 202.

Fig. 15A-15C show top views of different placement of antennas 1410 for radar sensors 172, 174, and 176, respectively. If there are separate transmitting and receiving antennas, the placement can be similar but spaced slightly apart from the each other to yield a desired beamwidth pattern. In Fig. 15A, the antennas 1410 are spaced uniformly at distance x_0 in a horizontal row. In Fig. 15B, the antennas 1410 are in two rows with a slight offset. In Fig. 15C, the antennas are in three rows.

Fig. 15D shows the side view of a different placement of antennas 1410 spaced both horizontally at a distance x_0 and vertically, at a distance d . A strong signal is likely to be received by either the top set of antennas or the bottom set of antennas depending on the distance. The antennas can be designed for two or more frequencies or multiple antennas can be used at each selective frequency.

Fig. 15E shows the side view of the placement of antennas 1412 at an angle q and similar separation distance. This antenna placement allows for detecting the signals from a microwave reflector offset to the side instead of directly below. Fig. 15F shows the top view of the placement of antennas 1413 at an angle looking slightly forward or slightly backward from the radar sensor.

There are many different configurations of antenna placements and the above configurations are just examples and not an exhaustive catalog of all possible configurations. In addition to placement of antennas on a radar sensor, there could be multiple radar sensors attached to the front, the side, or the rear of the vehicle at various heights.

Different radars can be used to determine the position of the microwave reflector relative to the vehicle. Fig. 16 shows a similar CW radar as Fig. 11 with similar components except the processed signal from the low-pass filter 415 is sent directly into the A/D converter of the radar processor 425. The radar processor 425 can be, for example, a microcontroller, a data processing unit, a computer, a smart device, or digital processor. The signal 1123 is generated by an oscillator 400 and sent out of the transmitting antenna 402. The returned signal 1122 is received by a receiving antenna 404 and converted via a mixer 408 with the transmitted signal via a path 406. The converted signal outputs a baseband signal, which is the DC amplitude of the returned signal 1122. The baseband signal is amplified by an amplifier 411 and filtered by a low-pass filter 415 and sent to the A/D converter of the radar processor 425.

Fig. 17 shows a FWCW (Frequency-Wave Continuous Wave) radar. In this embodiment, the processor 425 generates a DC (direct current) signal via a DAC (digital-to-analog converter) 421 to control a VCO (voltage controlled oscillator) 410. The VCO 410 generates a signal 1130 and sends the signal 1130 through the antenna 414. The signal 1132 is received via an antenna 416 and combined by a mixer 418 with the transmitting signal via path 412. The output of the mixer 418 is amplified and filtered via unit 419 and sent to the A/D (analog-to-digital) converter 420. The processor 425 receives the signal from the A/D converter 420 and processes the signal for distance and amplitude information. An advantage of using a FMCW radar over CW radar is that both the distance and signal amplitude can be determined.

Fig. 18 shows an embodiment of an UWB impulse radar unit. In this embodiment, the UWB impulse radar unit generates short pulses via a pulse generator 440 and transmits the short pulses through an antenna 436, and then the signal propagates to the ground surface and microwave reflector (not shown). When the signal meets the ground surface and microwave reflector, some of the signal is reflected from the ground surface, but significantly more of the signal is reflected from the microwave reflector and propagates back to the antenna 435. The returned ground surface signals can be filtered out by several methods. One method is to select only signals above a certain amplitude threshold. Another method is to receive signals without the reflector and then use that base signal to filter out the ground surface. There are many other schemes to filter out all or some of the ground surface signals. The signals 1142 from the ground surface and microwave reflector are amplified by an amplifier 449 and sent to a sampler/data acquisition unit 442. The sampler/data acquisition unit 442 samples the received signal 1142 at various times from the initial transmit signal 1140 generated by a timer 430 via the pulse generator 440. The timer 430 initiates the pulse via pulse generator 440, but the timer 430 is also used for timing signal to sample the incoming delays. The incoming signal 1142 is sampled in time at different delays and the amplitude of the incoming signal 1142 is recorded at those different times. At a certain time, the returned signal will be of a certain amplitude representing the returned signal from the microwave reflector. A computer 428 processes the information from the sampler/data acquisition unit 442 to determine, at least approximately, the distance from the radar unit to the microwave reflector. The time delay between the

transmitted signal 1140 and the received signal 1142 represents the distance between the radar unit and the microwave reflector. The impulse radar uses pulses with short duration and wide frequency band to provide high-resolution distance measurements. Advantages of this embodiment include high accuracy and low power.

5

Fig. 19 shows an impulse radar unit 454 as described above with multiple transmitter and received antennas 1151-1155. As shown in Fig. 19, this embodiment, is a multiple-input, multiple-output radar system comprising an antenna array 1150, an impulse radar subsystem 454, and a computer 480. The antenna array 1150 is composed of multiple
10 antennas 1151-1155, typically between two to several hundred antennas. The antennas can be of any types known in the art such as, for example, printed antennas, waveguide antennas, dipole antennas, or Vivaldi broadband antennas. The antenna array 1150 can be linear or two-dimensional, flat or conformal to the region of interest.

15 The impulse radar unit 454 generates microwave signals and transmits the microwave signals via the antenna array 1150. The impulse radar unit 454 receives the returned signals from the antenna array 1150. The signals can be, for example, pulse signals, stepped-frequency signals, or the like. The generation circuitry within the impulse radar 454 can involve oscillators, synthesizers, mixers, or it can be based on pulse-oriented circuits such as
20 logic gates or step-recovery diodes. The conversion of the signals can include down conversions, sampling, /or the other similar techniques. The impulse radar can perform transmission and reception with multiple antennas at a time or select one transmit and one receive antenna at a time. The impulse radar unit preferably has data acquisition capability to collect and digitize the signals from the antenna array 1150. The data acquisitions
25 capability will typically include analog-to-digital converters, data buffers, and filtering functions. The computer 480 may convert the collected signals into responses characterizing the microwave reflector 459 and performs algorithms for converting the sets of responses into image data (two- or three-dimensional) of the microwave reflector. The microwave reflector image can be determined in respect to the antenna array 1150
30 alignment; therefore, the orientation of the microwave reflector 459 can be determined with respect to the antenna array 1150. Fig. 20 shows another embodiment of a radar sensor 116, which is typically an impulse radar sensor, with a multiple antenna array 1417

having two or more antennas positioned towards the microwave reflector 200 and the ground surface 300. The radar sensor 116 sends out signals 1119 from the antenna array 1417 via one or more the array's constituent antennas. Received signals 1118 can be processed for distance, amplitude, and angle to the microwave reflector 200. With this embodiment, each antenna provides information to the radar sensor 116 to continuously track the microwave reflector 200 with all the antennas. The radar antenna array 1417 can track side reflectors, as shown by way of example in Fig. 21. In this embodiment, the radar sensor 116 includes an antenna array mounted on the front side of the vehicle 182 and tracking the side microwave reflector 284. The microwave reflector 284 can be installed along the side of the roadway or the center of the roadway, and the reflector can be a continuous reflector or intermittent sections of reflective material.

Figs. 22A-22C illustrate a dual-band microwave reflector scheme. Fig. 22A illustrates a dual-band microwave reflector 244 as a painted strip, taped strip, or installed strip with small and large dipole crosses for reflecting two different microwave frequencies or frequency bands. The vehicle 180 uses a dual-band radar 102 or two separate radar sensors to follow the microwave reflector 244 on the straight roadway surface 300 shown in Fig. 22B. On the straight section of the roadway 300, the dual-band microwave reflector scheme allows for redundancy on the microwave reflector 244. If, for any reason, one frequency or one band of frequencies is interfered with or not operating satisfactorily, the other frequency or band of frequencies would allow for continual operation. When in the intersection, as shown in Fig. 22C, the dual-band microwave reflector 244 splits into separate bands as microwave reflectors 246 and 248 at a location x_1 . The microwave reflector 246 continues for some distance on the straight section of the roadway and then reverts back to the dual-band reflector 244 at location x_2 . The microwave reflector 248 veers off to the right and then reverts back to the dual-band reflector 244 at distance x_3 . An onboard vehicle controller, not shown, would either track the microwave reflector 246 to go straight through the intersection or would track the microwave reflector 248 to make a right turn.

Figs. 23A-23C illustrate another dual-band microwave reflector scheme. Fig. 23A illustrates a dual-band microwave reflector 250 as painted strip, taped strip, or installed strip with

alternating sections of small dipole crosses 246 and sections of large dipole crosses 248 for reflecting two different microwave frequencies or two different bands of microwave frequencies. The vehicle 180 uses a dual-band radar sensor 102 or two or more separate radar sensors to follow the microwave reflector 250 on the straight roadway surface 300, as shown in Fig. 23B. On the straight section of the roadway 300, the dual-band microwave reflector scheme allows for redundancy on the microwave reflector 250. If, for any reason, one frequency or band of frequencies is interfered with or not operating well, the other frequency or band of frequencies can allow continued operation. When in the intersection, as shown in Fig. 23C, the dual-band microwave reflector 250 splits into separate bands and microwave reflectors 246 and 248 at a location X_1 . The microwave reflector 246 continues for distance on the straight section of the roadway and then reverts back to the dual-band reflector 250 at location X_2 . The microwave reflector 248 veers off to the right and then reverts back to the dual-band reflector 250 at location X_3 . The onboard vehicle controller, not shown, would either track the microwave reflector 246 to go straight through the intersection or would track the microwave reflector 248 to make a right turn. Figure 23A shows different microwave reflectors 246 and 248 spaced closed to each other, but these reflectors could be spaced with gaps of road surface between the reflectors. Besides frequency differences between the two microwave reflectors, the microwave reflectors could have similar or different frequency properties, but the physical size and shape of the different microwave reflectors could be used to distinguish different pathways. For example, the microwave reflector 246 could have a narrow shape, and the microwave reflector 248 could have a wide shape, such that the radar imaging process could distinguish the two different physical microwave reflectors.

Fig. 24 shows another embodiment of the radar sensor scheme. Here, the vehicle is a robotic lawnmower 188 with a radar sensor 104 mowing a field 320 by following embedded microwave reflectors 261, 263, 265, and 267. The microwave reflectors 261, 263, 265, and 267 can be installed in the soil just below the vegetation, e.g., grass. Also, one could use pre-installed irrigation pipes or install irrigation pipes in a certain configuration as the microwave reflectors for the radar sensor to track. Fig. 24 shows two vehicles 188 and 189, but they can be the same vehicle at different locations on the field 320. In this embodiment, the radar sensor 104 installed on the vehicles is longer than the width of the

vehicle. The first vehicle 188, located at coordinates x_1, y_1 , tracks the microwave reflector 261 with the left side of the radar sensor 104, and the second vehicle 189 located at coordinates x_2, y_2 , tracks the microwave reflector 263 using the right side of the radar sensor 104. The vehicles 188 and 189 can move towards the right after each travelling around the field by the onboard vehicle controller, not shown, and pick up the next (more inwardly, as shown) microwave reflector. There are other configurations for installation of the microwave reflectors such as installation of a microwave reflector installed at a section of the field to join adjacent microwave reflectors.

Another configuration shown in Figs. 25A and 25B allows the radar sensor 100 on one side of the vehicle to move to the other side by a mechanical movement mechanism. Fig. 25A shows a top view of a vehicle 190 with a mechanical mechanism 713 that moves the radar sensor 100 along an entire sensor guide 118. Fig. 25B shows a front view of the just the radar sensor 100 and the guide 118. This embodiment employs a mechanical means to move the smaller radar, but the radar sensor can be designed to electronically move the beam using a multiple-antenna radar array or have a significant number of antennas spaced across the entire sensor guide 118.

Fig. 26A and 26B show side and top views of an agricultural tractor 184 with the radar sensor 100 mounted on the front of the tractor 184. The radar sensor antennas are pointed downward towards the ground surface 302. A microwave reflector 210 is installed slightly below the surface at a distance/depth x . The radar sensor 100 receives returned signals reflected from the ground surface and from the embedded microwave reflector 210. An onboard computer, not shown, could steer the tractor 184 along the embedded microwave reflector 210 or prompt a driver (not shown) to adjust the tractor's steering to better align its trajectory to the reflector 210.

Another application of the radar sensor scheme is shown in Fig. 27. In this embodiment, a radar sensor 119 is mounted on the front of an indoor mobile appliance 190, e.g., a vacuum cleaner, floor scrubber, ice resurfacing machine (e.g, Zamboni[®] brand machine). The microwave reflector 244 may be installed under the carpet or floor board in a room 340. The mobile appliance 190 tracks the microwave reflector 244 and its onboard

computer/steering mechanism (not shown) could steer the mobile appliance around the room following the microwave reflector 224 (or assist an operator who performs manual steering). The microwave reflector 244 can be installed in a rectangular or other suitable pattern with different microwave reflective surfaces to provide guidance information to the
5 onboard computer via the radar sensor 119.

As shown in Fig. 28, the radar sensor 100 can track location markers 731, 732, and 733 made from different reflective surfaces, besides the microwave reflector 220 for lateral control. In this embodiment, the vehicle 188 using the radar sensor 100 follows the
10 microwave reflector 220 and also indicates when the vehicle is over the location markers 731, 732, and 733.

For redundancy and higher reliability, the radar sensor 100 can be integrated with other sensors such as a GPS receiver 901, Lidar sensor 902, vision sensor 903, forward-looking
15 radar 904, or other location sensors 905, as shown in Fig. 29. The output of a onboard processor 437 may include highly reliable location information 914, steering information 912, and speed information 910.

Conclusion

20

The terms and descriptions used above are set forth by way of illustration and example only and are not meant as limitations. Those skilled in the art will recognize that many variations, enhancements and modifications of the concepts described herein are possible without departing from the underlying principles of the invention. The scope of the
25 invention should therefore be determined only by the following claims and claims presented in any continuing patent or patent application, with full recognition of the scope of all equivalents to every element in such claims.

