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(54) **VEHICULAR TRAFFIC SENSOR**

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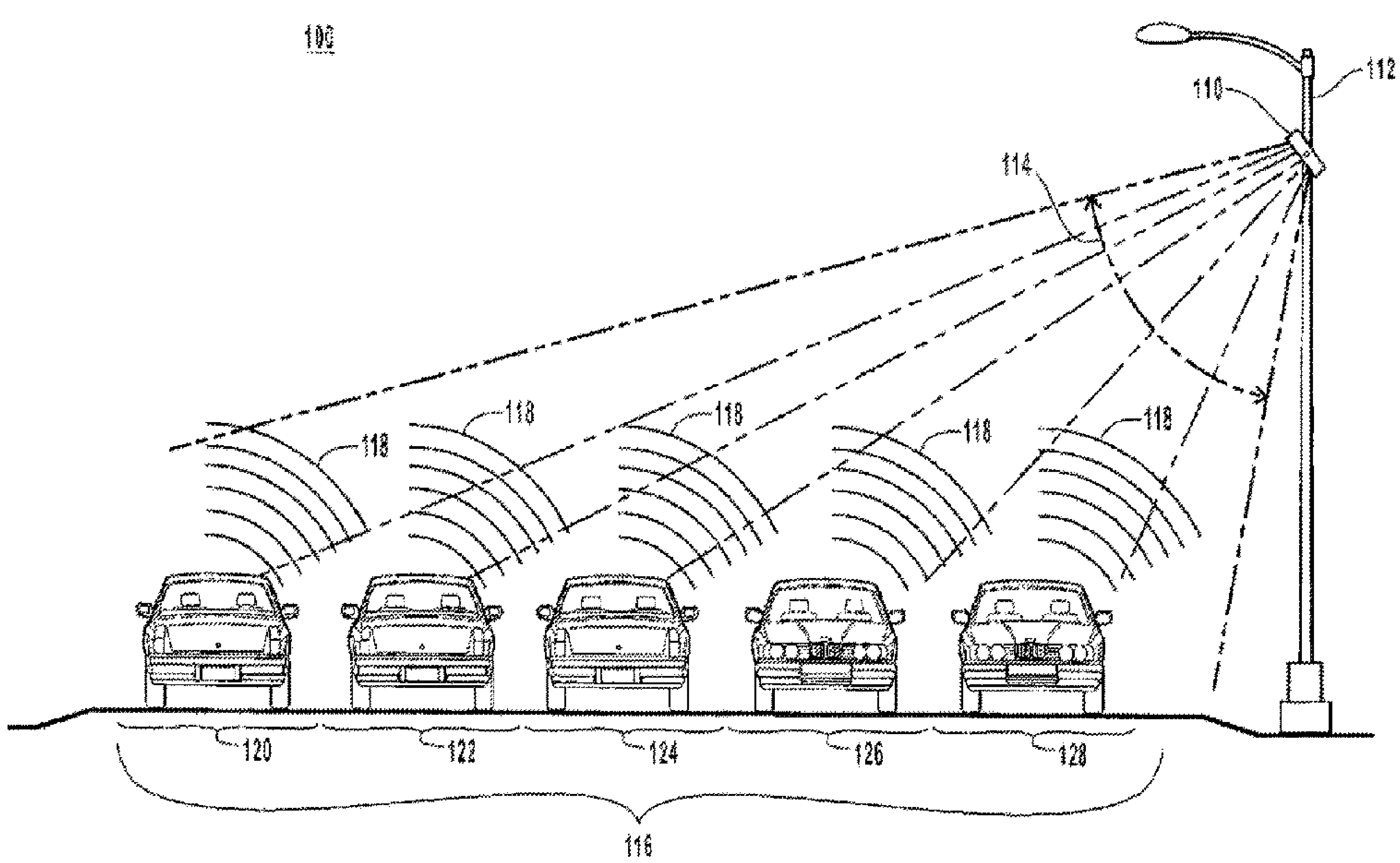
(57) **ABSTRACT**

A vehicle traffic sensor for detecting and monitoring vehicular targets is presented. The sensor employs a planar design resulting in a reduced profile sensor. The sensor includes a multi-layer radio frequency board with RF components on one of the sides and both isolation and planar array antennas on the opposing side. The antennas are preferably tapered planar array antennas which include one transmit antenna and one receive antenna. The sensor also includes at least one logic or signal processing board populated with components on a first side and a ground plane on a second side positioned toward the RF componentry of the RF board to form an RF shield. The boards are housed within a housing that is permeable, at least on the side through which the antenna structures propagate.

72 Claims, 15 Drawing Sheets



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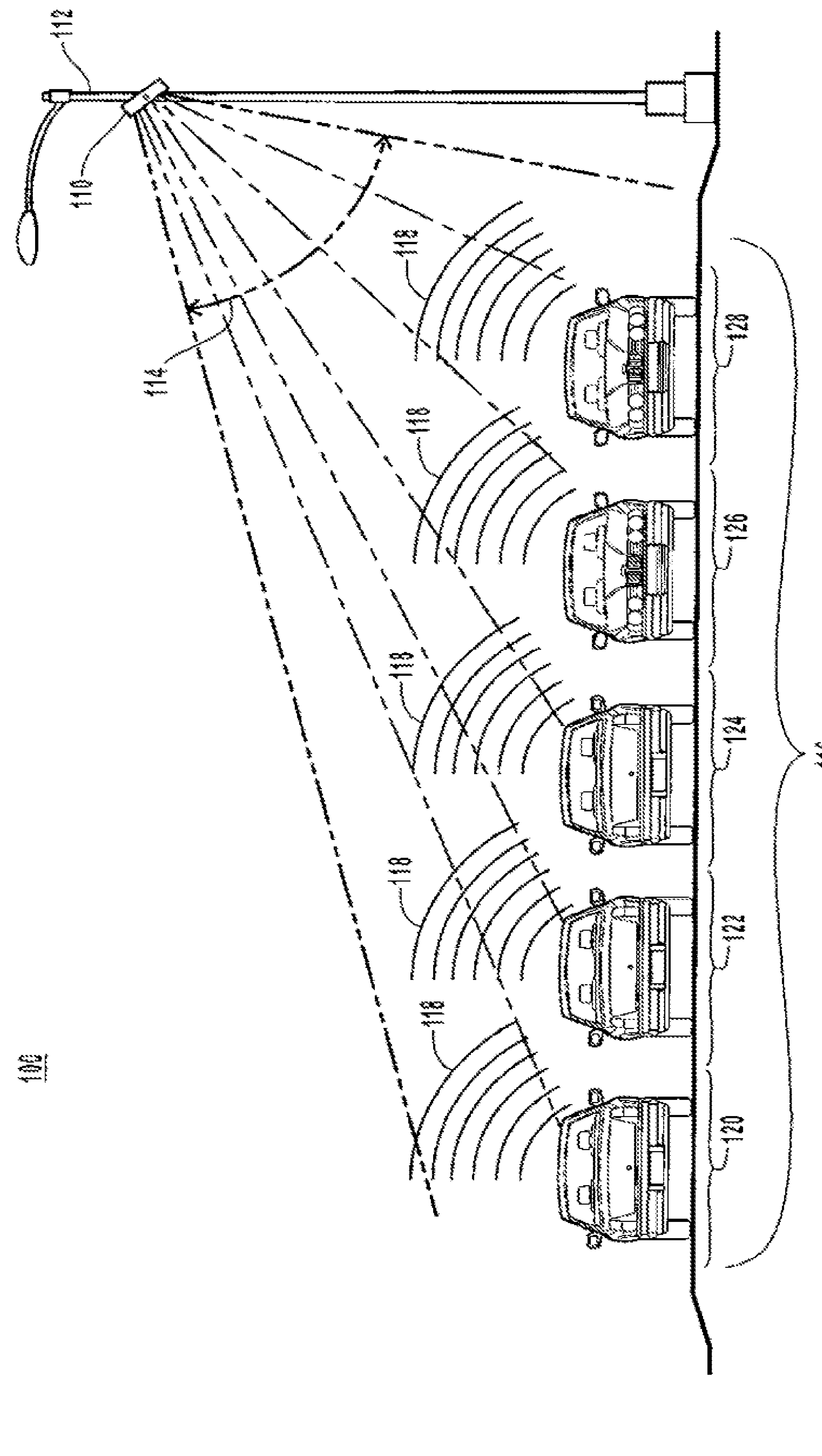


