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(54) **AUTOMOTIVE RADAR SENSOR BLOCKAGE
DETECTION SYSTEM AND RELATED
TECHNIQUES**

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See application file for complete search history.

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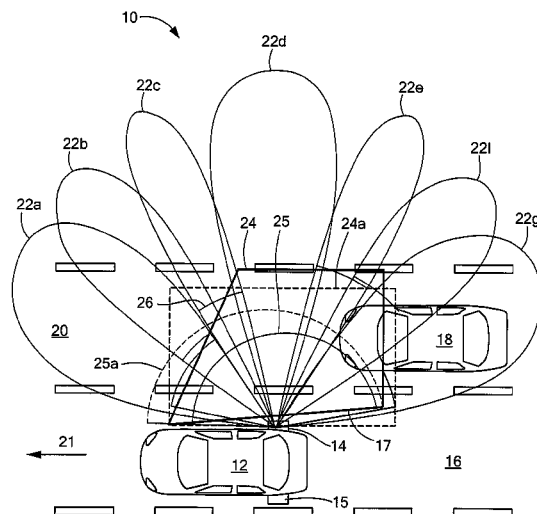
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(57) **ABSTRACT**

A blockage detection system and method for use in a sensor such as a side object detection (SOD) sensor in an automotive radar system is described. The sensor emits signals and receives return signals (i.e. reflected signals) from a passing object. If the passing object is within a virtual detection zone, the sensor uses the information from the passing object to determine if a blockage condition exists in the sensor. The technique utilizes statistics related to the passing object to determine whether a blockage condition exists within the sensor. In one embodiment, a SOD sensor mounted in a first vehicle uses information from a second passing vehicle (e.g. radar return information) to determine whether a blockage condition exists within the SOD sensor itself.

4 Claims, 9 Drawing Sheets



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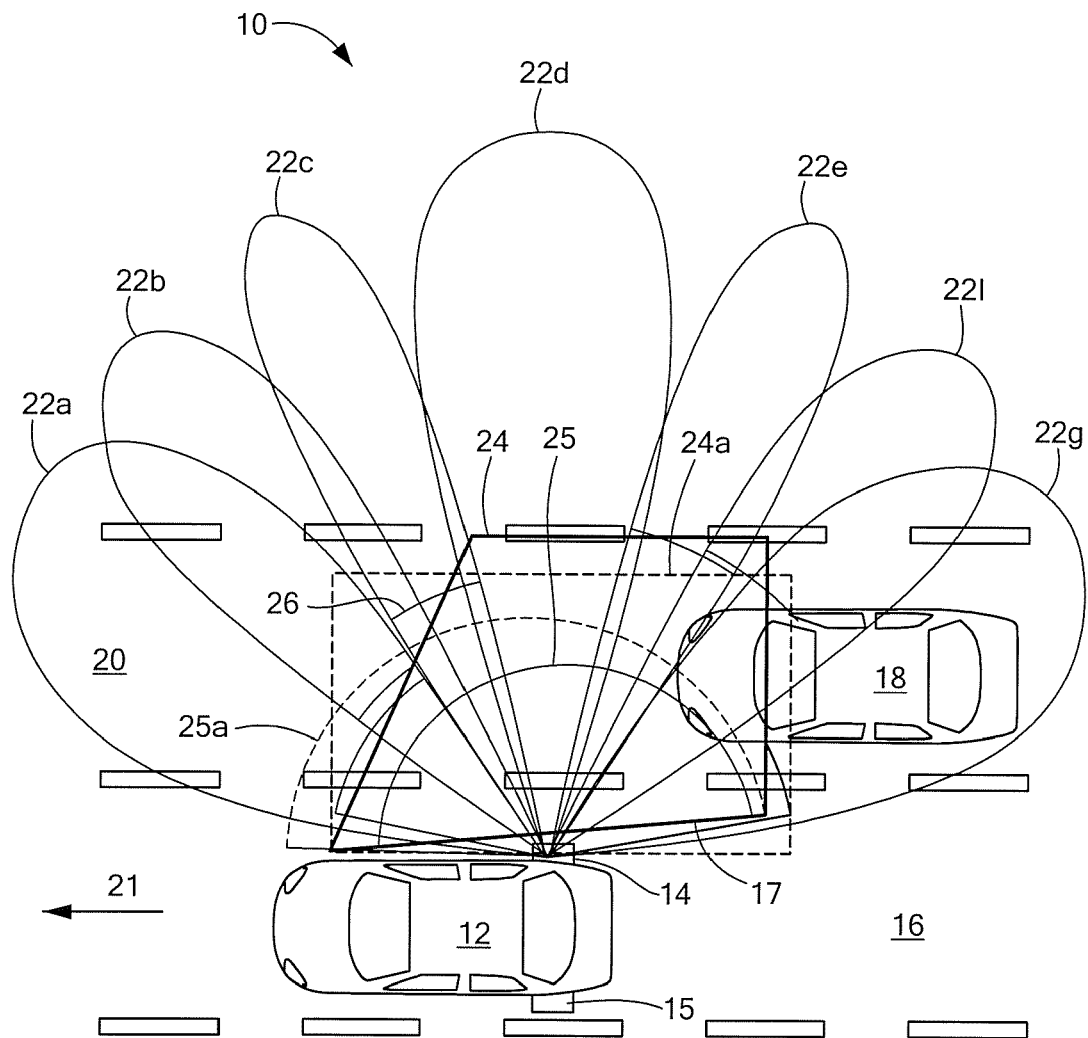