CLAIMS:

1) An apparatus for guiding a land vehicle along a pathway on which one or more microwave reflectors with different reflective signals than the pathway are distributed along the pathway in the direction of the vehicle travel, the apparatus comprising:

a downward-looking radar sensor mounted to the vehicle, wherein the radar sensor radiates a signal to and detects signal from the microwave reflectors on the pathway.

2) An apparatus as in claim 1, wherein the radar sensor comprises of a CW radar.

3) An apparatus as in claim 1, wherein the radar sensor comprises of a FMCW radar.

4) An apparatus as in claim 1, wherein the radar sensor comprises of a monopulse radar.

5) An apparatus as in claim 1, wherein the radar sensor comprises of multi-frequency radar.

6) An apparatus as in claim 1, wherein the radar sensor comprises of UWB radar.

7) An apparatus as in claim 1, wherein the radar sensor comprises of UWB impulse radar.

8) An apparatus as in claim 1, wherein the down-looking radar sensor has a plurality of antennas disposed in a single line perpendicular to the direction of the pathway, disposed in two dimensions perpendicular to the direction of the pathway, or disposed in three dimensions perpendicular to the direction of the pathway.

9) An apparatus as in claim 1, wherein the microwave reflector comprises a metallic paint, tape, strip, metallic mesh, corner reflectors, frequency-selective surfaces, round wire, flat conductor, or pipe.

10) An apparatus as in claim 9, wherein the frequency-selective surfaces comprises of dipoles, loops, combination of dipoles and loops, cross dipoles, rectangular loops, Y junctions, or crosses.

11) An apparatus as in claim 1, wherein the pathway is one of a road, street, highway, lawn, field, open terrain, room in a building, manufacturing floor, parking lot, warehouse, or depot.

12) A method for guiding a vehicle along a pathway, the method comprising:

directing radar waves downward toward the ground and an elongated microwave reflector distributed along the pathway;

receiving radar waves from the ground and the microwave reflector; and,

processing the received radar waves and the transmitted radar waves to determine an approximate position of the elongated microwave reflector with respect to the vehicle.

13) The method in claim 12, wherein the vehicle is controlled to follow the elongated microwave reflector.

14) An apparatus for use in guiding a land vehicle along a pathway having a microwave reflector with different reflective properties than the pathway distributed along the pathway in the direction of vehicle travel, the apparatus comprising:

a downward-looking impulse radar sensor mounted to the vehicle wherein the radar sensor consists of a plurality of receive/transmitter antennas, a signal processor coupled to receive signals received by the antennas to determine path lengths from the antennas to the microwave reflector to guide the vehicle along the pathway.

15) An apparatus as in claim 14, wherein the microwave reflector comprises a metallic paint, tape, strip, metallic mesh, corner reflectors, frequency selective surfaces, round wire, or pipe.

16) An apparatus as in claim 14, wherein the pathway is one of a road, street, highway, lawn, field, open terrain, room in a building, manufacturing floor, parking lot, warehouse, or depot.

17) And apparatus as in claim 14, wherein the down-looking impulse radar sensor has a plurality of antennas disposed in a single line perpendicular to the direction of the pathway, disposed in two dimensions perpendicular to the direction of the pathway, or disposed in three dimensions perpendicular to the direction of the pathway.

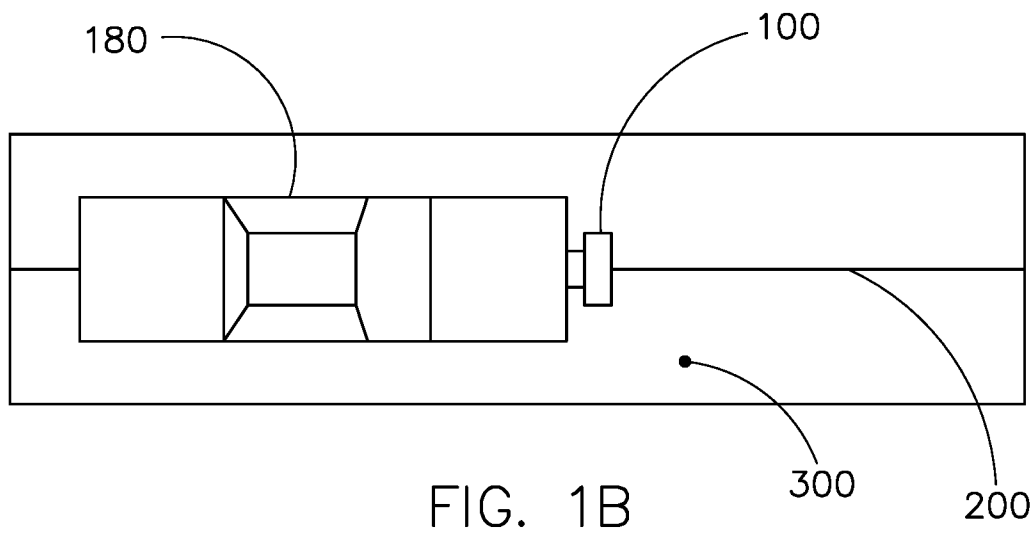
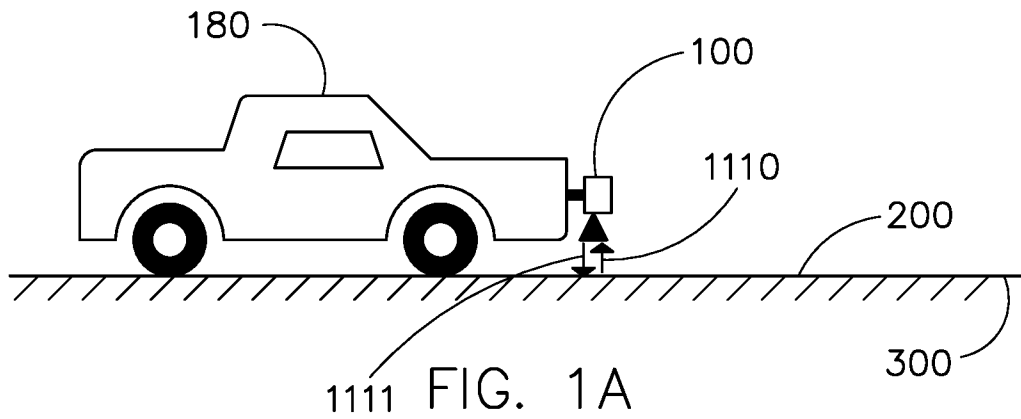
18) A method for guiding a vehicle along a pathway, the method comprising:

directing radar waves downward toward the ground and an elongated microwave reflector distributed along the pathway using a plurality of receiver/transmitter antennas that receive or transmit impulse radar pulses;

receiving radar waves from the ground and the microwave reflector via the antennas; and,

processing the received radar waves to determine different path lengths to the elongated microwave strip to determine an approximate position of the elongated microwave reflector with respect to the vehicle.

19) The method in claim 18, wherein the vehicle is controlled to follow the elongated.



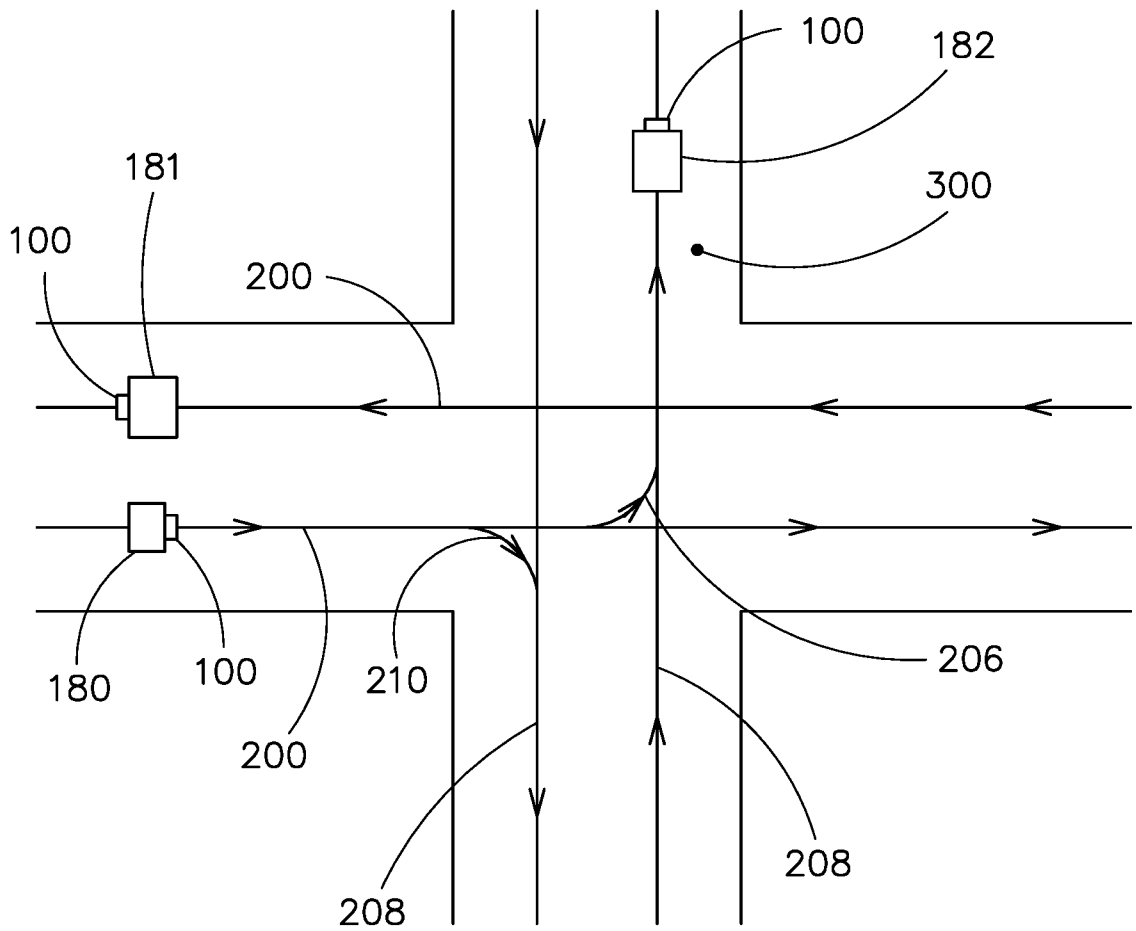


FIG. 2A

FIG. 2B

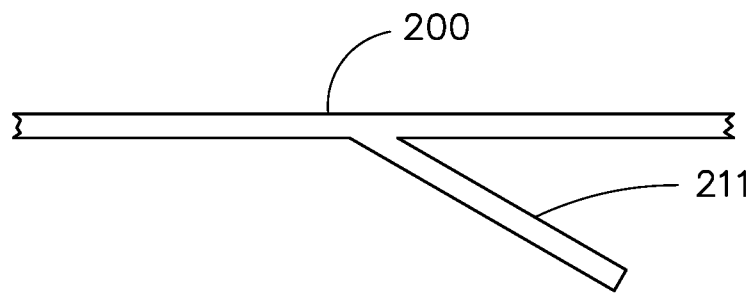
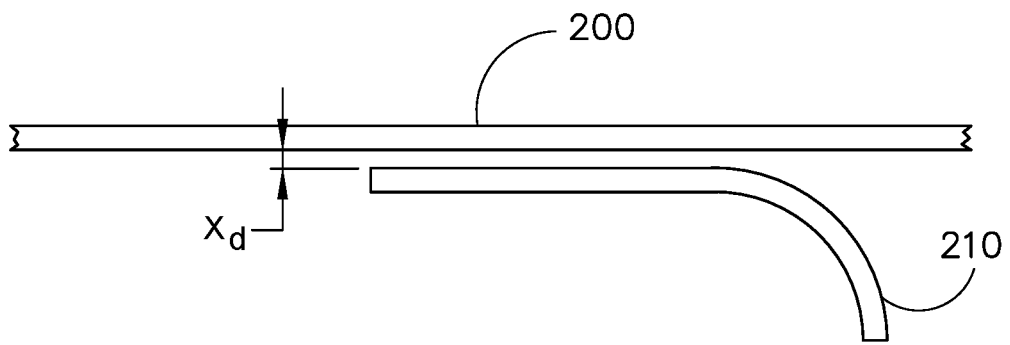