Fig. 1
NEW

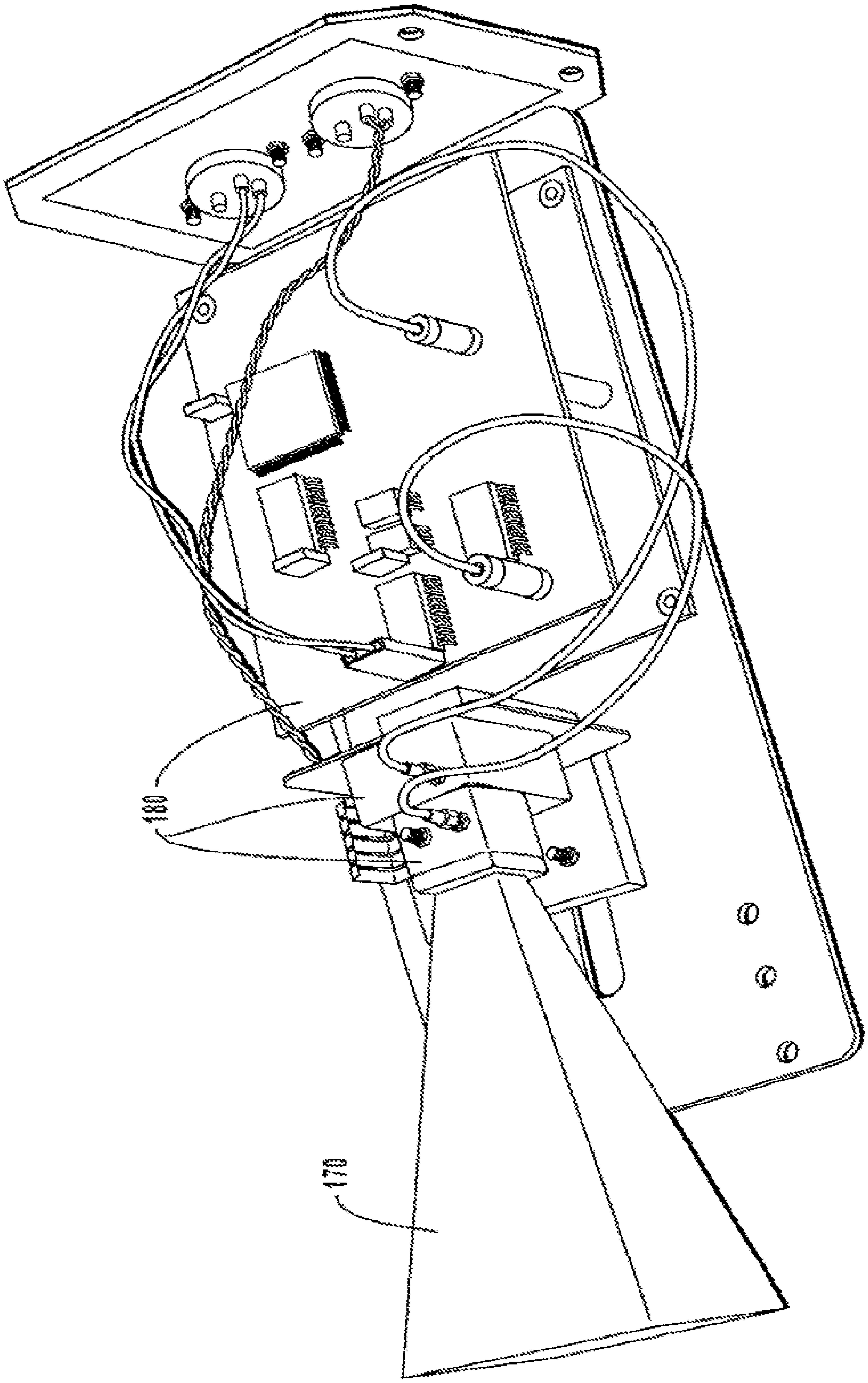


FIG. 2
(PRIOR ART)