FIG. 1

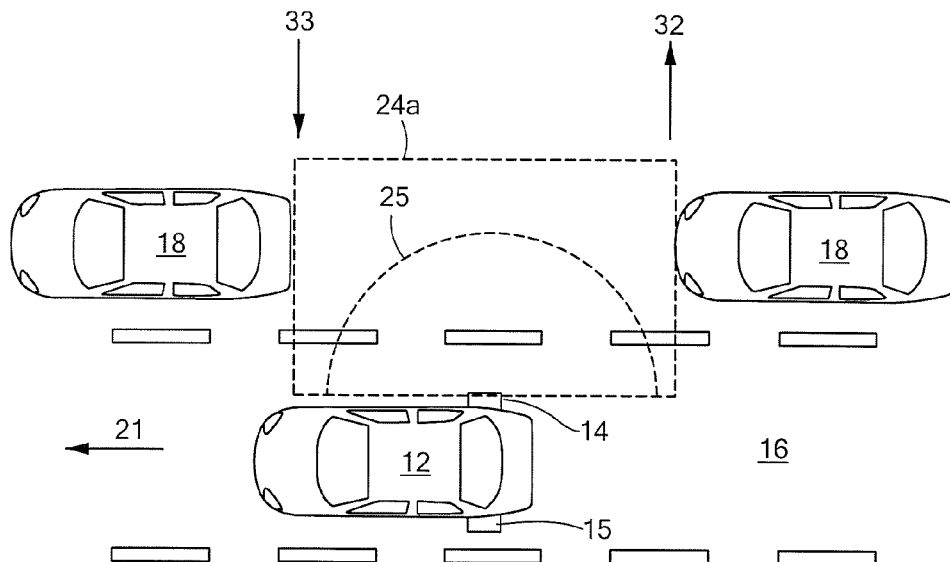


FIG. 1A

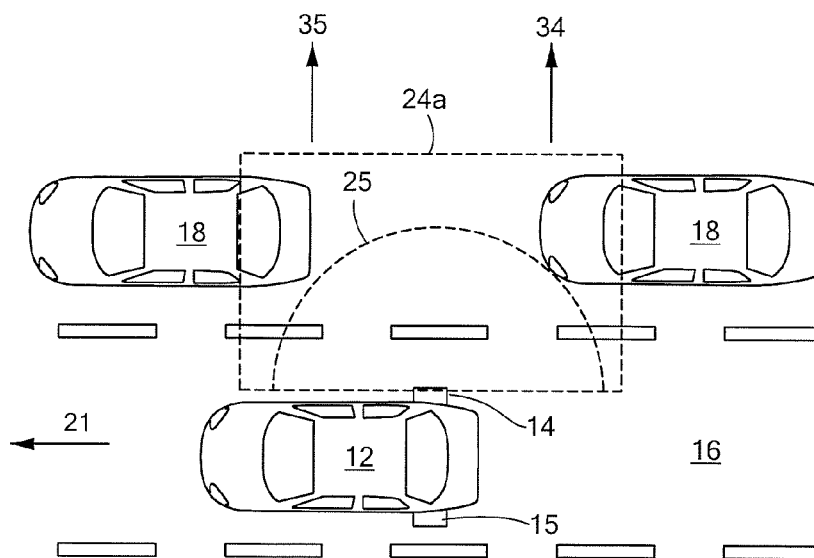


FIG. 1B

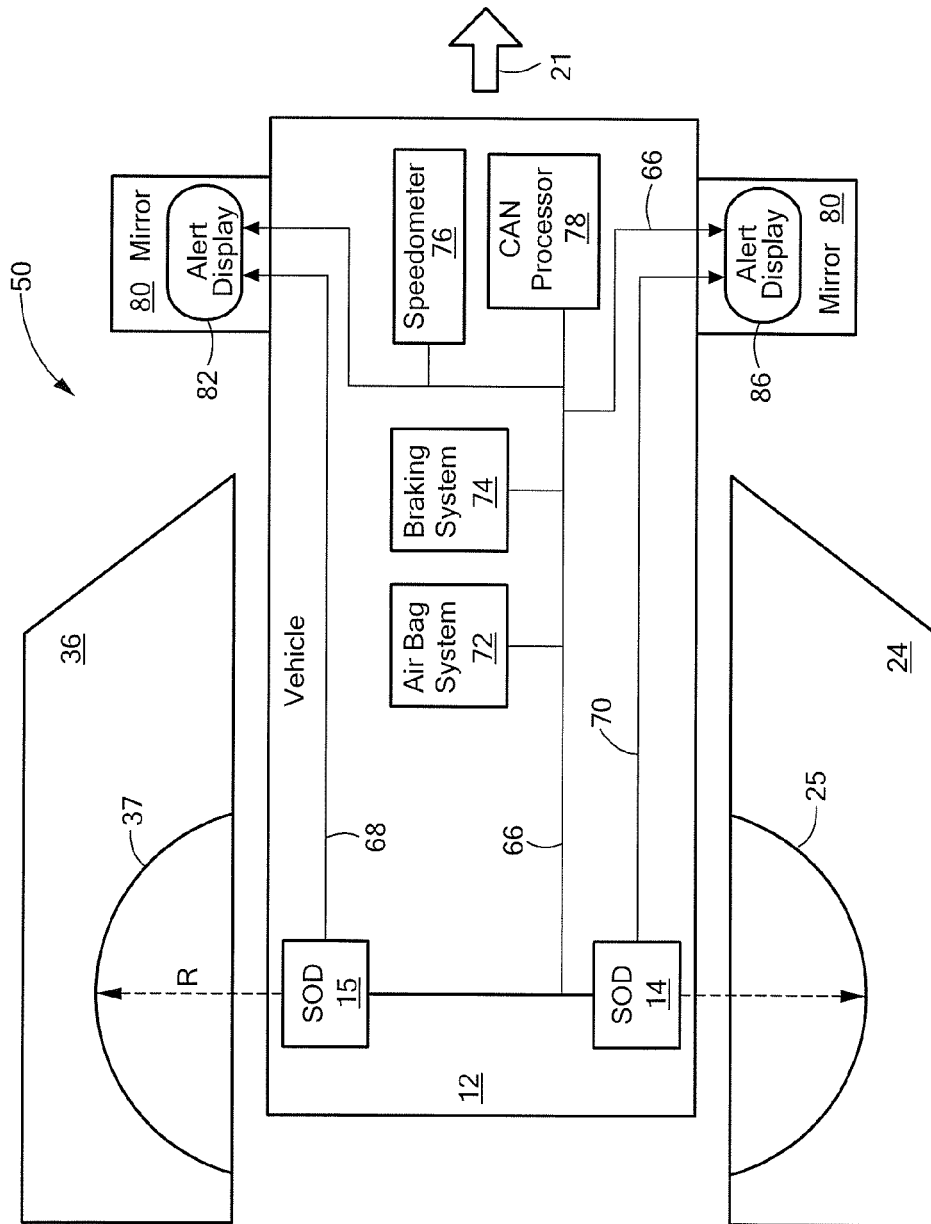


FIG. 2

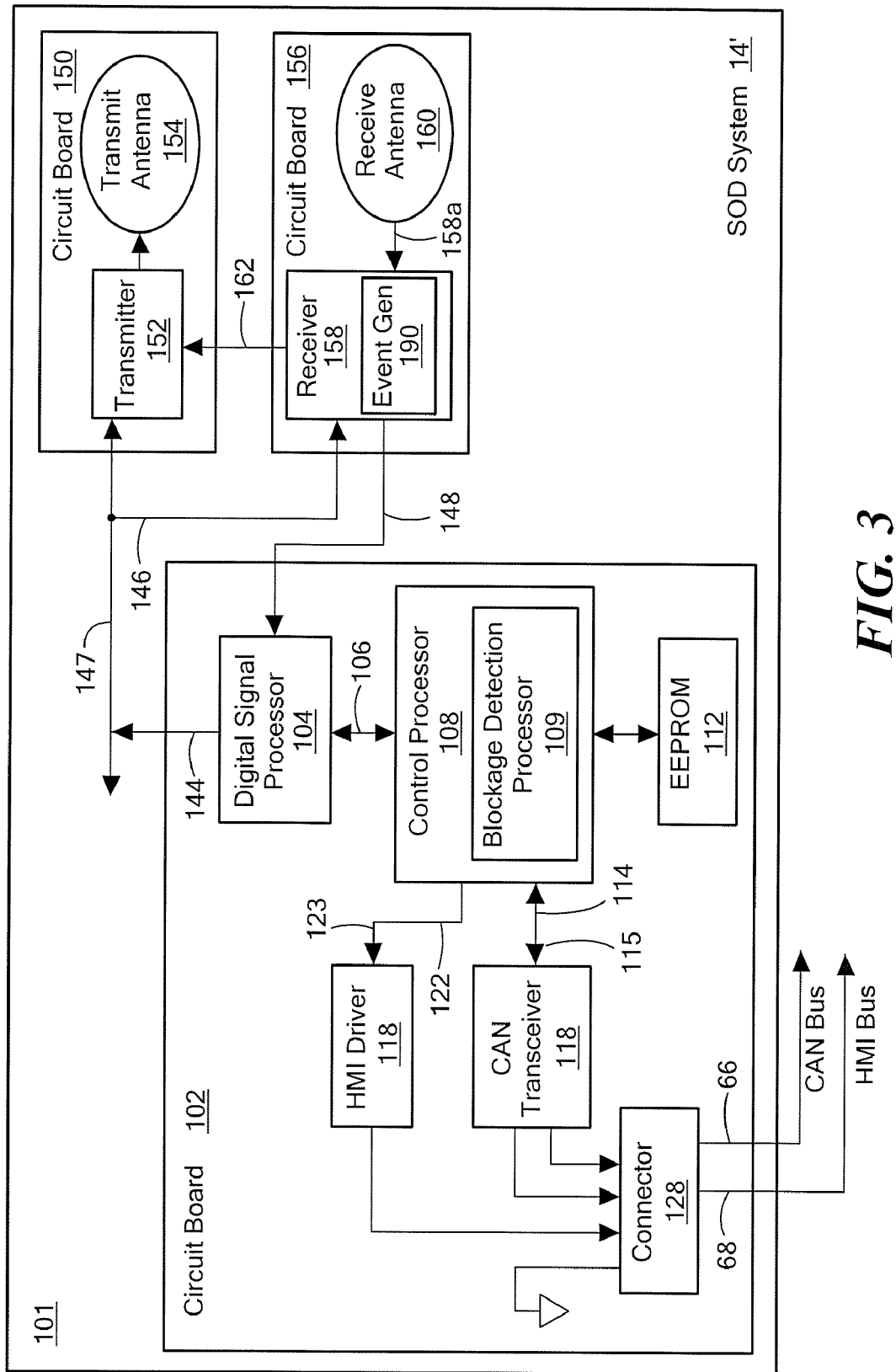


FIG. 3