FIG. 2C

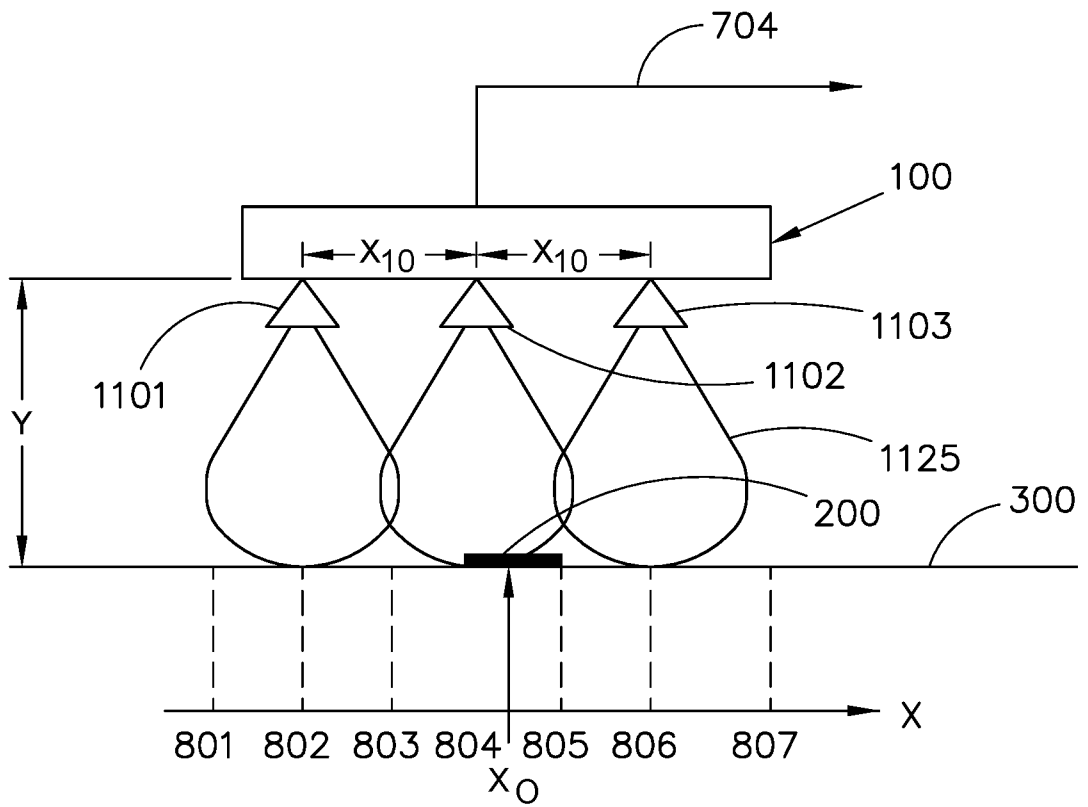


FIG. 3A

5/36

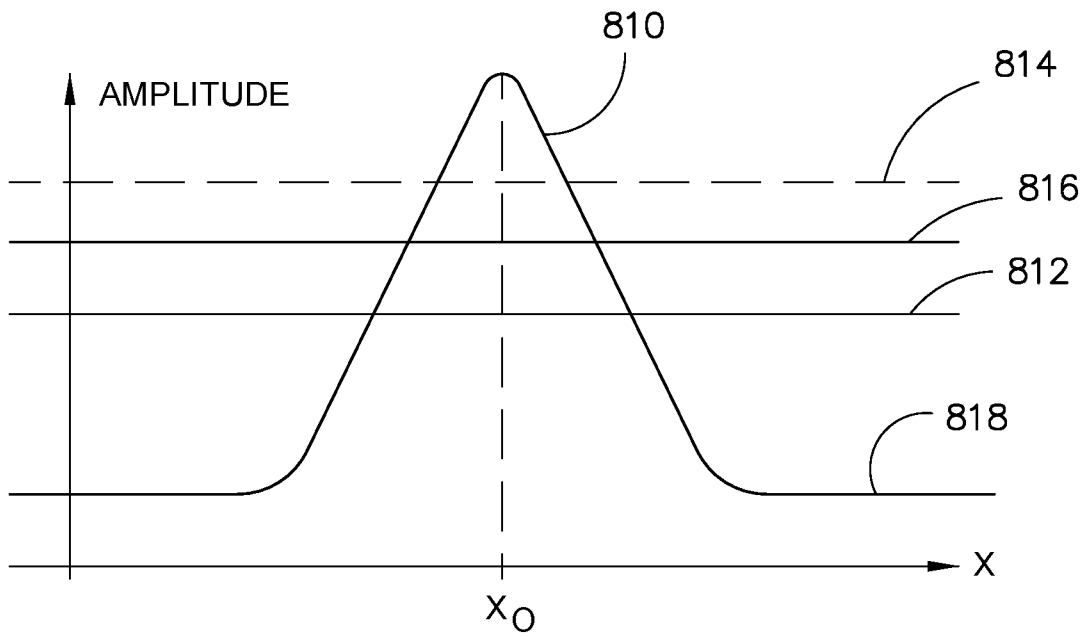


FIG. 3B

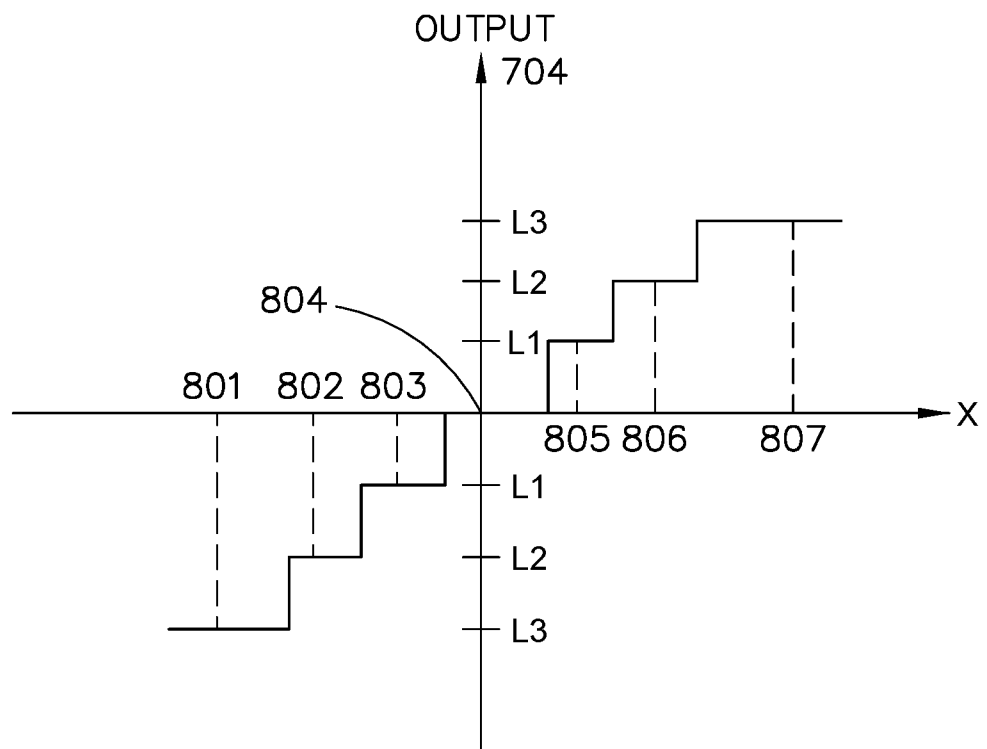


FIG. 3C

7/36

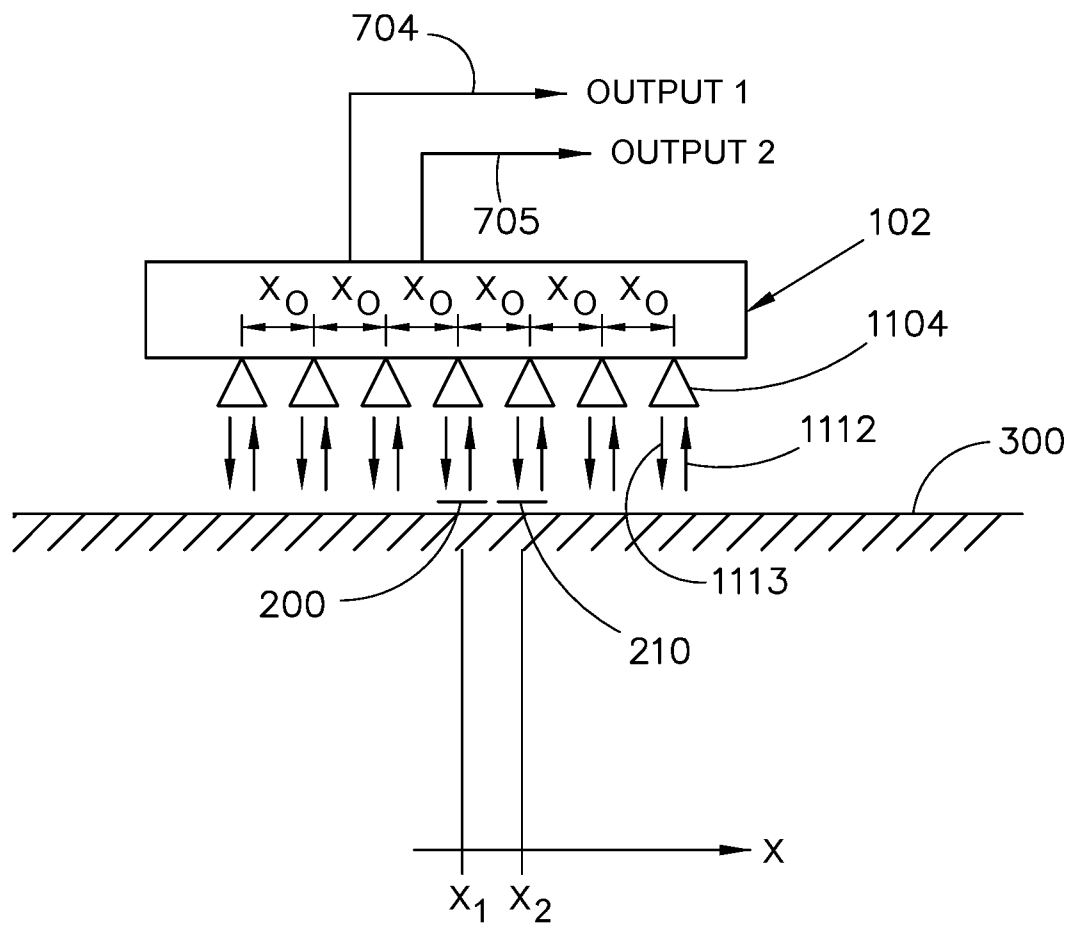


FIG. 4A

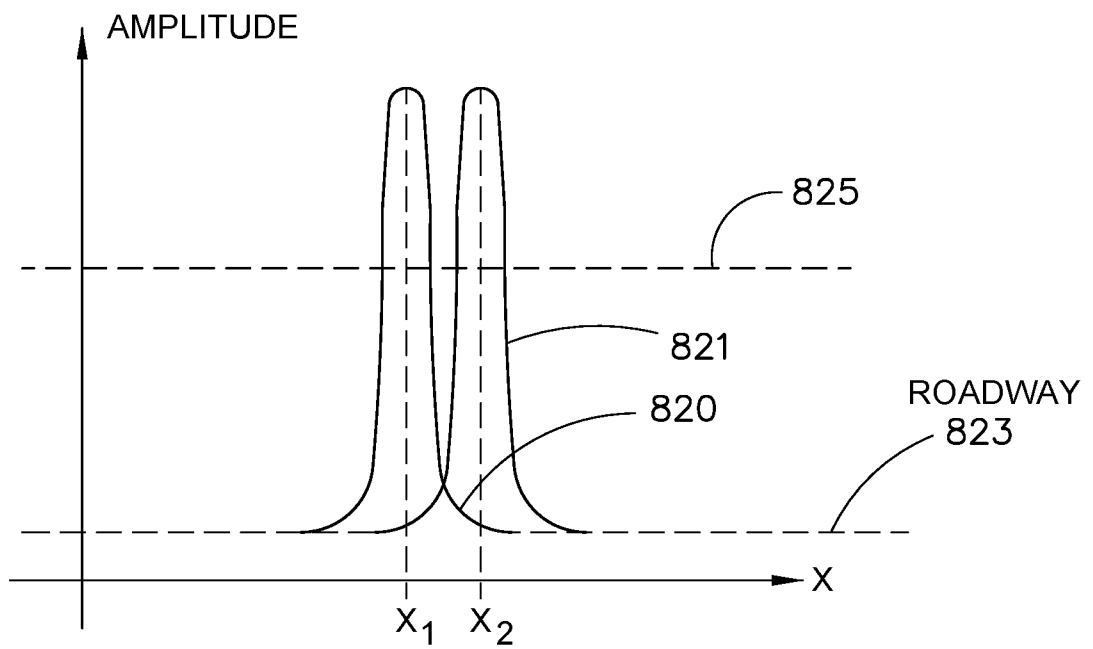


FIG. 4B

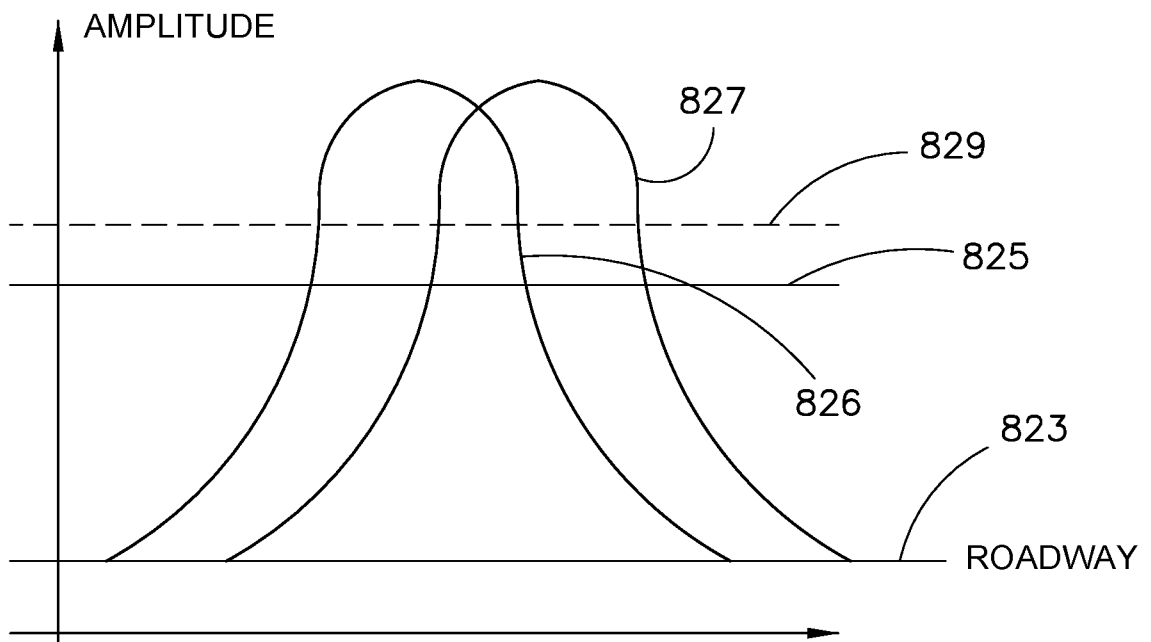


FIG. 4C

10/36

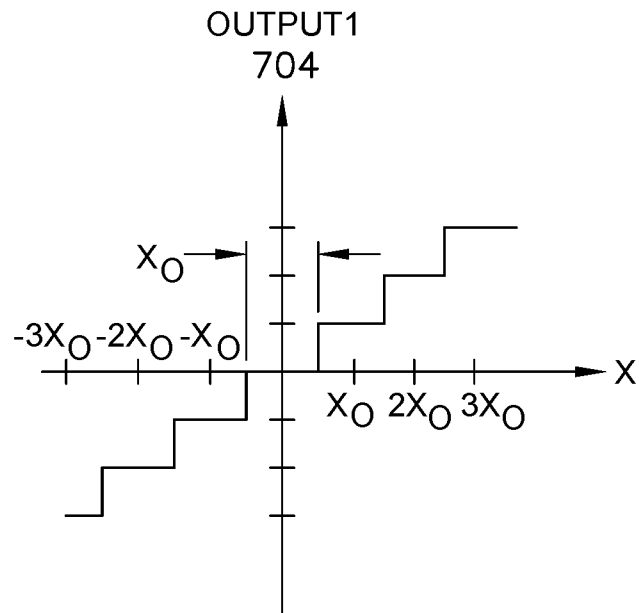


FIG. 4D

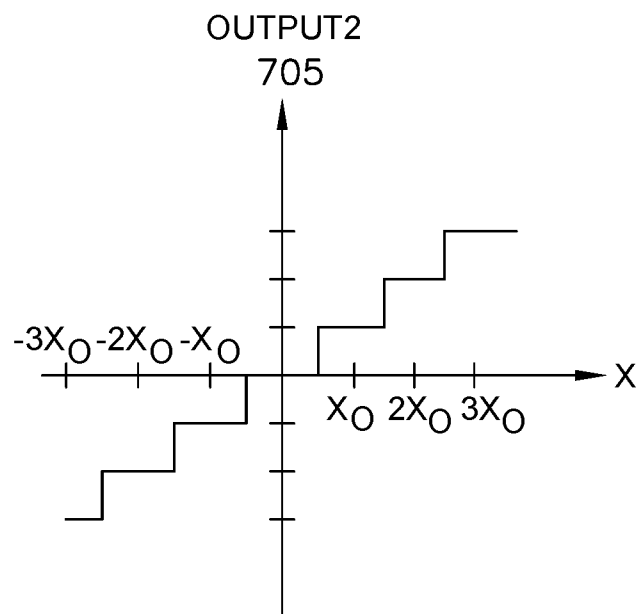


FIG. 4E

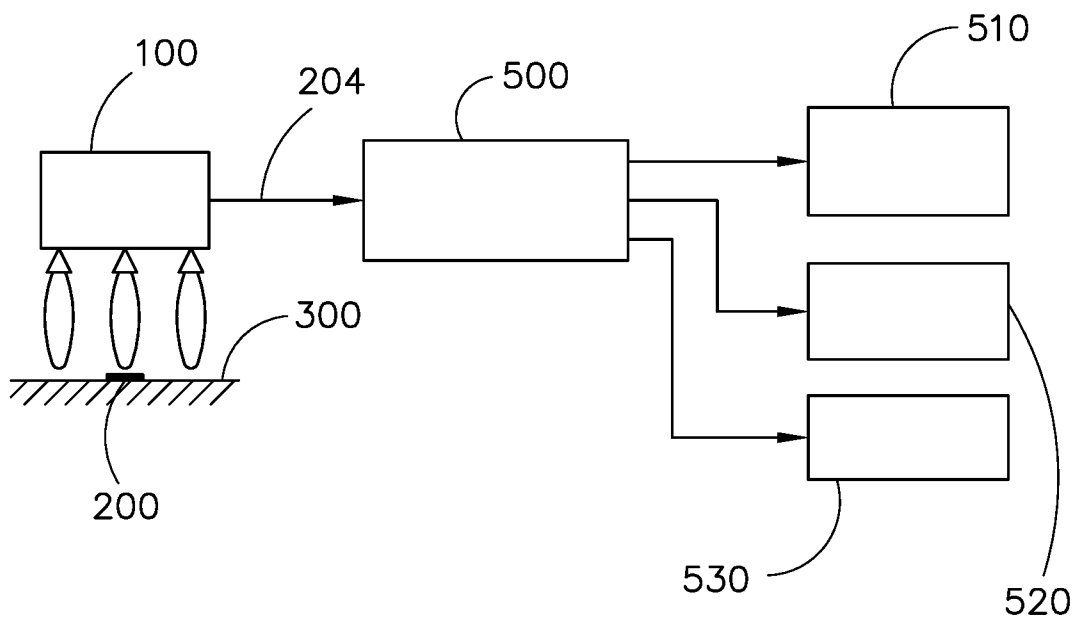


FIG. 5

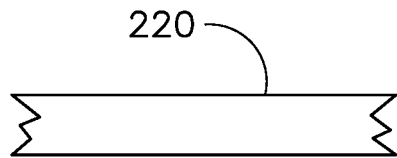


FIG. 6A

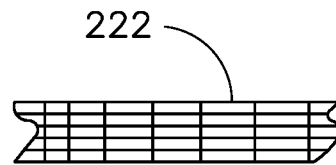


FIG. 6B

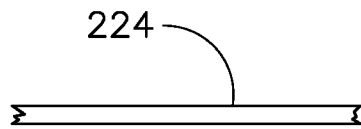


FIG. 6C

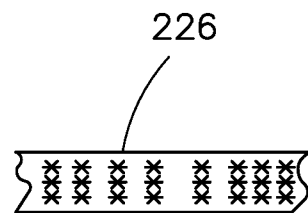


FIG. 6D

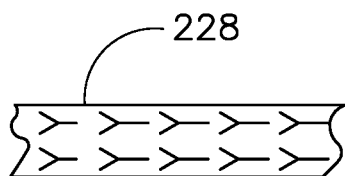