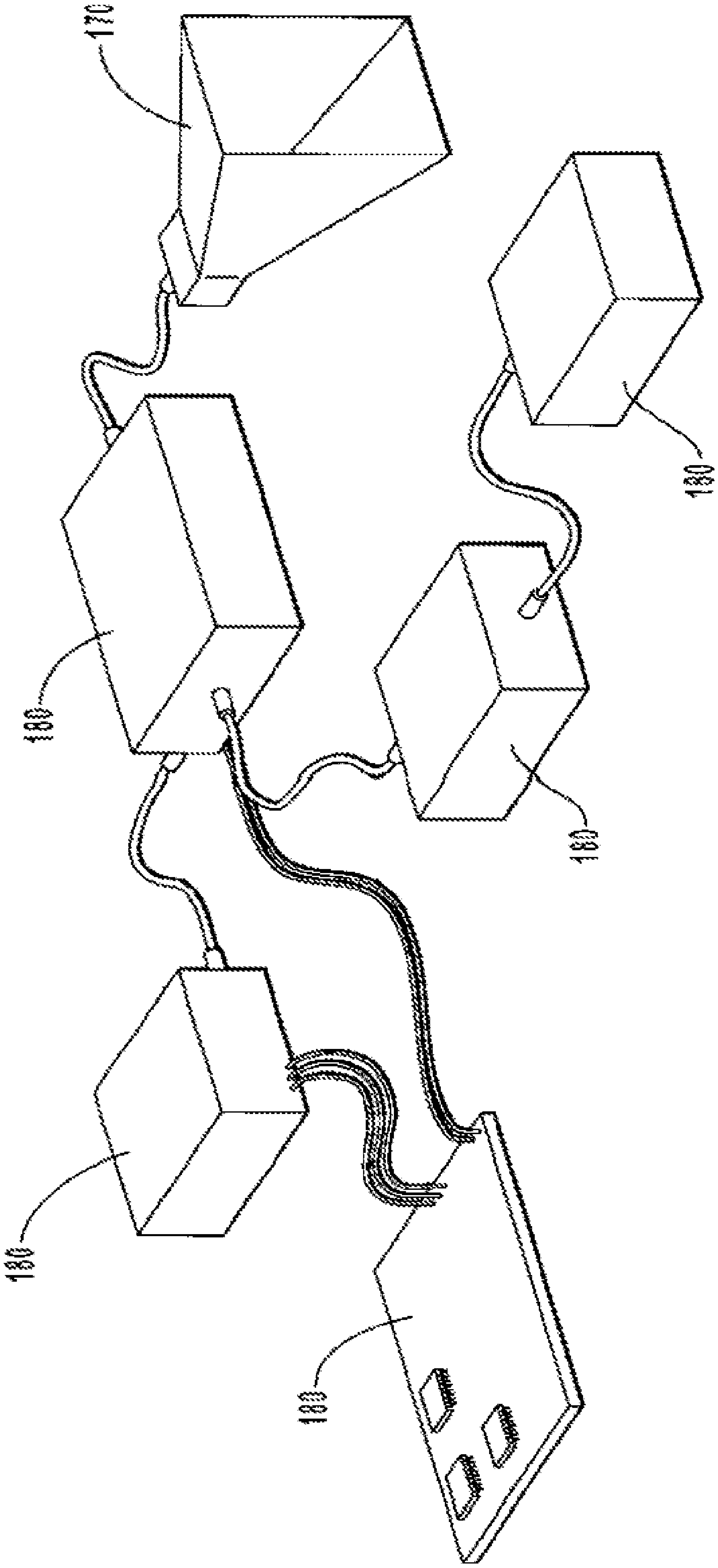


FIG. 3
(PRIOR ART)