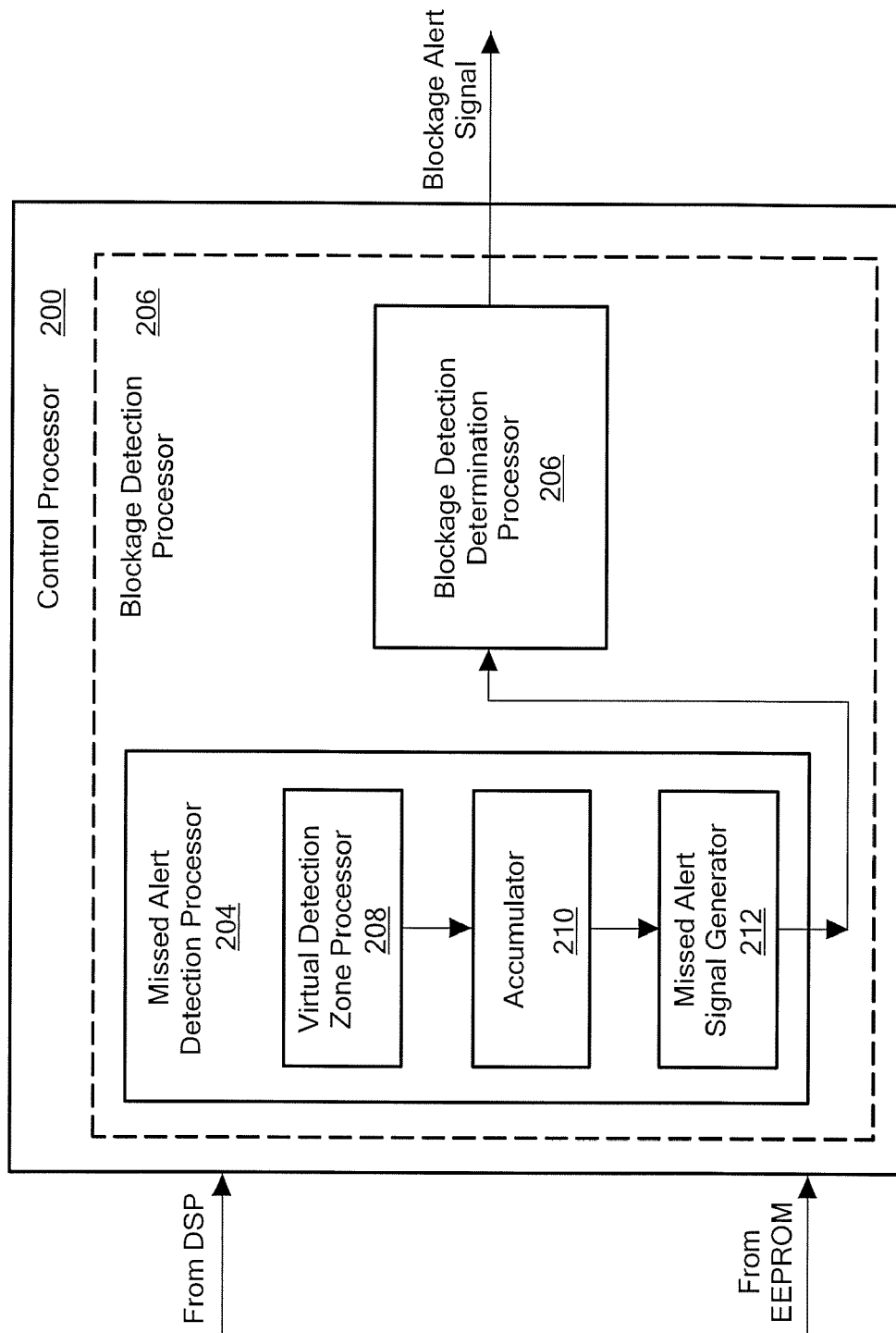


FIG. 4

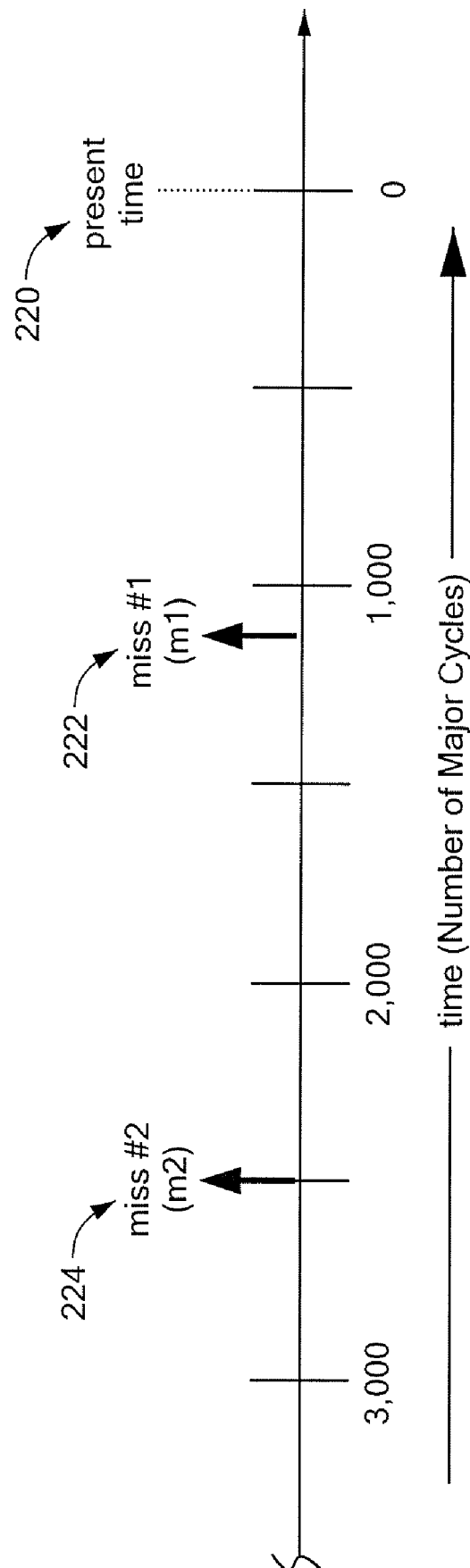
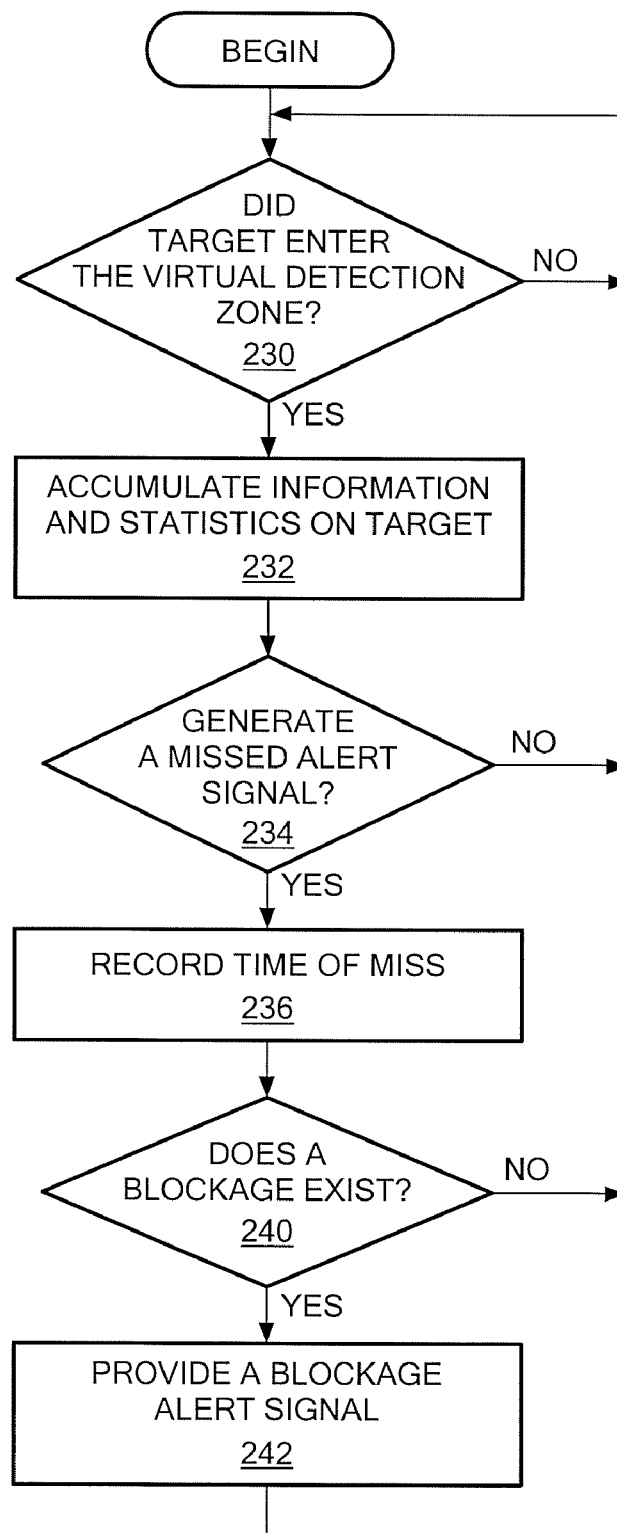


FIG. 5

**FIG. 6**

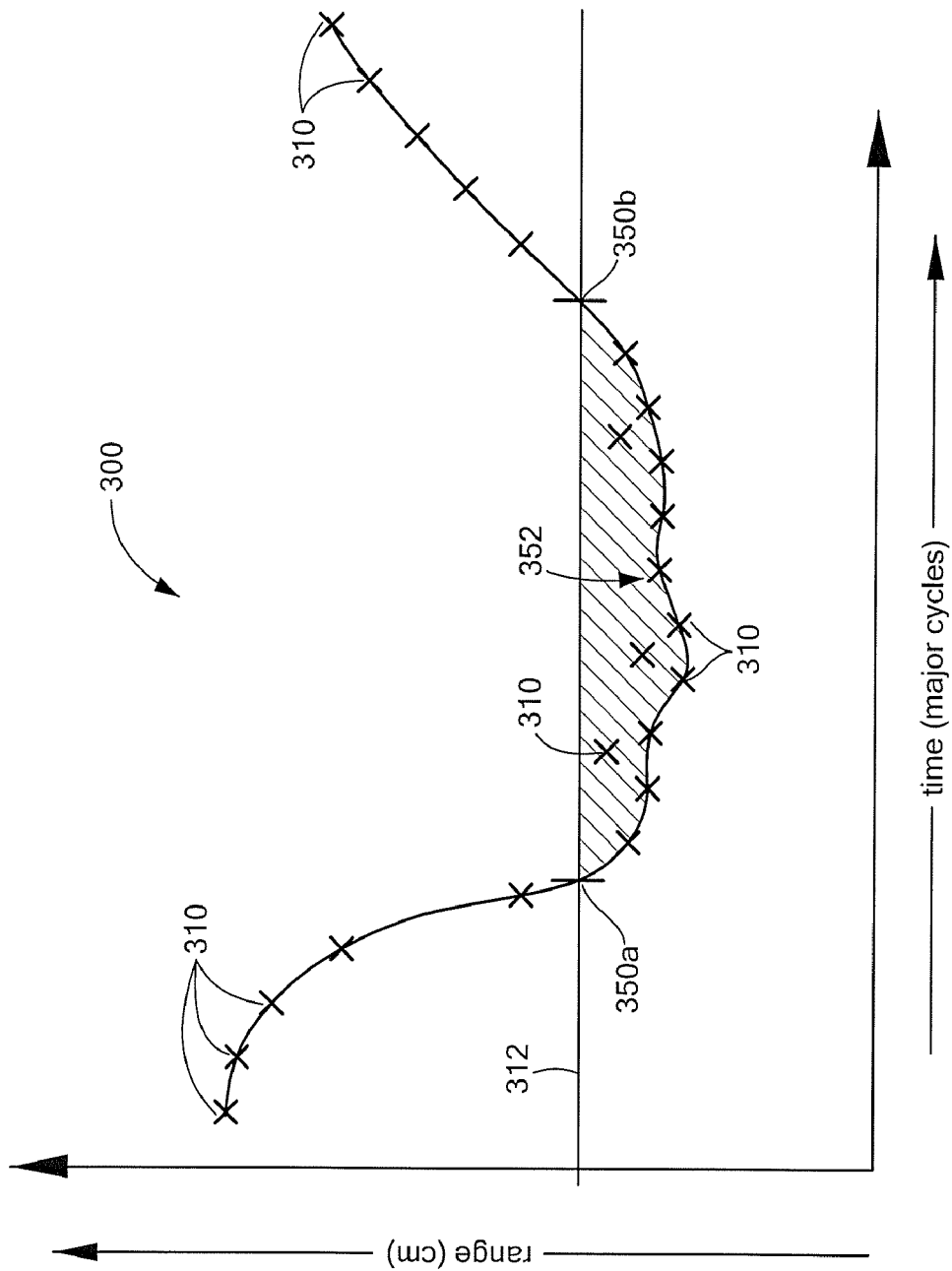
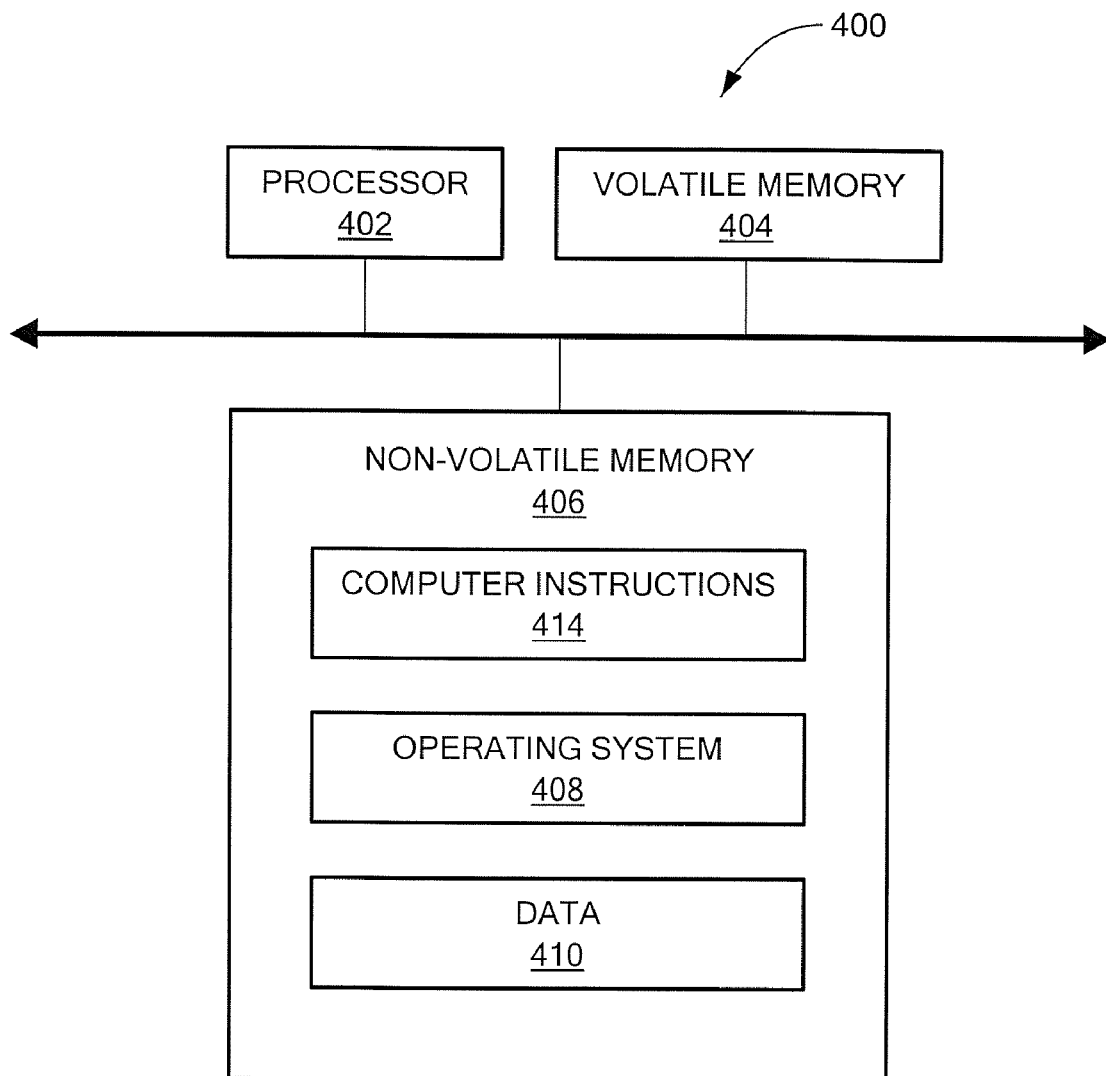