FIG. 6E

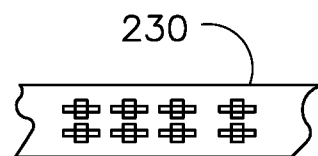


FIG. 6F

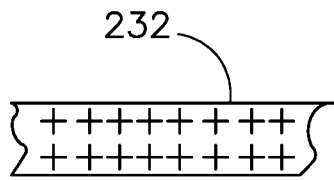


FIG. 6G

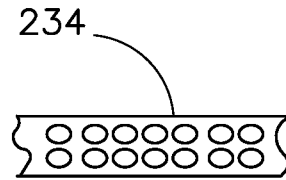


FIG. 6H

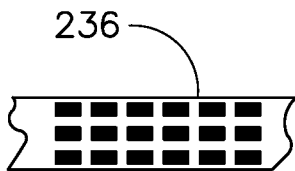


FIG. 6I

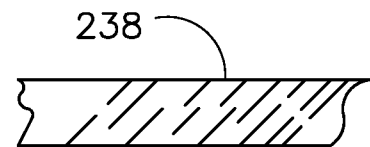


FIG. 6J

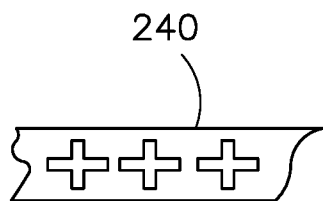


FIG. 6K

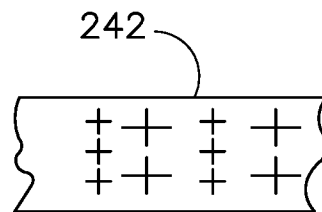


FIG. 6L



FIG. 6M

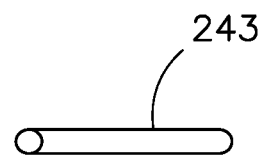


FIG. 6N

14/36

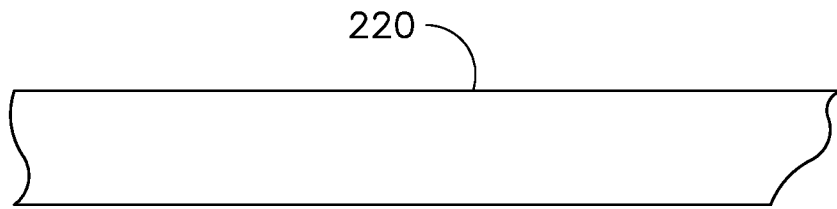


FIG. 7A

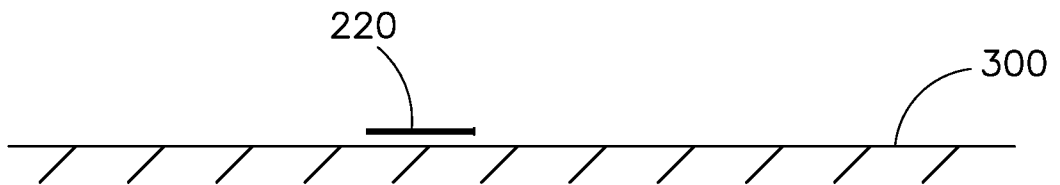


FIG. 7B

15/36

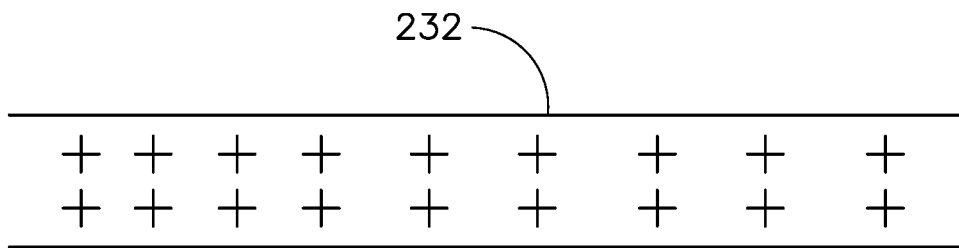


FIG. 8A

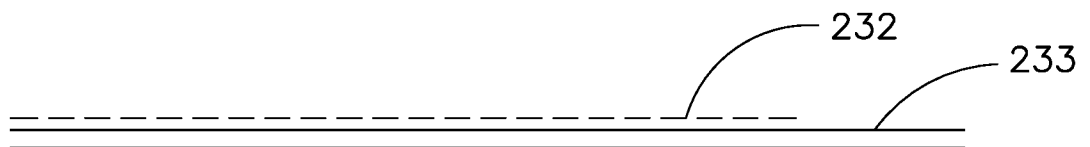


FIG. 8B

16/36

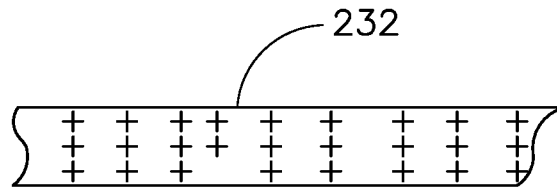


FIG. 9A