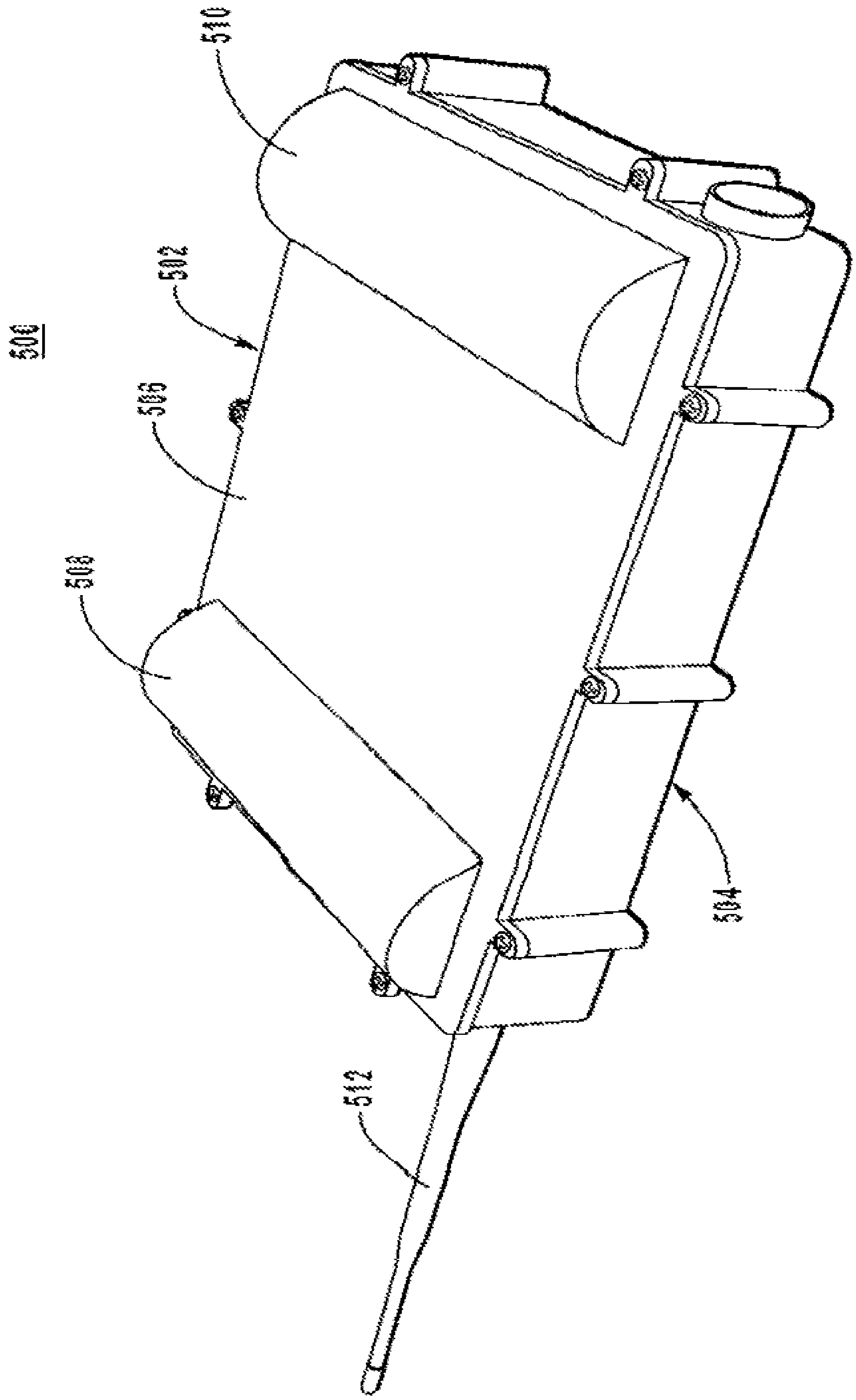
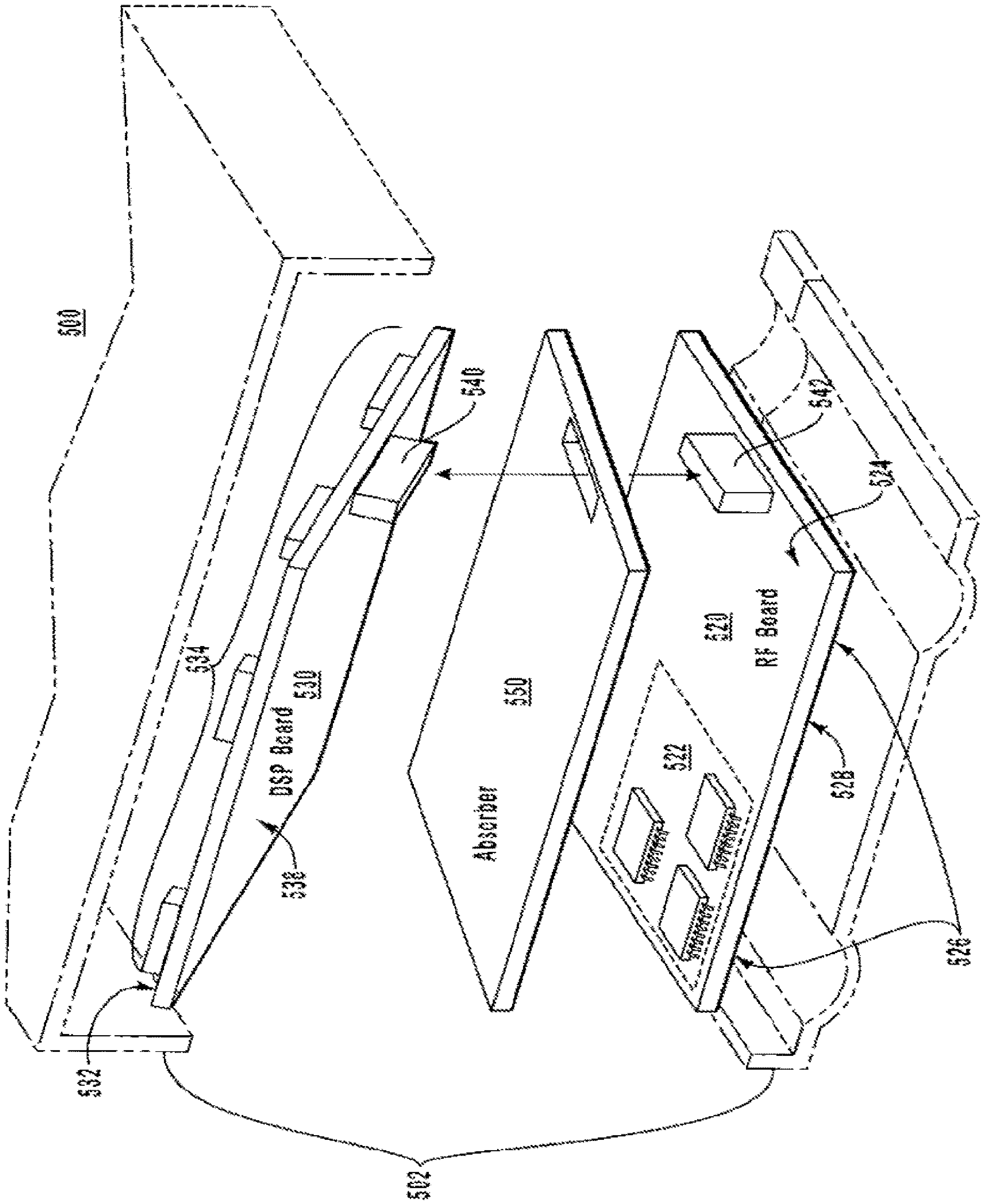


FIG. 4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DSP Board
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550
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RF Board
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Absorber
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538
526
532
502