FIG. 7

**FIG. 8**

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AUTOMOTIVE RADAR SENSOR BLOCKAGE DETECTION SYSTEM AND RELATED TECHNIQUES

RELATED APPLICATIONS

This application claims the benefit, under 35 U.S.C. §119 (e), of U.S. Provisional Application No. 61/040,948 filed Mar. 31, 2008 which application is hereby incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The structures and techniques described herein relate to radars and more particularly to structure and techniques for detecting a blockage in a radar such as an automotive radar.

BACKGROUND OF THE INVENTION

As is known in the art, the existence of foreign matter or objects on a radar such as an automotive radar sensor of the type described in U.S. Pat. No. 5,959,570, for example, can impact the accuracy and reliability of the radar. For example, the foreign matter or objects may undesirably block one or more portions of the radar sensor transmit and/or receive antennas and in particular may block portions of the RF energy propagating to and from the transmit and receive antennas of the radar sensor.

Such blockage may, for example, be the result of an accumulation, over a period of time, of foreign matter or objects in the region of an antenna aperture. Such foreign matter may be caused for example by environmental conditions such as temperature, humidity, ice, rain and the like. Such blockage can degrade, or in extreme cases even prevent, proper operation of the automotive radar sensor. If the foreign matter accumulates over time, there is a corresponding gradual decrease in sensor system performance over time. Since the accumulation is gradual, it is sometimes relatively difficult to detect the existence of antenna blockage due to the gradual accumulation of foreign matter and corresponding gradual decrease in radar sensor performance.

It would, therefore, be desirable to provide a radar which is capable of detecting blockage. It would also be desirable to provide a radar which is capable of detecting blockage due to the accumulation of foreign matter, such as mud, ice, snow or the like, on or proximate a radar radome. It would further be desirable to provide a radar which detects blockage and which notifies a system user of the existence of such blockage. It would be further desirable to provide an automotive radar sensor capable of detecting blockage. It would also be desirable to provide an automotive radar sensor which is capable of detecting blockage due to the accumulation of foreign matter, such as mud, ice, snow or the like, on the vehicle in or proximate that area of the vehicle in which the automotive sensor is mounted. It would further be desirable to provide an automotive radar sensor which detects blockage and which notifies a system user of the existence of such blockage.

SUMMARY OF THE INVENTION

In accordance with the techniques and concepts described herein, a blockage detection process includes (a) detecting a target within a virtual detection zone, (b) while the target is within the virtual detection zone, accumulating target-related information, and (c) based upon the information accumulated in (b), determining if a blind spot alert signal was missed. The process further includes (d) in response to a decision being

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made that a blind spot alert signal was missed, recording a time of the miss and (e) based upon information for each recorded miss, determining whether a blockage condition exists. With this particular arrangement, a process for detecting blockage in a sensor is provided. In one embodiment, once a decision is made that a blockage condition exists within the sensor, the process further includes providing an indication that a blockage condition exists. If the sensor is provided as an automotive radar sensor, then an indication that a blockage condition exists may be given to an operator of the vehicle on which the automotive radar sensor is disposed by a visual, audio or mechanical technique. The information related to the target may correspond to statistics, including, but not limited to one or more of target range history, range of closest approach, point of closest approach, angle, angle history, speed, time spent by a target in a virtual detection zone, number of total detections, raw radar detection count and detection density as a function of range and/or angle.

In accordance with a further aspect, a system for detecting blockage includes a transmit antenna, a transmitter coupled to provide a transmit signal to the transmit antenna, a receive antenna, a receiver coupled to receive signals from said receive antenna and a blockage detection processor configured to identify objects in a virtual detection zone and to determine if a blockage condition exists based upon information on recorded misses.

In accordance with a still further aspect, a method for determining a blockage condition in an automotive radar side object detection system includes establishing a virtual detection zone, emitting signals from the automotive radar side object detection system, and receiving, in the automotive radar side object detection system, a plurality of return signals from a target located in the virtual detection zone. The method further includes processing the plurality of return signals from the target located in the virtual detection zone to determine if a blockage condition exists. With this particular arrangement, a process which uses information from a passing object to determine if a blockage condition in a sensor is provided. For example, a SOD sensor mounted in a first vehicle uses information from a second passing vehicle (e.g. radar return information) to determine whether the SOD sensor itself has a blockage. Stated differently, the technique utilizes statistics related to passing objects (e.g. vehicles) to determine the existence of a blockage.

In one embodiment, once a blockage alert signal is generated if, at a later time, it does not appear that the blockage condition still exists (e.g. the system does not generate any new missed alert signals or the system generates one or more detection signals which indicate that the system is working), then the blockage alert signal is allowed to expire (i.e. a determination is made that system is no longer blocked). However, the system continues to monitor for blockage and if the system continues to look like a blockage condition exists (e.g. the system does generate new missed alert signals), then blockage alert signal does not expire.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of this invention, as well as the invention itself, may be more fully understood from the following description of the drawings in which:

FIG. 1 is a diagrammatic view of a pair of vehicles traveling along a roadway;

FIG. 1A is a diagrammatic view of a first vehicle entering and exiting a detection zone of a second vehicle as the vehicles travel along a roadway;

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FIG. 1B is a diagrammatic view of a first vehicle entering and exiting a virtual detection zone (VDZ) of a second vehicle as the vehicles travel along a roadway;

FIG. 2 is a block diagram of an automotive radar system;

FIG. 3 is a block diagram of a side object detection (SOD) system of a vehicle radar system;

FIG. 4 is a block diagram of a control processor which includes a blockage detection processor;

FIG. 5 is a plot of missed alert signals v. time;

FIG. 6 is a flow diagram of a process for detecting blockage in an automotive radar system;

FIG. 7 is a plot of radial range v. time; and

FIG. 8 is a block diagram of a processing system capable of performing blockage detection processing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Described herein is an approach for generating a missed alert signal and in particular, a blockage alert signal in a sensor such as a side object detection (SOD) sensor such as that described in U.S. Pat. No. 6,784,828 assigned to the assignee of the present application or a forward looking sensor (FLS) such as that described in U.S. Pat. No. 5,929,802 also assigned to the assignee of the present application. While the techniques described herein are described as used in a vehicle radar system (a/k/a an automotive radar system), it should be appreciated that the techniques described herein may be used in any fixed (i.e. stationary) or mobile sensor or detection system. Hence, the techniques described herein are not dependent upon any specific hardware configuration. Rather, as will be seen below, the technique can operate with input data from any sensor or detection system rather than being for operation solely with a radar system. Furthermore, reference is sometimes made herein below to a particular type of automotive radar system referred to as a side-object detection (SOD) system. It should be appreciated that such references are made merely to promote clarity in the description of the concepts described herein and such references should not be construed as limiting the structures and techniques described herein to use solely with a SOD system or solely with an automotive radar system. Rather, it should be appreciated that the structures and techniques described herein may be used with any type of radar, sensor or other detection system.

Referring now to FIG. 1, a first vehicle 12 traveling in a first traffic lane 16 of a road includes a side-object detection (SOD) system 14. The SOD system 14 is disposed on a side portion of the vehicle 12 and in particular, the SOD system 14 is disposed on a right rear quarter of the vehicle 14. The vehicle 12 also includes a second SOD system 15 disposed on a side portion of a left rear quarter of the vehicle 12. The SOD systems 14, 15 may be coupled to the vehicle 12 in a variety of ways. In some embodiments, the SOD systems may be coupled to the vehicle 12 as described in U.S. Pat. No. 6,489,927, issued Dec. 3, 2002, which is incorporated herein by reference in its entirety. A second vehicle 18 travels in a second traffic lane 20 adjacent the first traffic lane 16. The first and second vehicles 12, 18 are both traveling in a direction 21 and in the respective first and second traffic lanes 16, 20.