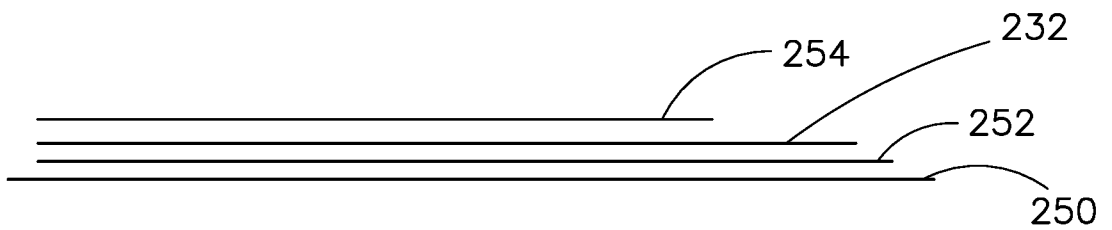


FIG. 9B

17/36

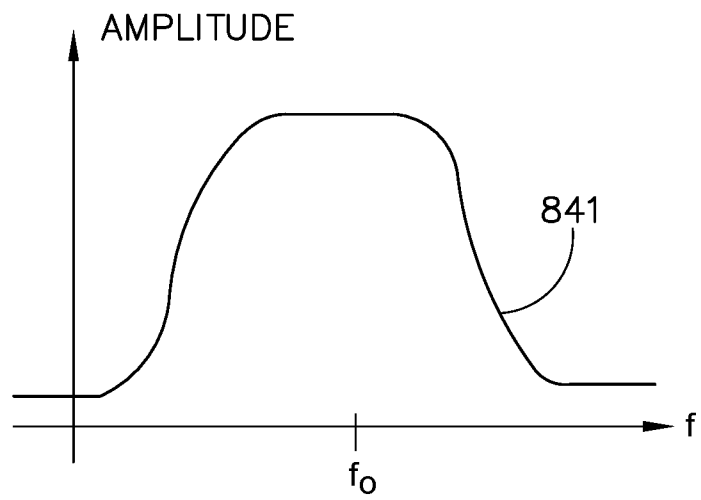


FIG. 10A

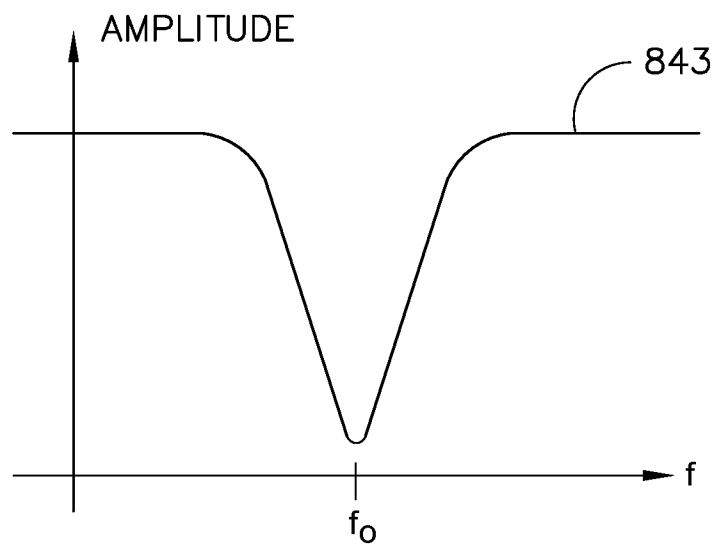


FIG. 10B

18/36

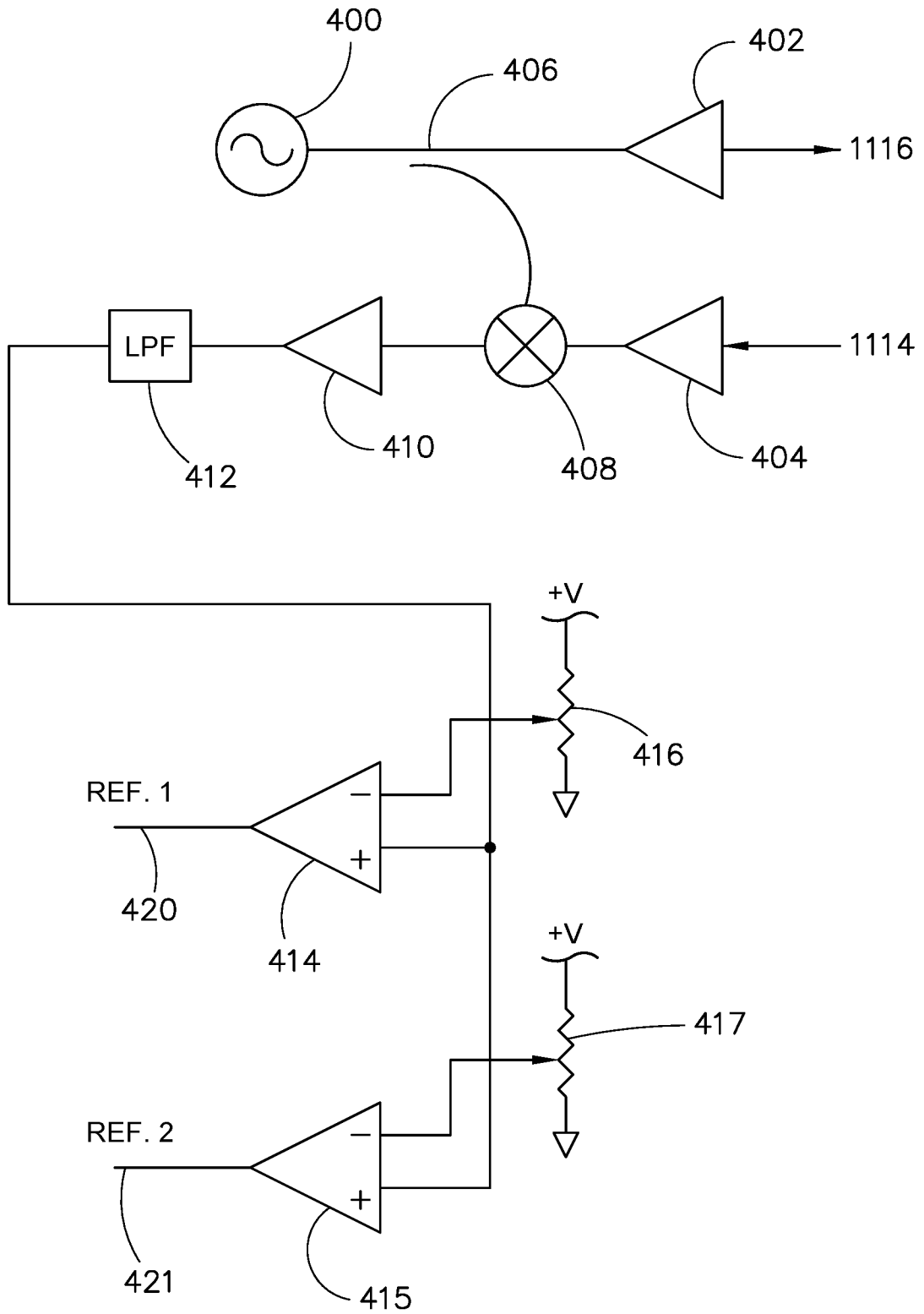


FIG. 11

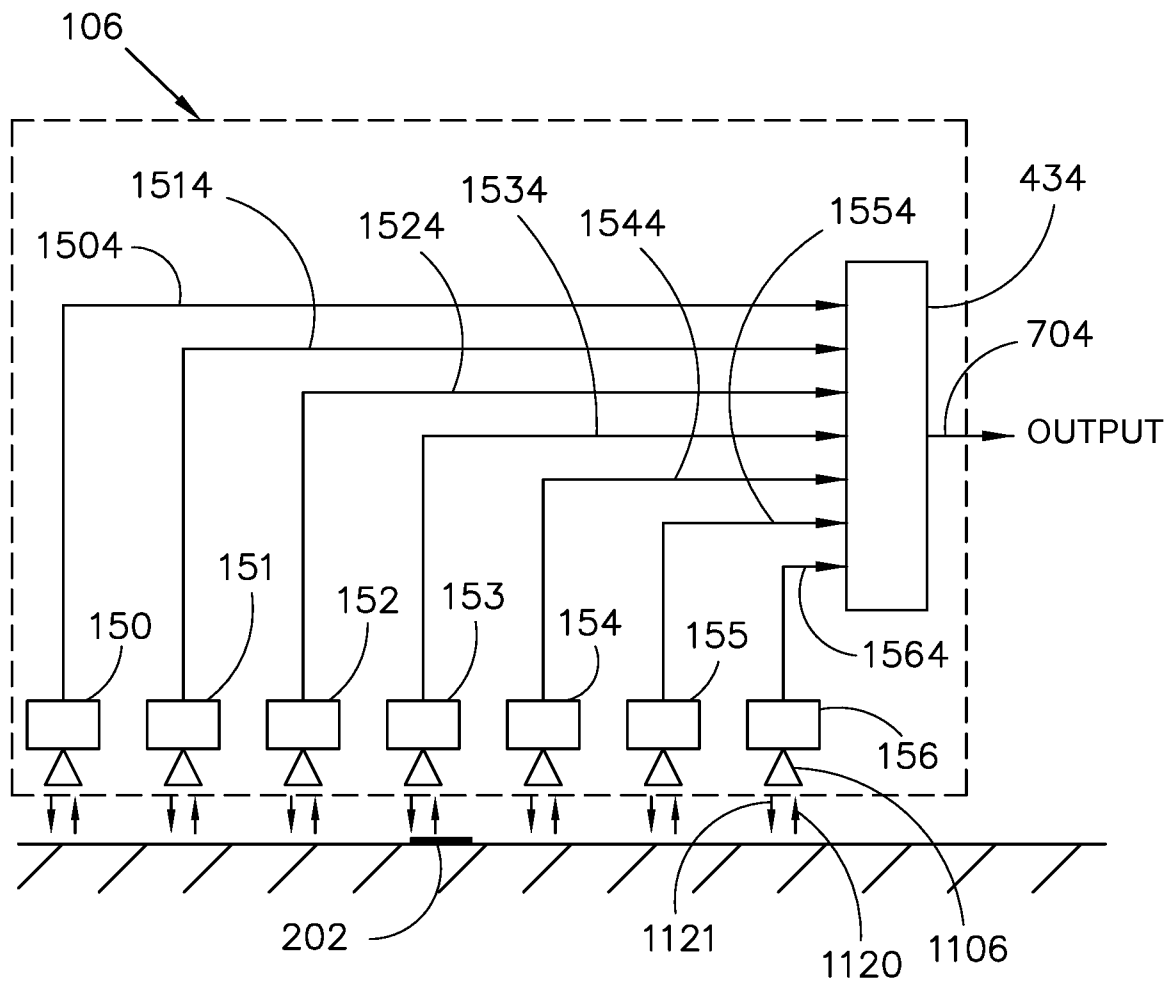


FIG. 12

20/36

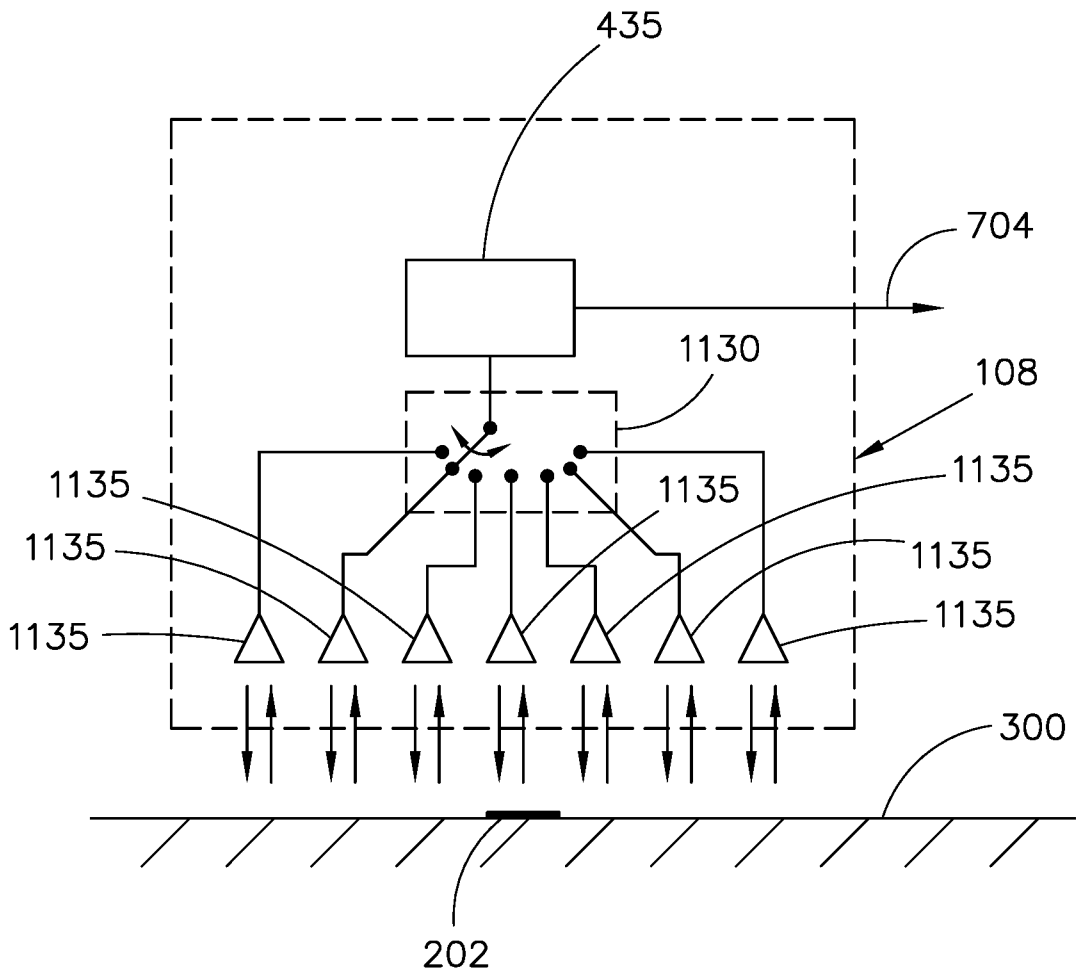


FIG. 13

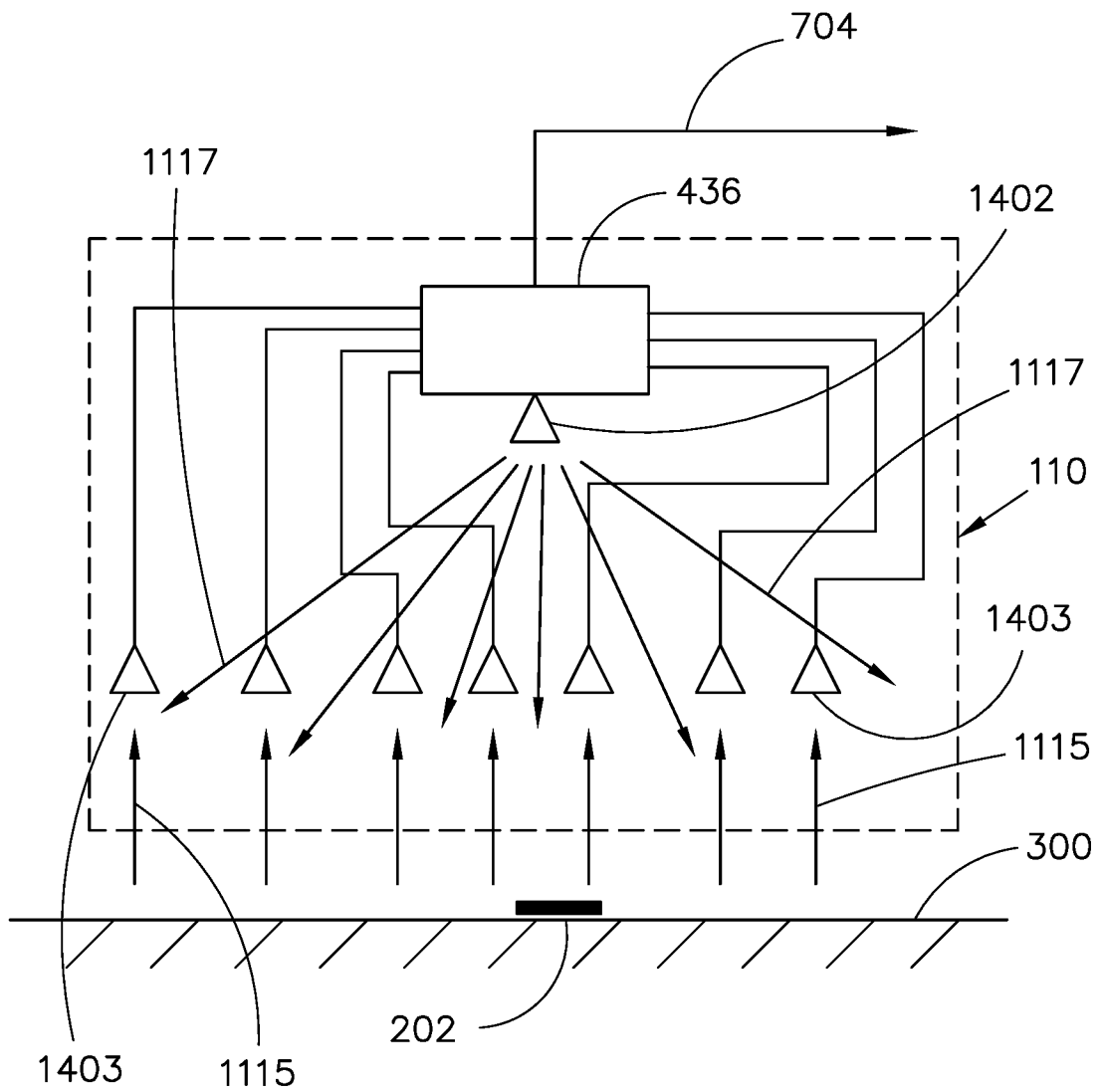


FIG. 14

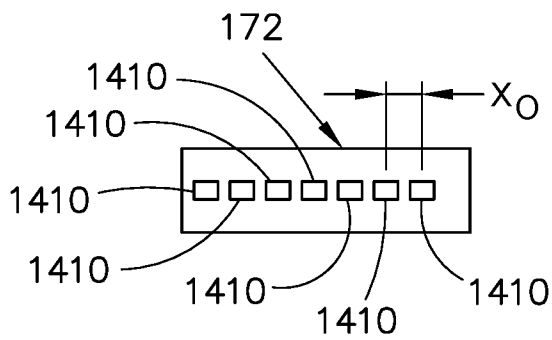


FIG. 15A

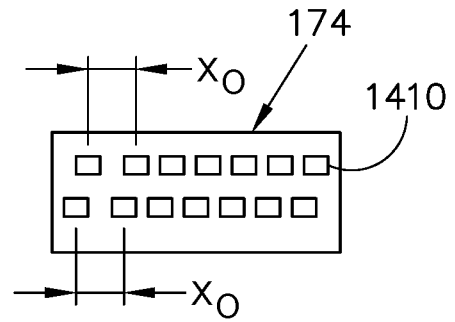


FIG. 15B

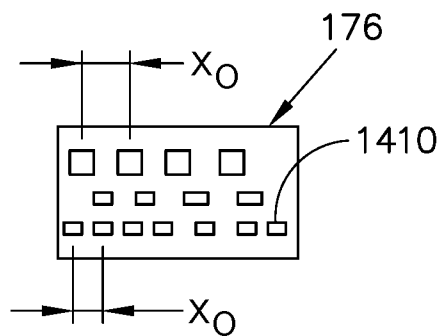


FIG. 15C

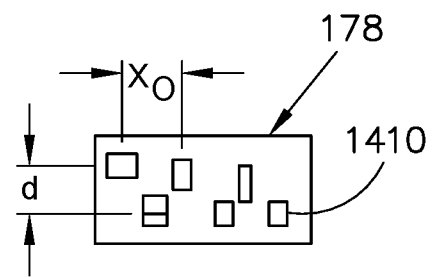


FIG. 15D

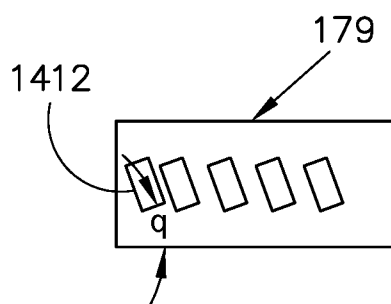


FIG. 15E

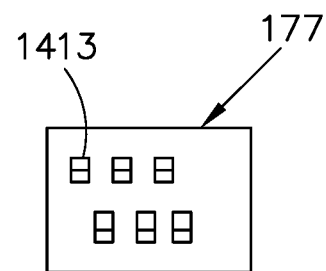


FIG. 15F

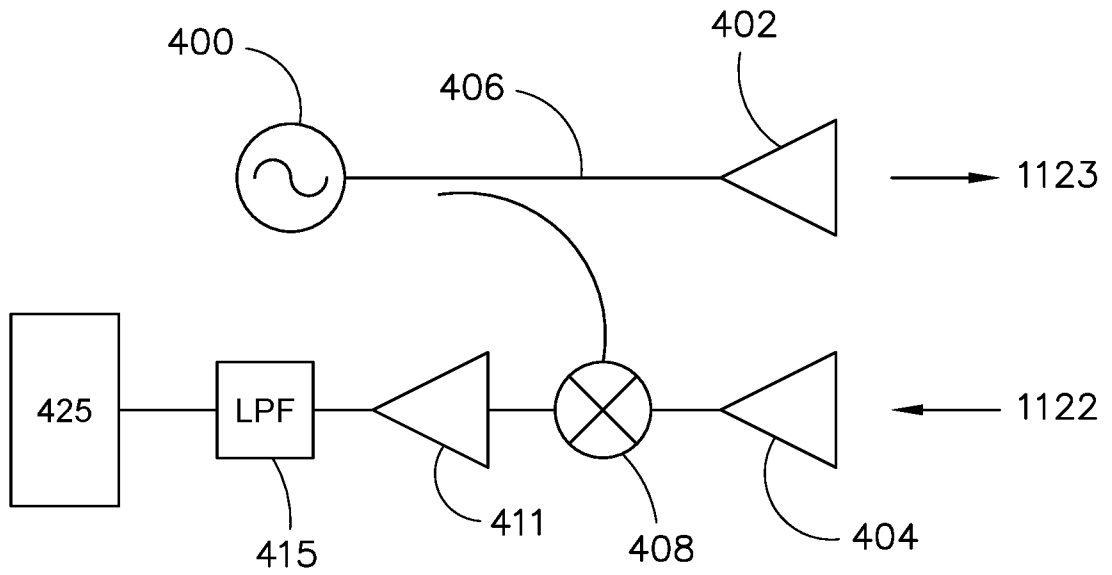