FIG. 5

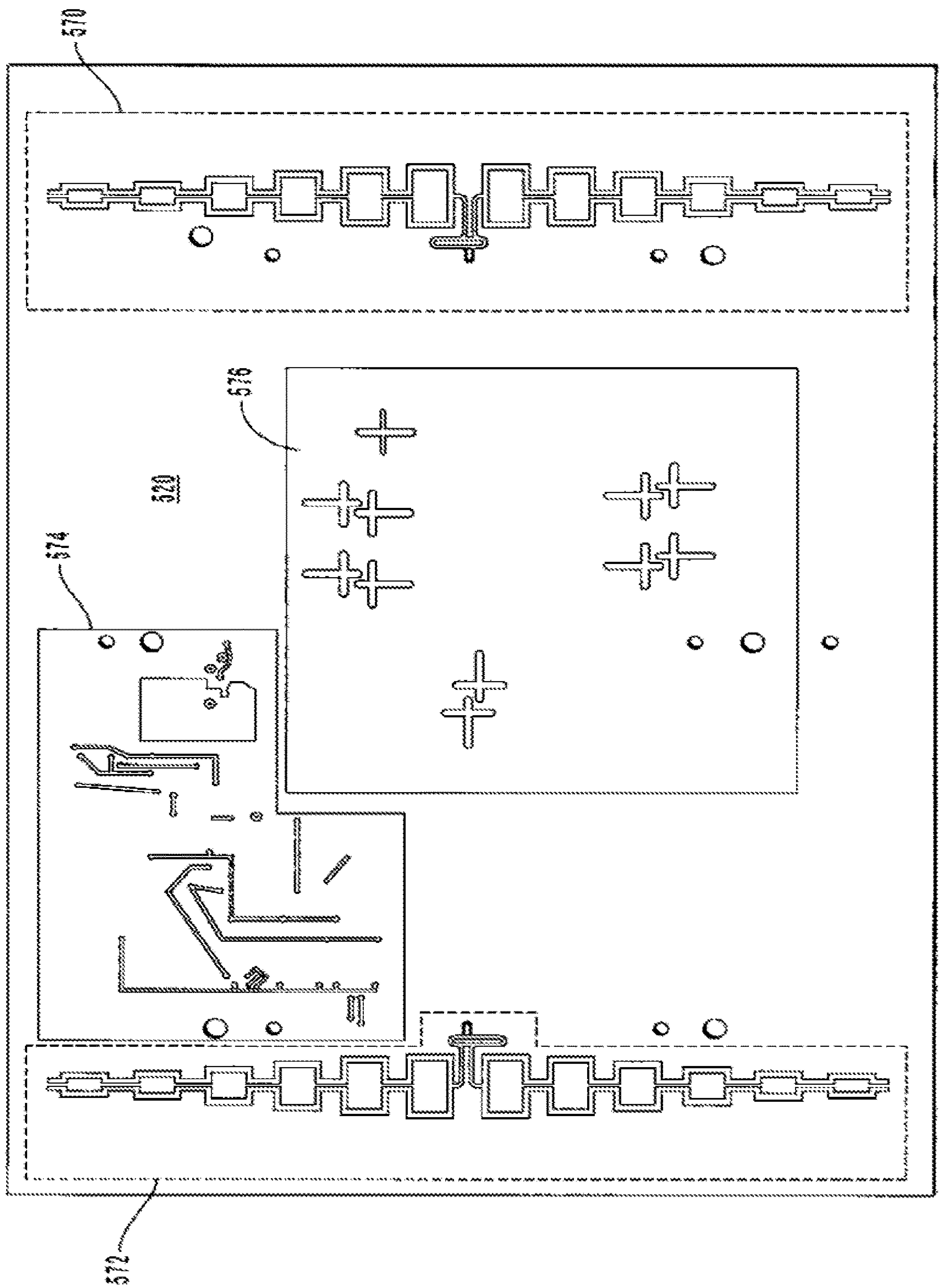
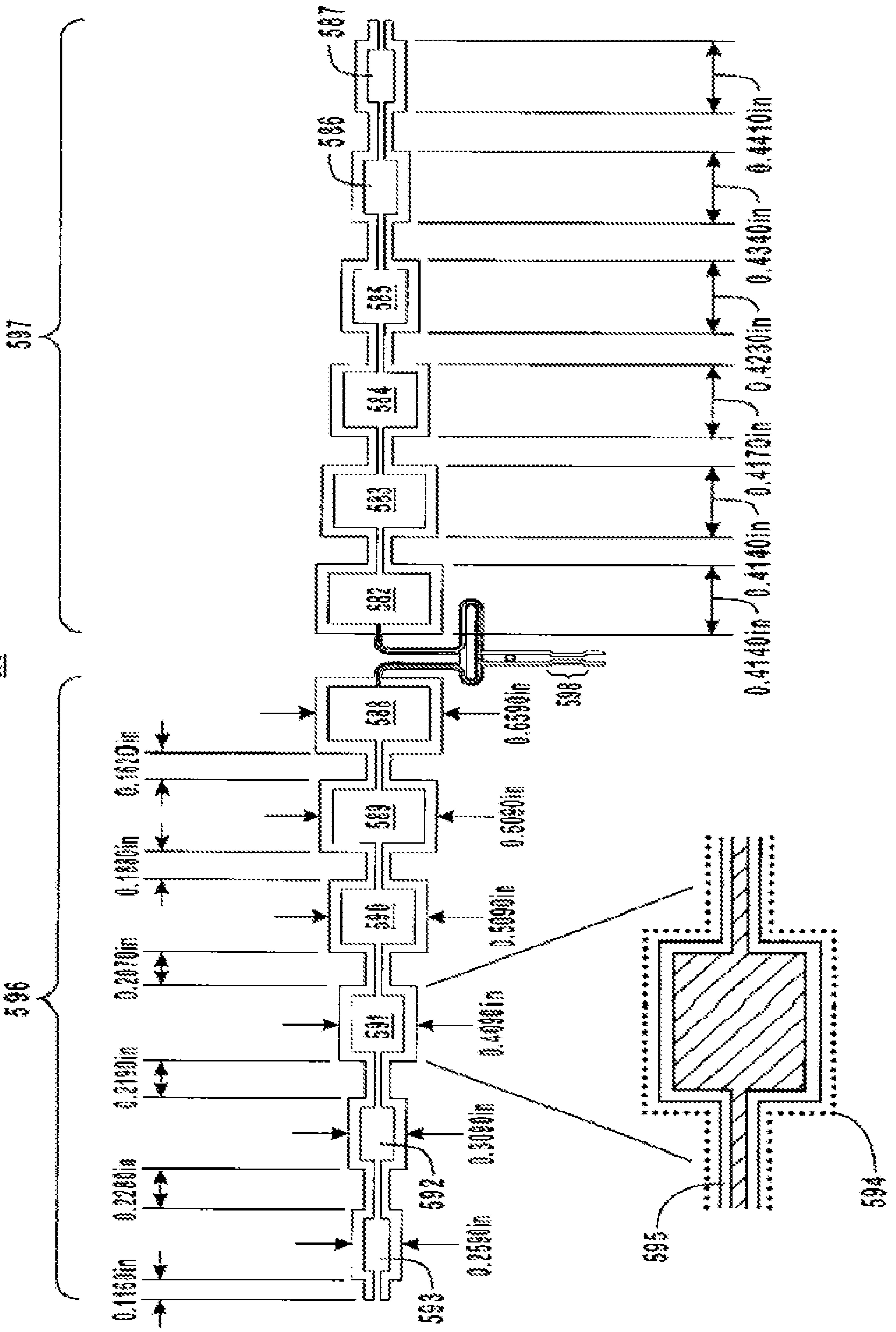


FIG. 6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0.4340in
0.4230in
0.4173in
0.4140in
0.4140in