The second vehicle 18 may be traveling slower than, faster than, or at the same speed as the first vehicle 12. With the relative position of the vehicles 12, 18 shown in FIG. 1, the second vehicle 18 is positioned in a "blind spot" of the first vehicle 12. In general, a blind spot is an area which an operator of a vehicle (e.g. vehicle 12) is unable to see. This may be, for example, an area located on a side of the first vehicle 12.

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In the exemplary embodiment of FIG. 1, the operator of the first vehicle (i.e. vehicle 12) is unable to see the second vehicle (i.e. vehicle 18) either through side-view mirrors 84, 86 (see FIG. 2) or a rear-view mirror (not shown) of the first vehicle 12.

In the exemplary system described herein, the SOD system 14 generates multiple receive beams (e.g., a receive beam 22a, a receive beam 22b, a receive beam 22c, a receive beam 22d, a receive beam 22e, a receive beam 22f and a receive beam 22g) which detect objects in an associated detection zone 24. The shape of the detection zone 24 is formed by the SOD system 14 by selection of maximum detection ranges associated with each one of the receive beams 22a-22g. In the exemplary embodiment of FIG. 1, for example, the maximum detection ranges of each of beams 22a-22g are selected to provide a detection zone such as detection zone 24 having a desired shape. For example, beam 22c has a maximum detection range associated therewith which is designated by reference line 26. Each of the beams 22a-22g may also have a minimum detection range (not shown), forming an edge 17 of the detection zone 24 closest to the first vehicle.

It should thus be appreciated that detection zone 24 may be provided having any number of different desired shapes such as a substantially rectangular shape denoted by reference numeral 24a in FIG. 1. Other shapes, may of course, also be used. One of ordinary skill in the art will appreciate how to select a detection zone shape for a particular application.

In one particular embodiment, the SOD system 14 is a frequency modulated continuous wave (FMCW) radar, which transmits continuous wave chirp radar signals, and which processes received radar signals accordingly. In some embodiments, the SOD system 14 may be the same as or similar to the type described, for example, in U.S. Pat. No. 6,577,269, issued Jun. 10, 2003; U.S. Pat. No. 6,683,557, issued Jan. 27, 2004; U.S. Pat. No. 6,642,908, issued Nov. 4, 2003; U.S. Pat. No. 6,501,415, issued Dec. 31, 2002; and U.S. Pat. No. 6,492,949, issued Dec. 10, 2002, which are all incorporated herein by reference in their entirety.

In operation, the SOD system 14 transmits a radio frequency (RF) signal. Portions of the transmitted RF signal impinge upon and are reflected from objects in the path of the transmitted signal such as the second vehicle 18. The reflected signals (also referred to as "echo" signals) are received in one or more of the receive beams 22a-22g. Other ones of the radar beams 22a-22g, which do not receive the echo signal from the second vehicle 18, receive and/or generate other radar signals, for example, noise signals. As used herein, the term "noise signal" is used to describe a signal comprised of one or more of a thermal noise signal, a quantization noise signal, a crosstalk signal (also referred to as leakage or feed through signal), and an ambient RF noise signal.

In some embodiments, the SOD system 14 may transmit RF energy in a single broad transmit beam (not shown). In other embodiments, the SOD system 14 may transmit RF energy in multiple transmit beams, for example, in seven transmit beams associated with the receive beams 22a-22g. In still other embodiments, the SOD system may transmit RF energy in multiple transmit beams and receive return signals in a single receive beam.

In operation, the SOD system 14 may process the received radar signals associated with each one of the beams 22a-22g in sequence, in parallel, or in any other time sequence. The SOD system 14 identifies an echo signal associated with the second vehicle 18 when any portion of the second vehicle 18 is within the detection zone 24. Therefore, the SOD system 14 is adapted or configured to detect the second vehicle 18 when at least a portion of the second vehicle is in or near the blind

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spot of the first vehicle **12**. One form of blind spot detection processing is described in PCT application number PCT/US2007/023019 published in the English language as WO/2008/063367 on May 29, 2008 and incorporated herein in by reference in its entirety.

SOD systems **14**, **15** are also able to detect a blockage condition (or more simply a “blockage”) via a blockage detection system. The operation of such a blockage detection system will be described in detail below in conjunction with FIGS. 2-8. For reasons which will become apparent from the description hereinbelow, the blockage detection system establishes a virtual detection zone (VDZ) **25**. In one embodiment, VDZ **25** corresponds to a region defined by a 3.5 meter radius as measured from SOD **14**.

It should thus be appreciated that VDZ **25** may be provided having any number of different desired shapes. For example, in some embodiments, it may be desirable to establish a VDZ having substantially the same shape as detection zone **24**. In other embodiments, it may be desirable to provide a VDZ having a portion thereof outside detection zone **24**. For example VDZ **25a** has a front portion outside of detection zone **24**. In other embodiments, a VDZ may be provided having a back portion outside of detection zone **24**. In still other embodiments, a VDZ may be provided having both front and back portions outside of detection zone **24**. Also, although VDZ **25** is shown having a radial shape, other shapes, may of course, also be used. After reading the description provided herein, one of ordinary skill in the art will appreciate how to select a VDZ shape for a particular application.

Referring briefly to FIGS. 1A and 1B in which like elements of FIG. 1 are provided having like reference designations, when an object such as vehicle **18** first enters detection zone **24a**, SOD **14** generates (i.e. turns on) a blind spot alert (BSA) signal **32**. BSA signal **32** stays on while vehicle **18** is in the detection zone **24**. When vehicle **18** leaves the detection zone **24a**, the blind spot alert signal turns off (i.e. SOD **14** stops generating the BSA signal) as indicated by reference numeral and arrow **33**. It should be appreciated that SOD may generate BSA signal **32** at any time during which a target (e.g. vehicle **18**) is in the detection zone **24a**. Thus, although in the exemplary scenario illustrated in FIG. 1A, BSA signal **32** is shown being generated immediately upon entry of vehicle **18** in detection zone **24a**, it should be appreciated that in other then scenarios, BSA signal **32** may not be generated until vehicle **18** has traveled a further distance into detection zone **24a**.

In still other scenarios, (e.g. in the case of a blockage on SOD **14**), SOD **14** may not be able to collect enough data or collect enough detections of a target (e.g. a target such vehicle **18**) while the target is in the detection zone **24a** to allow generation of a BSA signal. Thus, in this scenario, SOD **14** does not generate a BSA signal (i.e. due to a lack of data or a lack of target detections collected by SOD **14**).

Nevertheless, even though the SOD **14** has not generated a BSA signal, SOD **14** continues to collect data while vehicle **18** is in the detection zone **24**. Furthermore, if SOD **14** determines that vehicle **18** enters VDZ **25**, SOD **14** (and in particular, a blockage detection system within the SOD) collects data/information concerning vehicle **18** while vehicle **18** is in the VDZ **25**. Reference numeral **34** in FIG. 1A, denotes entry of vehicle **18** in VDZ **25** and it is at this point that SOD **14** begins collects data/information concerning vehicle **18**.

Based upon the information collected in the VDZ **25** and logic applied to such information, SOD **14** may determine that a vehicle is in the detection zone even though the SOD **14** never generated a BSA signal. In this case, when vehicle **18**

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leaves the VDZ **25**, if SOD **14** has still never generated a BSA signal for vehicle **18**, then the SOD generates a missed alert signal **35**. Thus, reference numeral **35** in FIG. 1B, denotes both exit of vehicle **18** from the VDZ **25** and the generation of a missed alert signal **35**.

Referring to FIG. 2, an exemplary vehicle system **50** which may be the same as or similar to the vehicle systems included in vehicles **12**, **18** described above in conjunction with FIG. 1, includes vehicle systems such as SOD systems **14**, **15**, an air bag system **72**, a braking system **74**, and a speedometer **76**.

Each one of the SOD systems **14**, **15** is coupled to a Controller Area Network (CAN) processor **78** through a Controller Area Network (CAN) bus **66**. As used herein, the term “controller area network” is used to describe a control bus and associated control processor typically found in vehicles. For example, the CAN bus **66** and associated CAN processor **78** may control a variety of different vehicle functions such as anti-lock brake functions, air bags functions and certain display functions.

The vehicle **12** includes two side-view mirrors **80**, **84**, each having an alert display **82**, **86**, respectively, viewable therein. Each one of the alert displays **82**, **86** is adapted or configured to provide a visual alert to an operator of a vehicle in which system **50** is disposed (e.g., vehicle **12** in FIG. 1) to indicate the presence of another vehicle in a blind spot of the vehicle. To this end, in operation, the SOD system **14** forms detection zone **24** and a virtual detection zone **25** and SOD system **15** forms a detection zone **36** and a virtual detection zone **37**.

In one embodiment, VDZs **25**, **37** are each provided having a substantially arc shape with an length of about 160 degrees and an arc radius of about 350 centimeters (cm) as measured from substantially the centerlines of the respective SODs **14**, **15** (i.e. VDZ are provided having 160 degree wedge extending from SOD at center with radius of 350 cm). The VDZs **25**, **37** may, of course, be provided having a radius which is greater or less than 350 cm. For example, radii of 250 cm or 450 cm may also be used. After reading the description herein, those of ordinary skill in the art will appreciate how to select a radius for a particular application. Furthermore, as mentioned above, in some embodiments VDZs **25**, **37** may be provided having a shape which is different than an arc shaped (e.g. a rectangular, triangular, oval or irregular shape may be used). It should also be appreciated that VDZs need not have identical or substantially identical shapes. That is, in some applications it may be desirable to provide VDZ **25** having a first shape which substantially corresponds to one of an arc, rectangular, triangular, oval or irregular shape while VDZ **37** is provided 25 having a second different shape which substantially corresponds to a different one of an arc, rectangular, triangular, oval or irregular shape.