FIG. 16

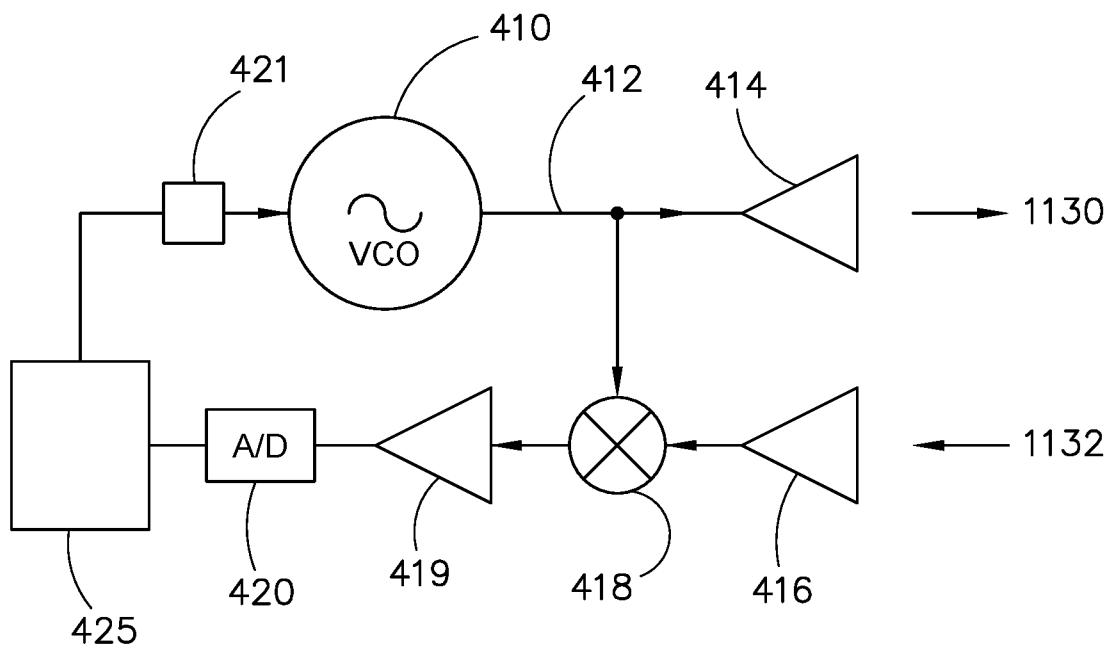


FIG. 17

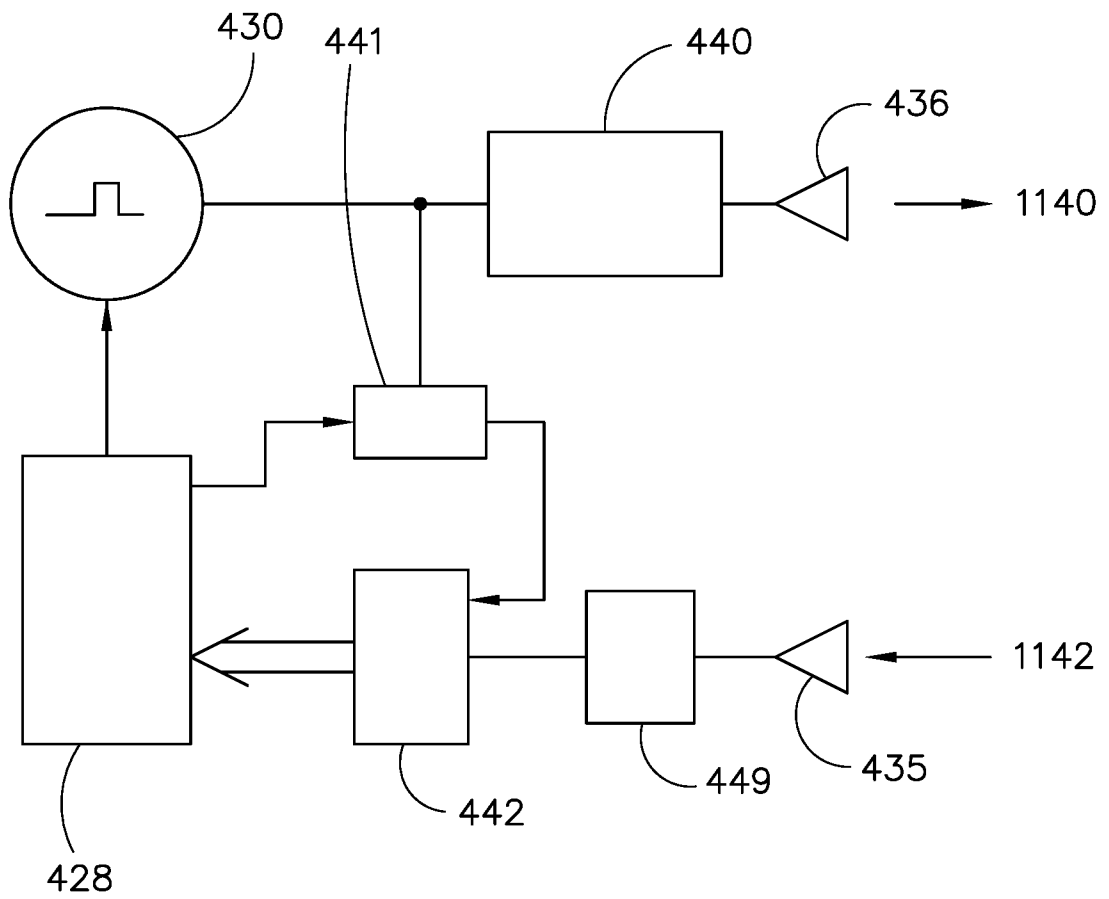


FIG. 18

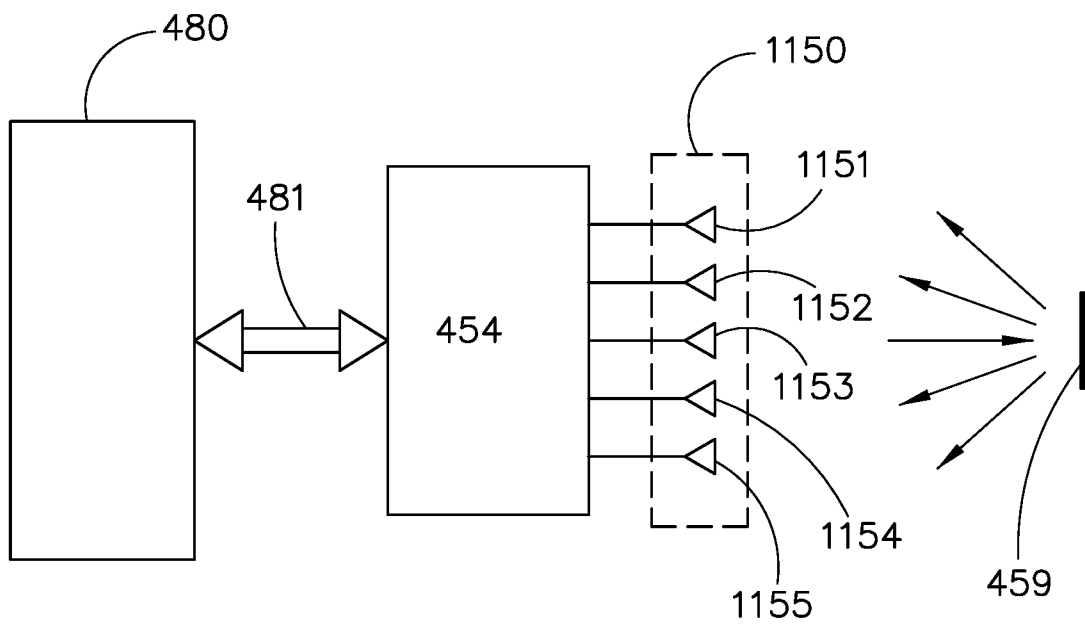


FIG. 19

27/36

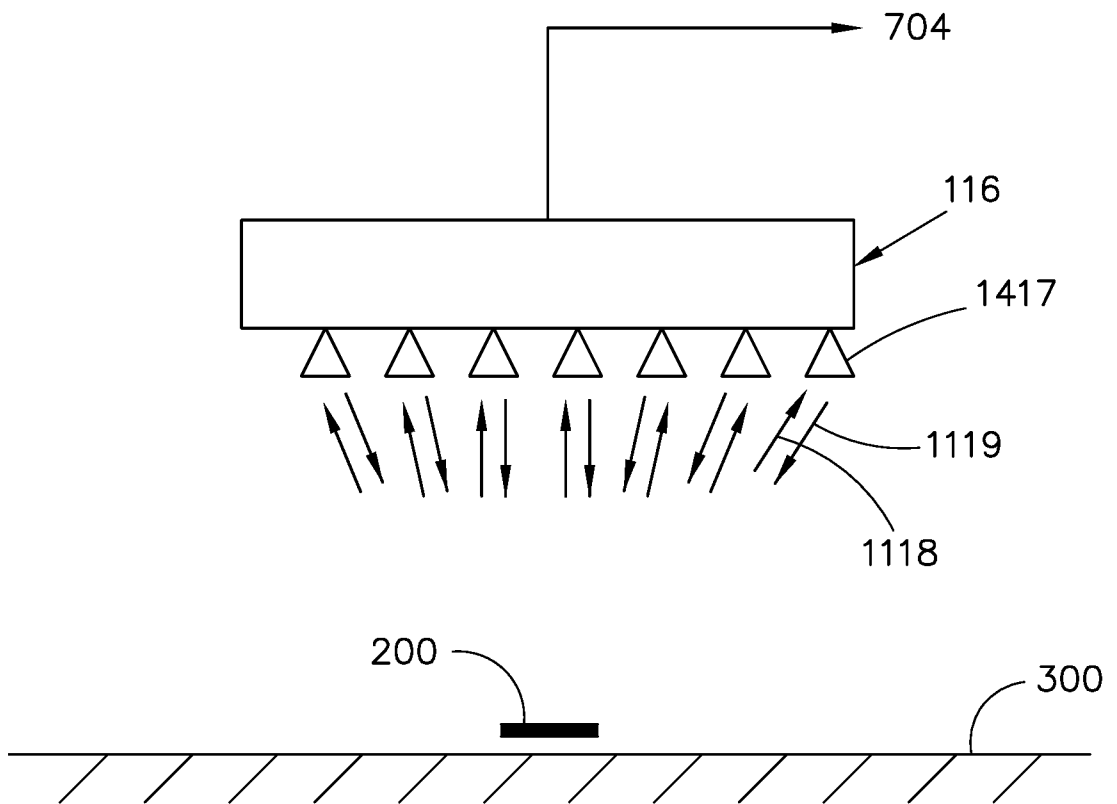


FIG. 20

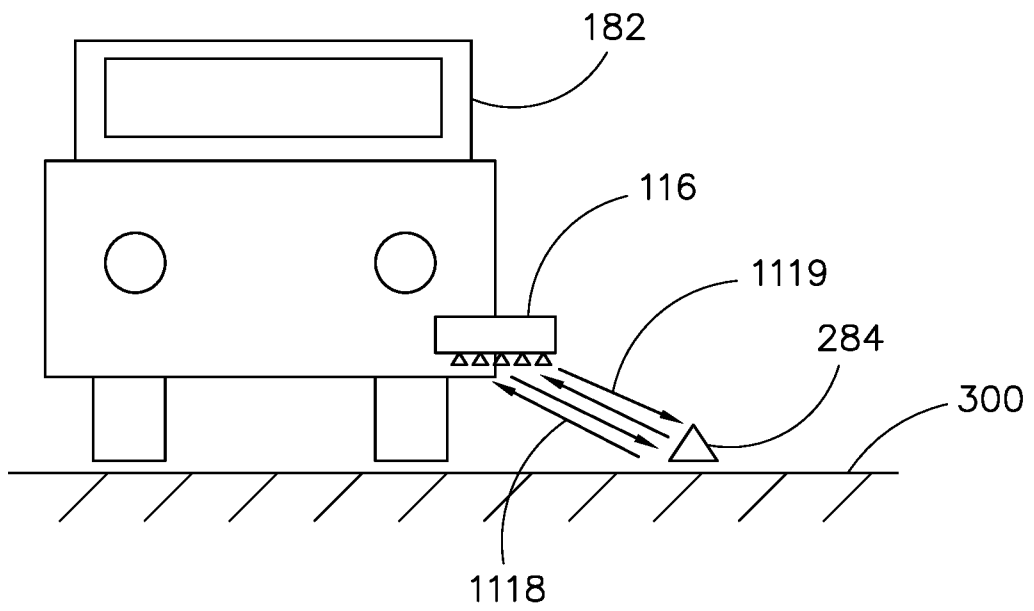


FIG. 21

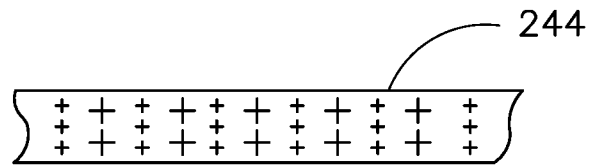


FIG. 22A

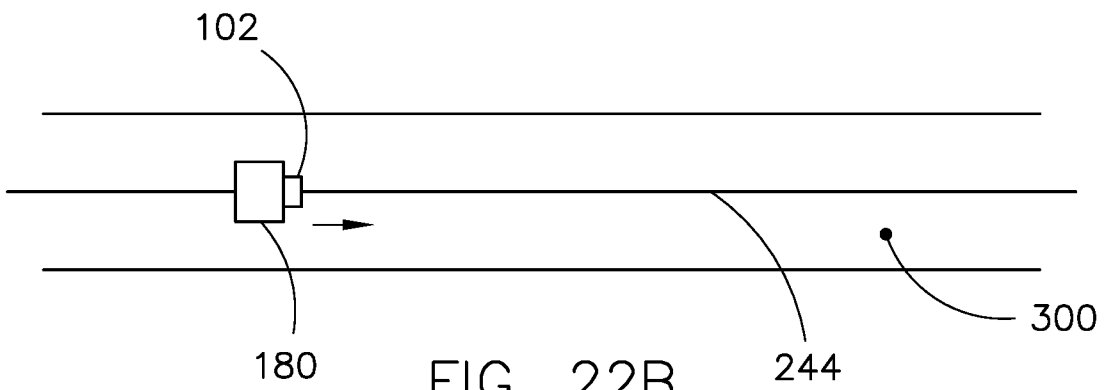


FIG. 22B

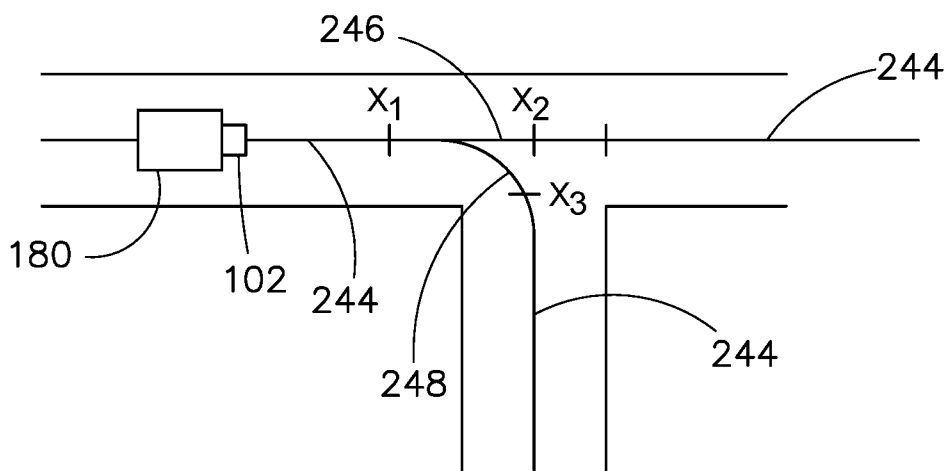


FIG. 22C

30/36

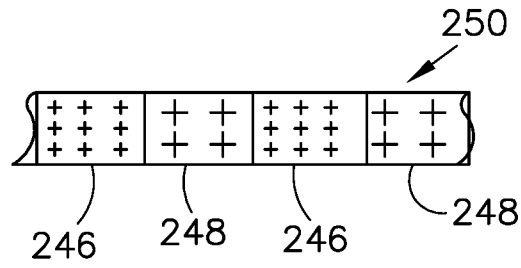


FIG. 23A

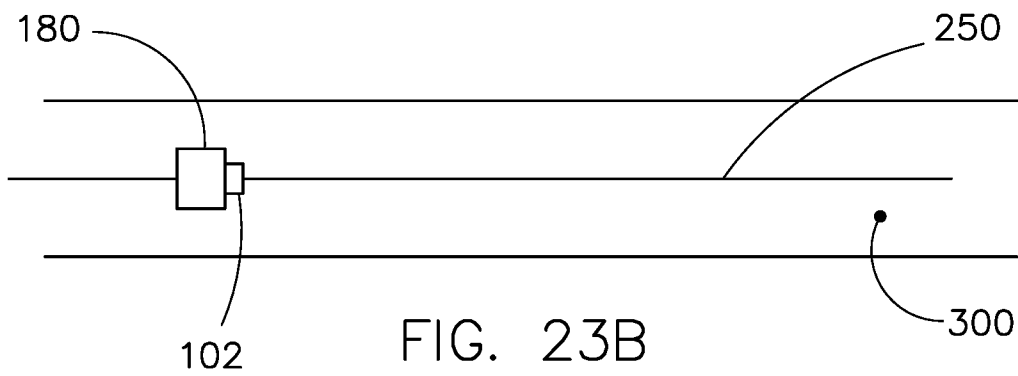


FIG. 23B

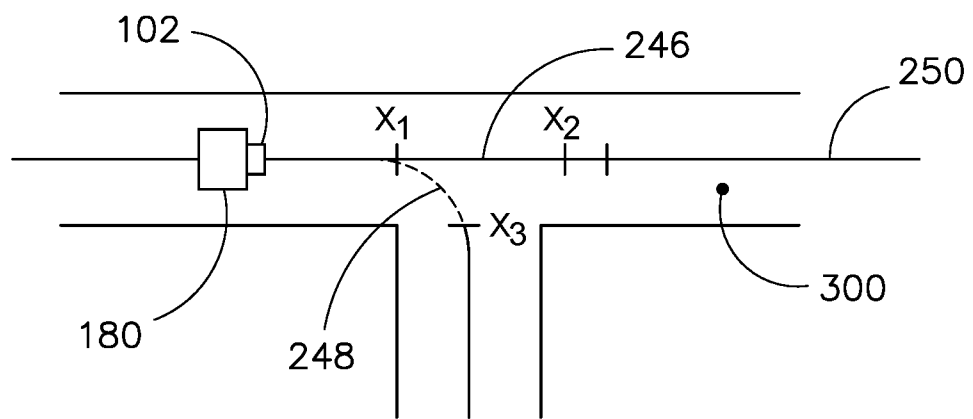


FIG. 23C

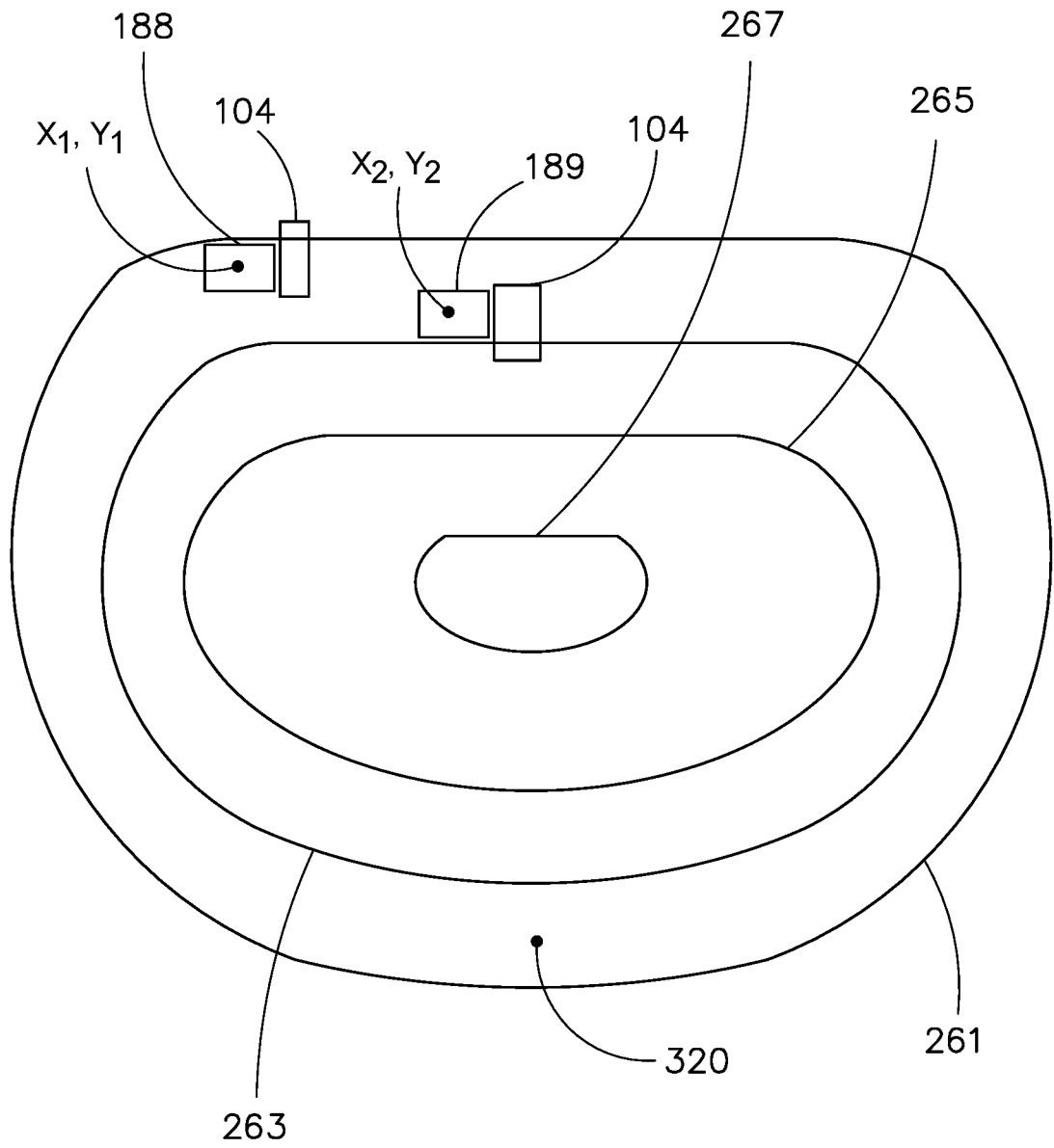


FIG. 24

32/36

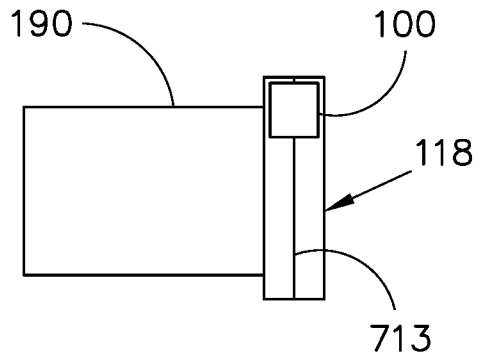


FIG. 25A

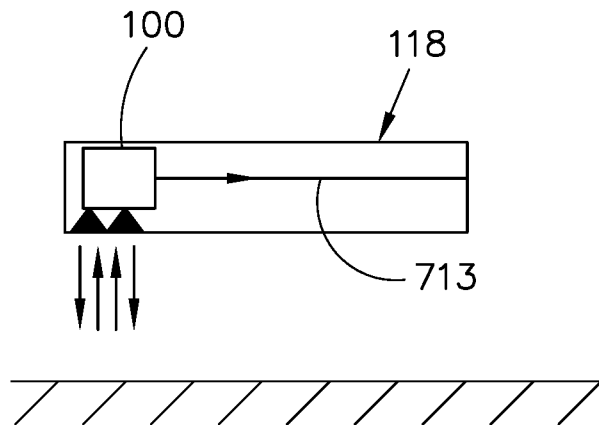