FIG. 7

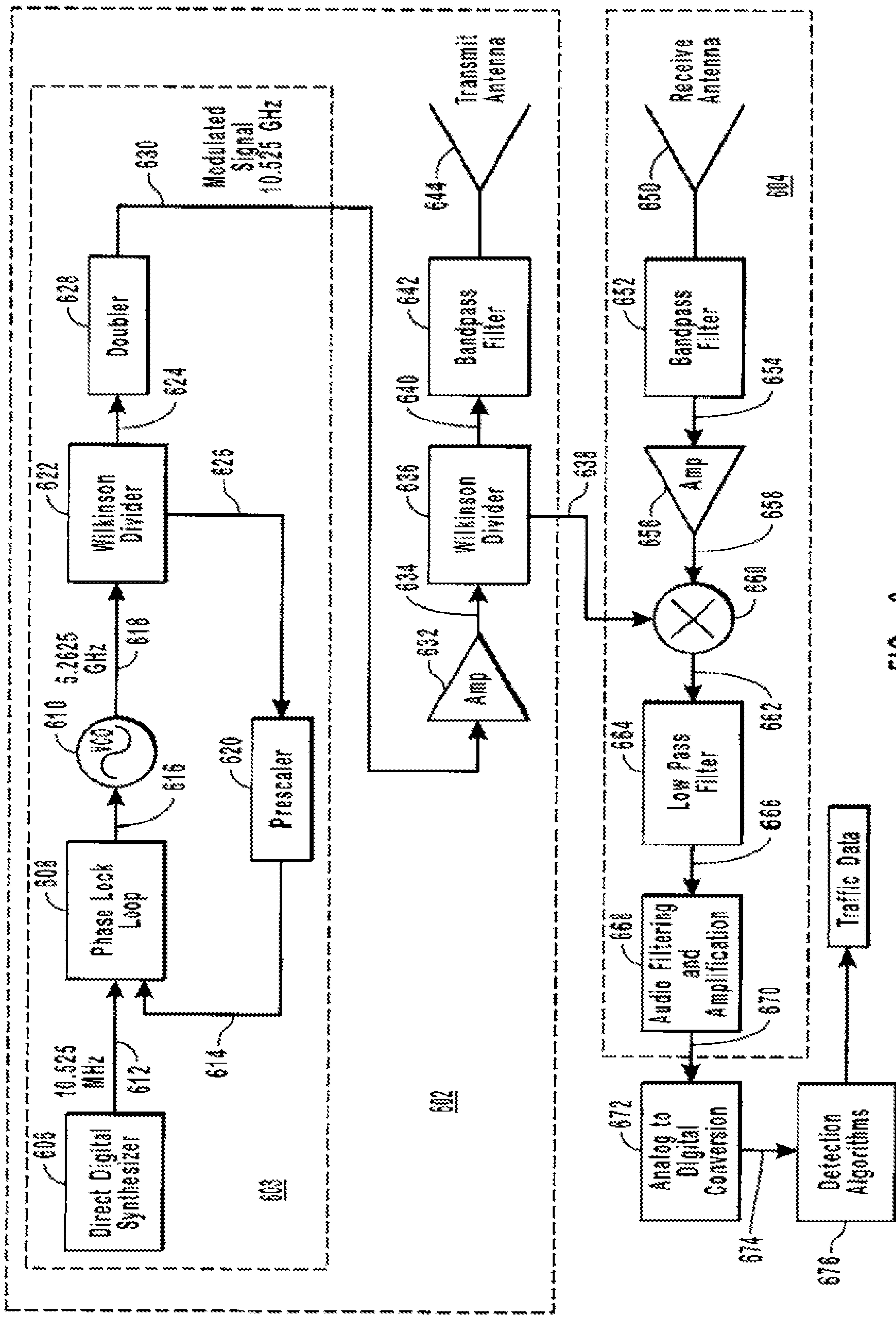
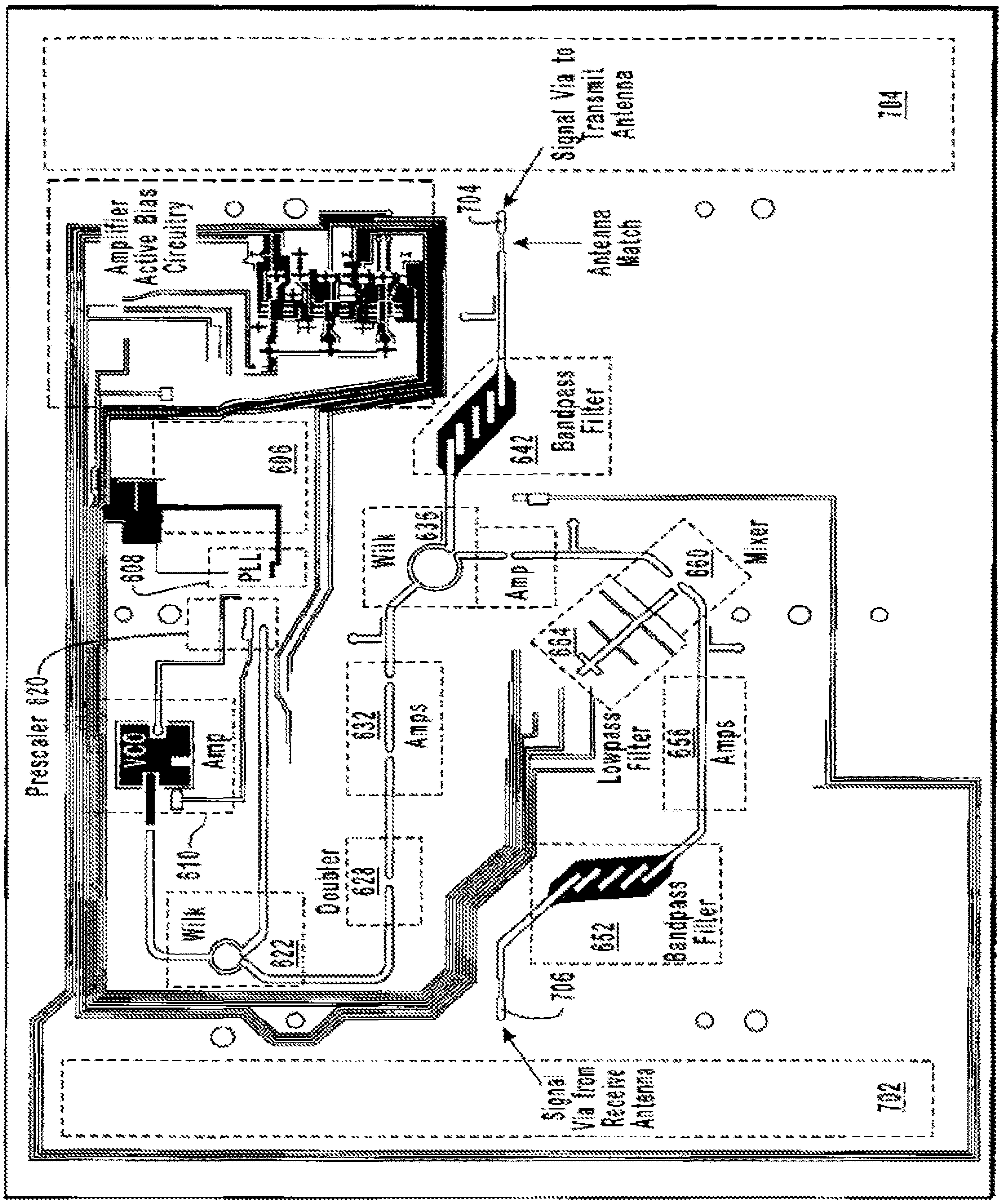