Upon detection of an object (e.g., another vehicle, a guard rail, a tree, a building and so forth) in the detection zone **24**, the SOD system **14** sends an alert signal indicating the presence of an object to either or both of the alert displays **82**, **86** through the CAN bus **66**. In response to receiving the alert signal, the alert displays provide an indication through an indicator (e.g., a visual, audio, or mechanical indicator) which indicates the presence of an object. Similarly, upon detection of an object in the detection zone **36** SOD system **15** sends an alert signal indicating the presence of another vehicle to one or both of alert displays **82**, **86** through the CAN bus **66**. However, in an alternate embodiment, the SOD system **15** may communicate the alert signal to the alert display **82** through a human/machine interface (HMI) bus **68**. Similarly, SOD system **14** may communicate the alert signal to the other alert display **86** through another human/machine interface (HMI) bus **70**. As used herein an alert signal may

include an alert signal to turn on an alert or an alert signal to turn off an alert. As will be described below, the mere detection or lack of detection of an object in the detection zone **24**, **36** may not necessarily generate an alert signal. Other circuitry and/or program code logic may be implemented within or external to the SOD to ensure that the alert signal is sent when certain criteria are met based upon the data received at the receiver **158** (see, for example, FIGS. **5** to **12**).

Referring now to FIG. **3**, a SOD system **14'** which may be the same as or similar to SODs **14** and **15** described above in conjunction with FIGS. **1** and **2**, includes a housing **101** having a plurality of circuit boards **102**, **150**, **156** disposed therein. It should be appreciated that while any number of circuit boards can be used, in this exemplary embodiment, three circuit boards are used and the particular type of material from which each circuit board is provided is selected to satisfy all circuit performance and cost requirements. For example, circuit board **102** may be provided as a fiberglass circuit board; circuit board **150** may be provided as a low temperature co-fired ceramic (LTTC) circuit board or as a polytetrafluoroethylene (PTFE) circuit board **150**; and circuit board **156** may be provided as an LTCC circuit board **156**. Other materials may, of course, also be used for each circuit board as long as circuit performance and cost criteria are satisfied. Those of ordinary skill in the art will understand how to select a particular material for each circuit board depending upon a variety of factors including but not limited to technical (e.g., engineering) requirements and cost.

The circuit board **102** has disposed thereon a digital signal processor (DSP) **104** coupled to a control processor **108**. In general, the DSP **104** is configured to perform signal processing functions, for example, fast Fourier transforms (FFTS) on signals provided thereto from the receiver. In some embodiments, the DSP **104** may be of a type described, for example, in U.S. Pat. No. 7,071,868, filed Apr. 8, 2005 assigned to the assignee of the present application and which is incorporated herein by reference in its entirety. The control processor **108** is also configured to perform digital functions, for example, to identify conditions under which an operator of a vehicle on which the SOD system **14** is mounted should be alerted to the presence of another object such as a vehicle in a blind spot or to determine whether a blockage condition exists. For example, DSP **104** computes a list of individual sensor detection ranges (e.g. detections **250** in FIG. **7**) for each of the radar beams and provides such information (or data) to control processor **108** for use by a blockage detection processor **109** in determining whether a blockage condition exists.

The control processor **108** is coupled to a memory **112** which is here illustrated as an electrically erasable read-only memory (EEPROM) **112**. Other types of memory may, of course, also be used. Memory **112** is adapted or configured to retain a variety of values including but not limited to calibration values. For example, control processor **108** receives calibration parameters related to counter and timer settings from external memory **112** (which may be provided as an EEPROM, for example) for use in determining whether a blockage condition exists. Other memories, including other read only memories, associated with processor program memory are not shown for clarity. The control processor **108** is coupled to a CAN transceiver **120**, which is adapted or configured to communicate, via a connector **128**, on the CAN bus **66**. A blockage alert signal **115** can be provided to either or both of HMI driver **118** or CAN transceiver **120**. In the case where blockage alert signal **115** is provided to HMI driver **118** the blockage alert signal **115** propagates on the HMI bus and can be electrically coupled to an icon which turns on to alert a driver to a blockage condition. Alternatively or additionally,

if blockage alert signal **115** is provided to CAN transceiver **120**, the blockage alert signal **115** propagates on the CAN bus and can be electrically coupled to a screen display (e.g. a scrolling screen display) to alert a driver to a blockage condition.

The control processor **108** is also coupled to an optional human/machine interface (HMI) driver **118**, which in turn is coupled via the connector **128**, to the HMI bus **68**. The HMI bus **68** may include any form of communication media and communication format, including, but not limited to, a fiber optic media with an Ethernet format, and a wire media with a two state format.

The circuit board **150** includes a radar transmitter **152** coupled to a transmit antenna **154**. Transmitter **152** is also coupled to DSP **104** through an interface **147** and a bus **144**. In one embodiment, the interface **147** is provided as a serial port interface (SPI) **147**.

The circuit board **156** includes a receive antenna **160** coupled to a receiver **158**. Receiver **158** includes an event generator which may be the same as or similar to the type described in PCT Application PCT/US2007/023019 published in the English Language on May 29, 2008 as WO 2008/063367 which application is assigned to the assignee of the present invention and hereby incorporated herein by reference in its entirety. Receiver **158** is, in turn, coupled to the DSP **104** and to the transmitter **152**. In some embodiments, the receiver **158** is coupled to the DSP **104** through a bus **146** which is coupled to interface **147** which in turn is coupled to bus **144** through the SPI **147** and a bus **146**. The radar transmitter **152** and the radar receiver **158** may receive regulated voltages from a voltage regulator. The receiver **158** also provides RF signals to the transmitter **152** through a signal path **162**.

In operation, the DSP **104** initiates one or more chirp control signals (also referred to as ramp signals) by providing a command signal to event generator **190** via signal path **148**. In response to the command signal from the DSP, the event generator **190** generates the chirp control signals. Thus, the event generator removes the chirp control signal processing function from the DSP **104**. In other embodiments the chirp generator may be located in the receiver **158**. In still other embodiments, however, the event generator **190** can be located in other portions of the radar system **14'** (FIG. **3**).

It should be understood that by removing the control signal waveform responsibility from the DSP **104** and providing a dedicated event generator circuit which is separate from the DSP, the event generator may provide more comprehensive chirp control signals. This is because the DSP **104** must serve multiple and differing types of requests while the event generator serves only to generate control signals related to generation of the chirp control signals. Also, the required accuracy of the timing signals created by the event generator also precludes the event generator from being the direct responsibility of the DSP **104**. Also, the DSP **104** is now freed from this time consuming activity, so it can now perform additional critical tasks in parallel.

Each chirp control signal has a start voltage and an end voltage. The chirp control signal is provided to a signal source. In response to the ramp signals, the signal source generates RF signals having waveform and frequency characteristics determined or controlled by the chirp control signal. The transmitter feeds the RF signals to the transmit antenna **154** which emits (or radiates) the RF signals as RF chirp radar signals. As used herein, the term "chirp" is used to describe a signal having a characteristic (e.g., frequency, amplitude, or any other characteristic or combinations of any characteristics) that varies with time during a time window.

Typically, in those instances when the frequency of the signal is varied, each chirp has an associated start and end frequency. A chirp may be a linear chirp, for which the frequency varies in a substantially linear fashion between the start and end frequencies. The chirp may also be a non-linear chirp.

The DSP **104** initiates transmission of ramp signals by the event generator **190** for so-called major cycles. The DSP **104** causes the event generator to execute a pre-programmed set of actions, which will cause a signal source (e.g., a VCO) to be modulated accordingly, for each minor cycle in turn. A major cycle is a time period during which signals are received in a designated set of the receive beams **22a-22g**. The designated set of receive beams may be all of the receive beams **22a-22g** or the designated set of receive beams may be only some of the receive beams **22a-22g**. A major cycle is comprised of one or more so-called minor cycles. A minor cycle is a period of time during which signals are received in a subset (e.g. one or more) of the designated set of receive beams.

As mentioned above, the DSP **104** causes the event generator **190** (FIG. **4**) to execute for each minor cycle. Thus, for each major cycle, the DSP issues a so-called "go" command several times per major cycle. The event generator **190**, in turn, provides controls signals or values in each minor cycle including the transmission of the ramp control signals (or more simply "ramp signals") in each minor cycle.

The transmit antenna **154** may be provided having one or a plurality of transmit beams. Regardless of the particular number of transmit beams, the transmit antenna **154** emits one or more RF chirp radar signals in one or more desired fields of view (e.g., summed or individually covering the detection zone **24** in FIG. **1**). The transmit beams may be similar or different in antenna pattern and may be similar or different in fields of view. The fields of view of the transmit beams may overlap to varying extents, from completely overlapped to not at all overlapped.

The receive antenna system **160** may utilize one or a plurality of receive beams. The receive beams may be similar or different in antenna pattern and may be similar or different in fields of view. Like the transmit beams, the fields of view of the receive beams may overlap to varying extents, from completely overlapping to not overlapping at all. The SOD **14** in FIG. **1**, for example, utilizes seven receive beams **22a-22g** each of which overlaps at least one other beam.

Each of the receive beams receives return or echo radar signals, or otherwise generates and/or receives noise signals. Signals received through the receive beams are coupled to radar receiver **158**. Radar receiver **158** receives the RF signals provided thereto from the antenna, down converts the received RF signals to an intermediate frequency (IF) signal, and provides an output signal on signal path **148**. In addition to the frequency down conversion, the receiver **158** appropriately processes the RF input signals provided thereto from the receive antenna system **160** such that the output signals on the signal path **148** can be appropriately received and processed by the DSP **104**.

The signal provided to the input of DSP **104** has a frequency content, wherein signal level peaks which occur at different frequencies correspond to detected objects at different ranges. The DSP **104** analyzes the signals provided thereto and identifies objects in a detection zone e.g. detection zones **24** or **36**.

Some objects identified by the DSP **104** may be objects for which an operator of the first vehicle **12** (FIG. **1**) has little concern and need not be alerted. For example, an operator of vehicle **12** may not, in some instances, need to be alerted or continuously alerted as to the existence of a stationary guard-rail along the roadside. Thus, criteria additional to the pres-

ence of an object in or near the detection zone may be used to determine when an alert signal should be generated or terminated.