FIG. 25B

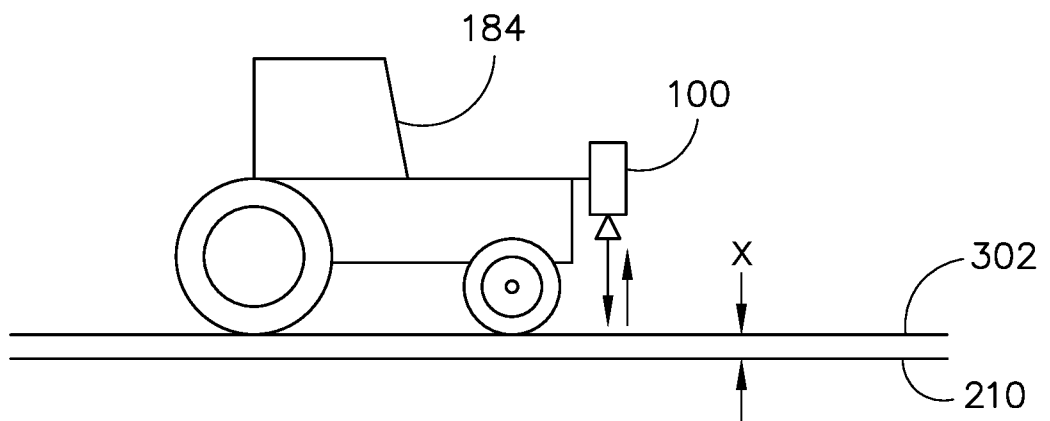


FIG. 26A

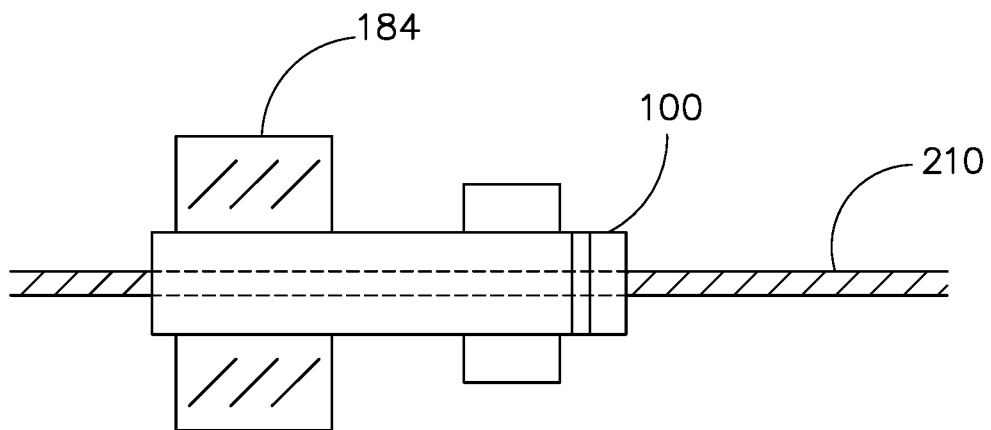


FIG. 26B

34/36

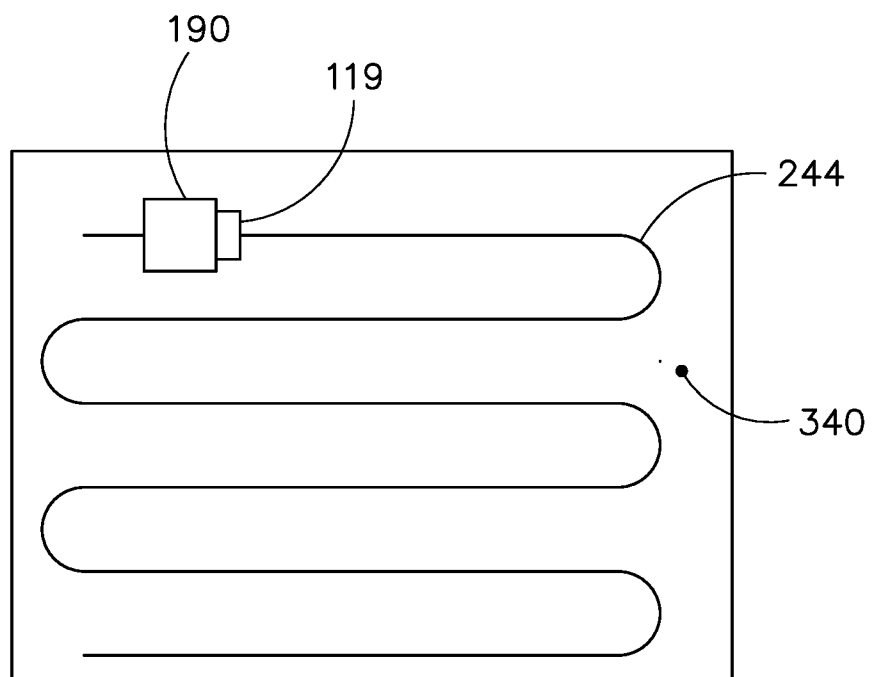


FIG. 27

35/36

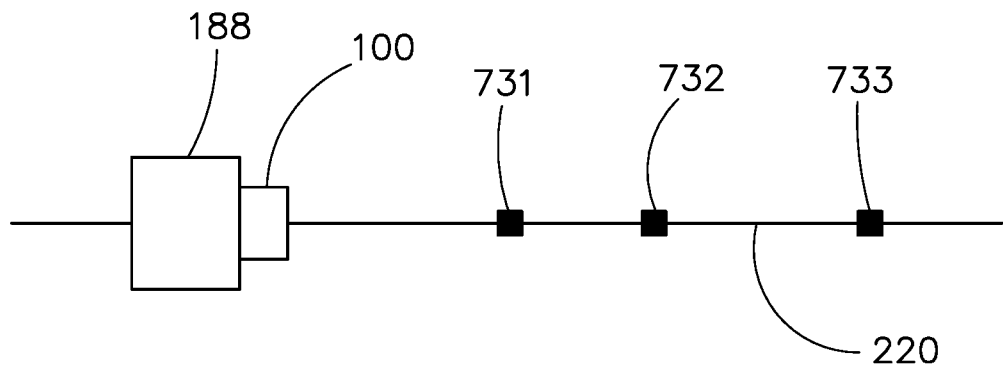


FIG. 28

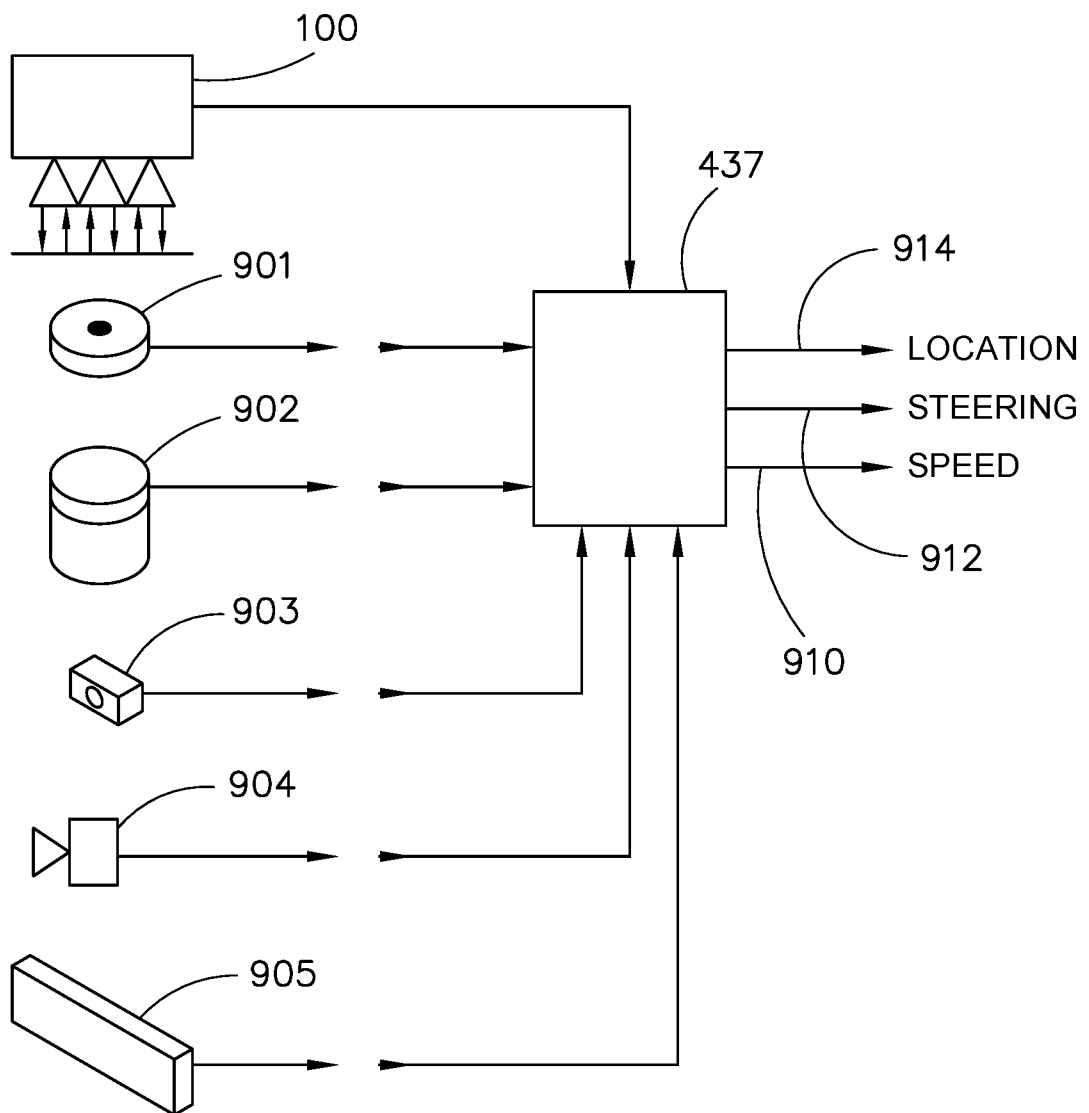


FIG. 29

INTERNATIONAL SEARCH REPORT

International application No. PCT/US2018/019047
--

A. CLASSIFICATION OF SUBJECT MATTER
 IPC(8) - B60W 10/20; G05D 1/00; G05D 1/02; G08G 1/16 (2018.01)
 CPC - B60W 30/16; G05D 1/024; B60W 10/20; G05D 2201/0213 (2018.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 USPC - 701/23; 701/25; 701/41 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2016/0132705 A1 (KOVARIK et al) 12 May 2016 (12.05.2016) entire document	1, 9, 11 --- 2-8, 10, 12-19
Y	US 9,261,590 B1 (BROWN) 16 February 2016 (16.02.2016) entire document	2, 3, 5, 8, 17
Y	US 6,005,511 A (YOUNG et al) 21 December 1999 (21.12.1999) entire document	4
Y	US 2014/0222246 A1 (MOHAMADI) 07 August 2014 (07.08.2014) entire document	6, 7, 14-19
Y	US 3,198,279 A (QUINN) 03 August 1965 (03.08.1965) entire document	10
Y	US 5,202,742 A (FRANK et al) 13 April 1993 (13.04.1993) entire document	12-19
A	US 2015/0303581 A1 (BODO) 22 October 2015 (22.10.2015) entire document	1-19

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 09 April 2018	Date of mailing of the international search report 10 MAY 2018
--	--

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774
---	--