Direct Digital Synthesizer
606
10.525 MHz
612
Phase Lock Loop
608
614
616
VCO
610
5.2625 GHz
618
Prescaler
620
Wilkinson Divider
622
626
624
Doubler
628
630
Modulated Signal 10.525 GHz
603
602
Amp
632
634
Wilkinson Divider
636
638
640
Bandpass Filter
642
644
Transmit Antenna
Receive Antenna
650
604
Bandpass Filter
652
654
Amp
656
658
660
662
Low Pass Filter
664
666
Audio Filtering and Amplification
668
670
Analog to Digital Conversion
672
674
Detection Algorithms
676
Traffic Data

FIG. 8

FIG. 9


Signal Via to Transmit Antenna
704
704
Amplifier Active Bias Circuitry
Antenna Match
Bandpass Filter
642
606
608
PLL
Wilk
636
Amp
Mixer
660
664
Prescaler 620
VCO
Amp
610
Lowpass Filter
656
Amps
632
Amps
Doubler
628
Wilk
622
652
Bandpass Filter
706
Signal Via from Receive Antenna
702

524

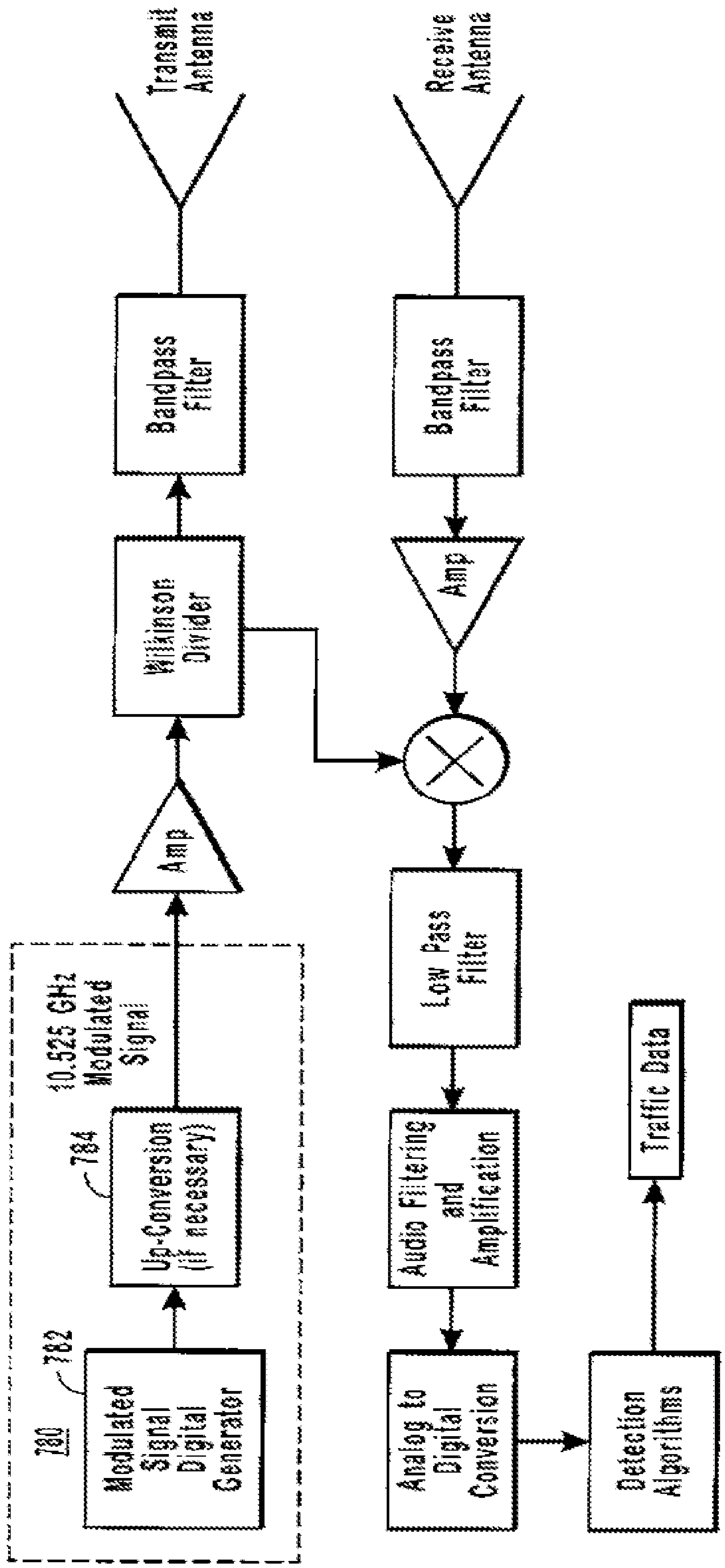

Transmit Antenna
Receive Antenna
Bandpass Filter
Bandpass Filter
Wilkinson Divider
Amp
Amp
10.525 GHz Modulated Signal
784
Up-Conversion (if necessary)
780
782
Modulated Signal Digital Generator
Low Pass Filter
Audio Filtering and Amplification
Analog to Digital Conversion
Detection Algorithms
Traffic Data