To utilize further criteria, the control processor **108** receives object detections on a bus **106** from the DSP **104**. The control processor **108** applies a series of factors and characteristics (i.e., criteria used in addition to that used by DSP **104** to identify an object) to control generation of an alert signal and/or a blockage detection signal. For example, upon determination by the control processor **108**, an alert signal or a blockage detection signal may be generated and sent through a bus **114** to CAN transceiver **120** and communicated on the CAN bus **66**. In the case of an alert signal, the signal is indicative not only of an object in the detection zone **24**, but also is indicative of an object having predetermined characteristics being in the detection zone. In other embodiments, an alert signal may be communicated by control processor **108** on a bus **122** through the HMI driver **118** to the HMI bus **68**. In the case of a blockage detection signal, the signal is indicative of the existence or the potential existence of a blockage which undesirably blocks portions of the RF energy propagating to and from the transmit and/or receive antenna of the SOD thereby affecting the effectiveness of the SOD system **14**.

The circuit board **102**, the circuit board **150**, and the circuit board **156** are comprised of materials having known behaviors for signals within particular frequency ranges. It is known, for example, that fiberglass circuit boards have acceptable signal carrying performance at signal frequencies up to a few hundred MHz. LTCC circuit boards and PTFE circuit boards are known to have acceptable signal carrying performance characteristics at much higher frequencies. Thus, in the case where circuit board **102** is provided as a fiberglass circuit board and circuit boards **150**, **156** are provided from LTCC and/or PTFE, circuits and circuitry which perform the lower frequency functions of the SOD system **14** are disposed on the circuit board **102**, while circuits and circuitry which perform the functions having relatively high frequencies (e.g. above approximately 2 GHz) are disposed on the LTCC and on the PTFE circuit boards **150**, **156**, respectively. Nevertheless, suitable materials other than those specifically mentioned herein may of course, also be used.

Referring now to FIG. **4**, a control processor **200**, which may be the same as or similar to control processor **108** described above in conjunction with FIG. **3**, includes a blockage detection processor **202** which may be the same as or similar to blockage detection processor **109** described above in conjunction with FIG. **3**. Blockage detection processor **202** receives data on one or more inputs (for explanation purposes two inputs are shown in FIG. **4**). The data provided to blockage detection processor **202** corresponds to radar return information which may or may not have been processed prior to being provided to the blockage detection processor **202**. In one embodiment, the inputs are provided from a processor (e.g. DSP **104** described above in conjunction with FIG. **3**) and a memory (e.g. EEPROM described above in conjunction with FIG. **3**) and the information related to the target may correspond to statistics, including, but not limited to one or more of target range history, range of closest approach, point of closest approach, angle, angle history, speed, time spent by a target in a virtual detection zone, number of total detections, raw radar detection count and detection density as a function of range and/or angle.

Blockage detection processor **202** includes a missed alert detection processor **204** coupled to a blockage detection determination processor **206**.

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In general overview, in response to the signals provided thereto, the missed alert detection processor **204** generates one or more missed alert signals and provides the missed alert signals to the blockage detection determination processor **206**. The blockage detection determination processor **206** analyzes the missed alert signals provided thereto and determines whether a blockage condition exists and/or if alert signal should be generated. Once a determination is made that a blockage condition exists and/or that blockage detection alert signal should be provided, the blockage detection determination processor **206** provides a signal indicating that an alert signal should be provided).

Missed alert detection processor **204** includes a virtual detection zone processor **208** coupled to an accumulator **210** which in turn is coupled to a missed alert flag generator **212**. Virtual detection zone processor **208** is configured to identify when a target detection occurs in a virtual detection zone. Once a target detection occurs, the accumulator begins accumulating information on the target which has been detected within the virtual detection zone. The accumulator continues to collect information on the target as long as it remains in the virtual detection zone. The accumulator collects statistics related to target behavior including but not limited to target range history, angle history, speed, time in virtual detection zone, and detection density as a function of range and angle and, if appropriate, the accumulator provides a signal to a missed alert signal generator. At some point the target leaves the virtual detection zone. It is at this point that the missed alert determination is made.

In turn, once a determination is made that an alert was missed, the missed alert signal generator provides a missed alert signal to the blockage detection determination processor **206**.

In general, the blockage detection determination processor **206** tracks the number of "misses" as well as the amount of time which elapses between misses. For example, the blockage detection determination processor **206** tracks the number of misses which occur by tracking the number of missed alert signals which are generated. Also, the blockage detection determination processor **206** can track time by tracking the number of major cycles which occur between missed alert signals. It should, of course, be appreciated that other indications of a target or object not being detected (i.e. a "miss" or more properly a "missed alert signal") can also be counted and that time can be tracked by simply utilizing a system clock. It should be appreciated that "a major cycle" as that term is used herein, refers to the time it takes for a SOD (e.g. SOD **14** in FIG. 1) to transmit a signal and receive a signal in all receive beams.

As shown in FIG. 5, a time line **220** (in units of the number of major cycles), illustrates that a "miss" **224** (denoted as "miss #2 in FIG. 5) was detected at 2,500 major cycles and that another miss **222** (denoted as "miss #1 in FIG. 5) was detected at 1,125 major cycles. It should be appreciated that the number of cycles is counted relative to a present time. Thus, miss #2 occurred (in time) prior to miss #1 (or stated differently miss #1 occurred more recently than miss #2) and as measured from a present point in time (i.e. $t=0$), the number of major cycles since the last miss is the number of cycles from the present time to miss #1—i.e. 1,125 major cycles.

In one embodiment, the system can utilize one or more metrics or logical conditions to determine if a blockage condition exists. For example, in one embodiment, if a predetermined number of missed alert signals (e.g. "M" missed alert signals or more simply "M misses") are generated within a predetermined period of time (e.g. N minutes), then a blockage condition is declared to exist. This metric can be selected

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prior to assembling a SOD on a vehicle and the values of M and N can be stored in a memory of the SOD (e.g. an EEPROM such as EEPROM **112** in FIG. 3). With this approach, inadvertent missed alert signals do not result in a blockage condition being declared by a SOD. That is, this technique reduces or in some cases suppresses the number of false blockage alert signals (i.e. signal **115** in FIG. 3) generated by the SOD. It should be appreciated that the data of FIG. 5 (e.g. one or more of the time of the misses, the number of misses, the time between misses, etc. . . .) can be stored in a memory (e.g. a RAM) in one of processors **108** or **109** or coupled to one of processors **108** or **109**. It should also be appreciated that the data is stored such that different time windows can be accessed (e.g. the number of misses in a 20 second window can be accessed as can the number of misses in a 10 minute window).

Referring again to FIG. 4, blockage detection determination processor **206** utilizes the information in the timeline and calibration parameter values (e.g. from a storage device such as the EEPROM **112** in FIG. 3) to determine whether the missed alerts are due to a blockage. For example, in one exemplary embodiment, blockage is determined to be present if the system detects M misses in N minutes. In one embodiment M and N are stored in a storage device such as EEPROM **112** in FIG. 3 during manufacture or set-up of a SOD. A calculation is made each major cycle to determine if the Mth miss as shown in FIG. 5 occurred in less than N minutes where the number of major cycles is converted to minutes using a factor of 7500 major cycles/minute for the calculation. If blockage detection determination processor **206** concludes that a blockage exists, then it provides a blockage alert signal or some other indication of a blockage condition.

FIG. 6 is a flow diagram which illustrates the processing performed by a processing apparatus which may, for example, be provided as part of an automotive radar system such as that described in conjunction with FIGS. 1 and 2 above to determine whether a blockage condition exists in a sensor such as a SOD sensor **14** described above in conjunction with FIGS. 1 and 2. The rectangular shaped elements in the flow diagram (typified by element **232** in FIG. 6) are herein denoted "processing blocks" and represent computer software instructions or groups of instructions. The diamond shaped elements in the flow diagrams (typified by element **230** in FIG. 6) are herein denoted "decision blocks" and represent computer software instructions or groups of instructions which affect the processing of the processing blocks.

Alternatively, the processing and decision blocks in FIG. 6 can represent processes performed by functionally equivalent circuits such as a digital signal processor circuit or an application specific integrated circuit (ASIC). The flow diagram does not depict the syntax of any particular programming language. Rather, the flow diagram illustrates the functional information one of ordinary skill in the art requires to generate computer software and/or to program or fabricate circuits, to perform the processing required of the particular apparatus. It should be noted that many routine program elements, such as initialization of loops and variables and the use of temporary variables are not shown.

It should also be noted that some of the processing blocks can represent an empirical or manual procedure or a database function while others can represent computer software instructions or groups of instructions. Thus, some of the steps described in the flow diagram may be implemented via computer software while others may be implemented in a different manner e.g. manually, via an empirical procedure, via

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hardware or via a combination of manual and empirical procedures and/or hardware and software.

It will be appreciated by those of ordinary skill in the art that unless otherwise indicated herein, the particular sequence described in FIG. 7 (and elsewhere herein) is illustrative only and can be varied without departing from the spirit of the concepts described and claimed herein.

Turning now to FIG. 6, processing begins in decision block 230 which implements a loop in which the system simply waits for a target to enter a virtual detection zone. Once a target enters the virtual detection zone, then processing proceeds to processing block 232 where information is accumulated on the target. Such information includes but is not limited to statistics related to the target including but not limited to target range history, angle history, speed, time in virtual detection zone, and detection density as a function of range and angle. Information is accumulated on the target as long as the target remains in the virtual detection zone.

Once the target leaves the virtual detection zone, processing then proceeds to decision block 234 in which a decision is made as to whether a missed alert signal should be generated. Such a decision is made by utilizing the information and statistics accumulated on the target while the target is in the virtual detection zone. In one embodiment, one or more logical conditions (sometimes referred to as "missed alert signal logic") are applied to the information to make the decision.

In one embodiment, the following set of eleven logical conditions are used.

Condition 1 (alertFlag is not set) requires that the SOD has not generated a BSA signal.

Condition 2 (alertVDuration is from 45 to 750 mc) requires that a target be in the virtual detection zone for a predetermined amount of time. In one embodiment, the time is selected to be in the range of 45 major cycle to 750 major cycles where 125 major cycles equals 1 second.

Condition 3 (rangeClosestApproach is from 40 to 280 cm) requires that a target be within a predetermined distance of the SOD. In one embodiment, the predetermined distance is selected to be in the range of 40 to 280 cm.

Condition 4 (Bm4 detections are more than 45% of total detection) requires that the number of detections in one or more particular beams be a percentage of a total number of detections. In one embodiment, beam 4 detections are more than 45% of the total number of detections.

Condition 5 (there are more than 5 bm4 detections) requires that a minimum number of detections occur in one or more particular beams. In one embodiment, there must be at least five detections in beam 4.

Condition 6 (Detect bm4 in more than 15% of total mc of alertVDuration) requires that a percentage of a total number of detections in a VDZ occur in a predetermined one or more beams. In one embodiment, 15% of the total detections in a VDZ must occur in beam 4 in a given number of major cycles.

Condition 7 (areaVrangeLongSmooth8 is less than 90% of areaVlowestDetInLastSecond) is an indirect way to determine sensor detection density. In the case where a blockage condition exists, the density of detections will be reduced relative to the density during normal operation yielding a ratio of less than 90%. In one embodiment, the closest detection in range within the previous 1 second (i.e. 125 major cycles) is identified and a curve (denoted the "lowestDetectionInLastSecond" line) is generated from a series of such points. Then, a region defined by a boundary defined by the lowestDetectionInLastSecond" line and a line which denotes the virtual detection zone line is identified. Once the region is identified, the mathematical area of this region denoted (areaVLowestDetectionInLastSecond) is computed. Next the condition 7

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requires that the closest detection in range smoothed over the previous 8 major cycles is identified and a curve (denoted the "rangeLongSmooth8" line) is generated. Then, a region defined by a boundary defined by the rangeLongSmooth8" line and the line which denotes the virtual detection zone line is identified. Once the region is identified, the mathematical area of this region denoted (area rangeLongSmooth8) is computed. Once the areas are known, condition 7 requires that areaVrangeLongSmooth8 be less than 90% of areaVlowestDetInLastSecond.

Condition 8 (Last alertV is more than 250 mc ago) requires that last missed alert signal have been generated a predetermined amount of time in the past. In one embodiment, the last missed alert signal must have been generated more than 250 major cycles ago.

Condition 9 (bm5Elimination flag was not set) requires that no more than a predetermined number of detections occur on one or more predetermined beams. In one embodiment, no more than 20 detections may have occurred in beam 5 in the 40 cm-1000 cm range and between the fifth and fifty-fifth major cycle.

Condition 10 (bm12 is less than 5) requires that no more than a predetermined number of detections occur on one or more predetermined beams within a predetermined amount of time. In one embodiment, less than five detections of beam 1 or beam 2 are allowed in the first 25 major cycles.

Condition 11 (Vehicle speed is greater than 30 km/hour) requires that the host vehicle speed be greater than a threshold value. In one embodiment, the host vehicle speed is greater than 30 km/hour.

It should, of course, be appreciated that other different logical conditions may also be used. The particular logical conditions to use in an application depend upon a variety of factors. For example, sensor characteristics such as the number of beams, beamwidths, beamshapes, beam overlap must be considered. If in decision block 234 a decision is made that a missed alert signal should not be generated, then processing returns to decision block 230 where the process again waits for a target (e.g. a vehicle such as vehicle 18 in FIG. 1) to enter the virtual detection zone.

If a decision is made in decision block 234 that an alert was missed, then processing flows to processing block 236 where the time of the miss is recorded.

Processing then proceeds to decision block 240 where a determination is made as to whether a blockage condition exists. In one embodiment, such a determination is made by evaluating a pattern of missed alert signals. For example, one or more logical conditions may be used (sometimes referred to as "blockage alert signal logic"). In one embodiment, a logical condition is used in which if a predetermined number of missed alert signals (e.g. "M" missed alert signals or more simply "M misses") are generated within a predetermined period of time (e.g. N minutes), then a blockage condition is declared to exist. It should be appreciated that the blockage alert signal logic may include multiple logical conditions. For example, a sliding scale of misses to time spent in a virtual detection zone may be used (e.g. 2 misses in 10 minutes or 4 misses in 20 minutes or 5 misses in 40 minutes). It should also be appreciated that a missed alert signal is generated only when a BSA signal has not been generated. Stated differently, in a preferred embodiment, whenever a BSA signal is generated for a given target, it is not necessary to generate a missed alert signal for that target.

If a decision is made in block 240 that a blockage condition does not exist (e.g. M misses have not occurred within N minutes), then processing returns to decision block 230 where the system waits for a target to enter a virtual detection zone.

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If on the other hand, a decision is made in decision block **240** that a blockage condition exists, then processing flows to processing block **242** where a blockage alert signal is provided. The blockage alert signal may be used to provide an indication (e.g. to a user of a vehicle) that a blockage condition exists in a sensor (e.g. SOD **14**, **15**). Processing then returns to decision block **230** where the system waits for a target to enter a virtual detection zone.

Once a blockage alert signal is generated if, at a later time, it does not appear that the blockage condition still exists (e.g. the system does not generate any new missed alert signals or the system generates one or more detection signals which indicate that the system is working), then the blockage alert signal is allowed to expire (i.e. a determination is made that system is no longer blocked). However, the system continues to monitor for blockage and if the system continues to look like a blockage condition exists (e.g. the system does generate new missed alert signals), then blockage alert signal does not expire.

Referring now to FIG. **7**, a plot **300** of radial range vs. number of major cycles includes a plurality of sensor detections denoted **310**. It should be appreciated that line **312** at 350 cm represents the virtual detection zone (i.e. the plot of FIG. **7** corresponds to a virtual detection zone having an arc shape (e.g. as shown by VDZ **25** in FIG. **1-3**) with a radius of 350 cm. Reference numeral **350a** denotes the point at which an object enters a virtual detection zone (e.g. processing block **230** in FIG. **6**) and reference numeral **350b** denotes the point at which the object exits the virtual detection zone (e.g. processing block **234** in FIG. **6**). Cross-hatched area **352** corresponds to the region in which statistics on the target are collected (e.g. processing block **232** in FIG. **6**).

Referring to FIG. **8**, a computer **400** which includes a processor **402** and a volatile memory **404**, a non-volatile memory **406** (e.g., a flash memory). Non-volatile memory **406** stores operating system **408** and data **410**. Non-volatile memory **406** also stores computer instructions **412**, which are executed by processor **402** out of the volatile memory **404** to perform all or part of processes described above in conjunction with FIGS. **1-7**.

It should be appreciated that all or part of processes described above in conjunction with FIGS. **1-7** are not limited to use with the hardware and software of FIG. **12**; it may find applicability in any computing or processing environment and with any type of machine that is capable of running a computer program. All or part of the processes described above in conjunction with FIGS. **1-7** may be implemented in hardware, software, or a combination of the two. All or part of the processes described above in conjunction with FIGS. **1-7** may be implemented in computer programs executed on programmable computers/machines that each includes a processor, a storage medium or other article of manufacture that is readable by the processor (including volatile and non-volatile memory and/or storage elements). Program code may be applied to data entered using an input device to perform All or part of the processes described above in conjunction with FIGS. **1-7** and to generate output information.

The system may be implemented, at least in part, via a computer program product (i.e., a computer program tangibly embodied in an information carrier (e.g., in a machine-readable storage device or in a propagated signal, for execution by, or to control the operation of, data processing apparatus (e.g., a programmable processor, a computer, or multiple computers)). Each such program may be implemented in a high level procedural or object-oriented programming language to communicate with a computer system. However, the programs may be implemented in assembly or machine language. The

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language may be a compiled or an interpreted language and it may be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program may be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network. A computer program may be stored on a storage medium or device (e.g., CD-ROM, hard disk, or magnetic diskette) that is readable by a general or special purpose programmable computer for configuring and operating the computer when the storage medium or device is read by the computer to perform all or part of the processes described above in conjunction with FIGS. **1-7**. All or part of the processes described above in conjunction with FIGS. **1-7** may also be implemented as a machine-readable storage medium, configured with a computer program, where upon execution, instructions in the computer program cause the computer to operate in accordance with all or part of the processes described above in conjunction with FIGS. **1-7**.

Having described preferred embodiments which serve to illustrate various concepts, structures and techniques which are the subject of this patent, it will now become apparent to those of ordinary skill in the art that other embodiments incorporating these concepts, structures and techniques may be used.

For example, the information related to the target and which is used to determine whether a missed alert signal should be generated is listed herein as including, but not limited to one or more of target range history, range of closest approach, point of closest approach, angle, angle history, speed, time spent by a target in a virtual detection zone, number of total detections, raw radar detection count and detection density as a function of range and/or angle. It should be appreciated, however, that the particular information used to determine whether a missed alert signal should be generated depends upon a variety of factors related to the sensor with which the technique described herein is being used. For example, it may be desirable or even necessary to use different information if the sensor has a different number of beams or different beam widths or different beam overlaps, etc. . . . After reading the description provided herein, those of ordinary skill in the art will appreciate how to select the necessary information need to determine whether a missed alert signal should be generated. Similarly, the selection of the necessary logic to apply determine whether a blockage condition exists depends upon a variety of factors related to the sensor and after reading the description provided herein, those of ordinary skill in the art will appreciate how to select such logic.

Accordingly, it is submitted that that scope of the patent should not be limited to the described embodiments but rather should be limited only by the spirit and scope of the following claims.

What is claimed is:

1. A blockage detection system comprising:

a missed alert detection processor configured to receive target data generated in a virtual detection zone of the blockage detection system, and in response to the target data to generate a missed alert signal; and
a blockage detection determination processor coupled to receive a missed alert signal from said missed alert detection processor and configured to provide a blockage alert signal at an output port thereof.

2. The blockage detection processor of claim **1** wherein said missed alert detection processor comprises:

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a virtual detection zone processor configured to determine when a target detection occurs in the virtual detection zone;
an accumulator for collecting information related to the object, said accumulator responsive to a signal from said virtual zone detection processor indicating that an object is within the virtual detection zone; and
a missed alert signal generator coupled to receive information from said accumulator, said missed alert signal generator configured to analyze information from said accumulator and to provide a missed alert signal in response to a metric being met.
3. The blockage detection processor of claim 2 wherein said accumulator collects one or more of:
(1) target range;
(2) target range history;

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(3) range of closest approach;
(4) point of closest approach;
(5) angle;
(6) angle history;
(7) speed;
(8) time spent by a target in a virtual detection zone;
(9) number of total detections;
(10) raw radar detection count; and
(11) detection density as a function of range and/or angle.
4. The blockage detection processor of claim 3 wherein said a blockage detection determination processor provides a blockage alert signal in response to receiving M missed alert signals from said missed alert detection processor within N amount of time.

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