FIG. 10

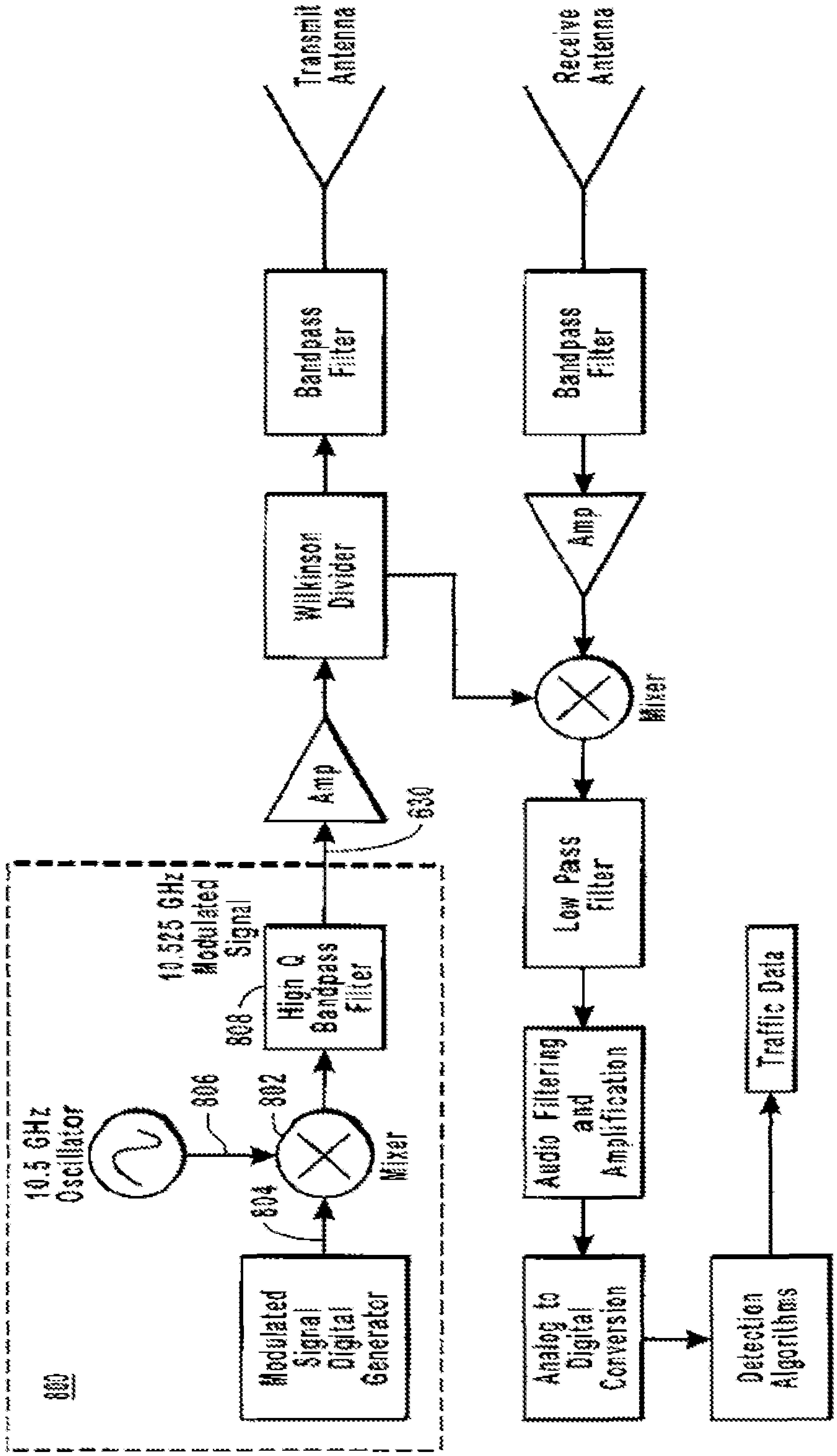

Transmit Antenna
Receive Antenna
Bandpass Filter
Bandpass Filter
Wilkinson Divider
Amp
Amp
Mixer
630
Low Pass Filter
10.525 GHz Modulated Signal
High Q Bandpass Filter
808
802
806
10.5 GHz Oscillator
Mixer
804
Modulated Signal Digital Generator
800
Traffic Data
Audio Filtering and Amplification
Analog to Digital Conversion
Detection Algorithms

FIG. 11

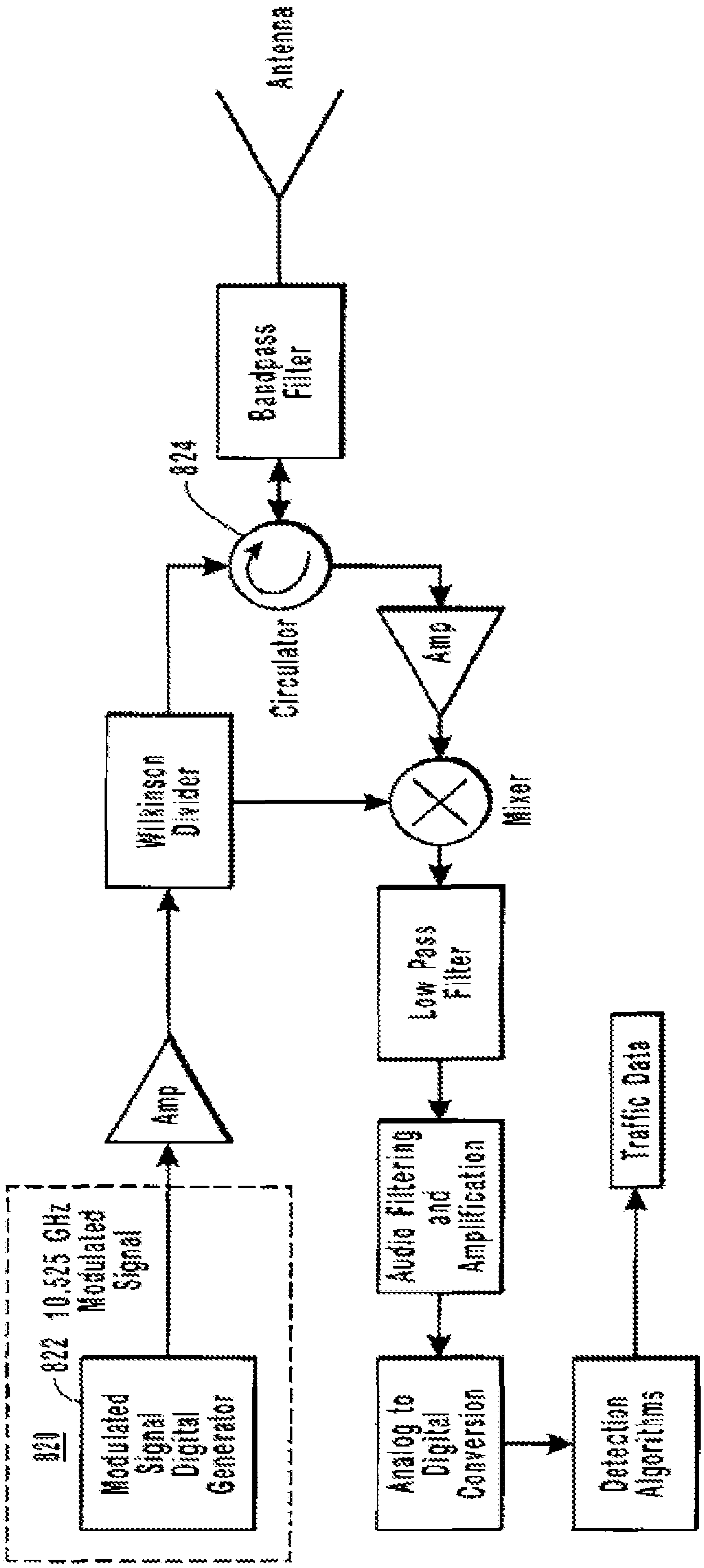

Antenna
Bandpass Filter
824
Circulator
Amp
Mixer
Wilkinson Divider
Low Pass Filter
Amp
820
822
10.525 GHz Modulated Signal
Modulated Signal Digital Generator
Audio Filtering and Amplification
Analog to Digital Conversion
Detection Algorithms
Traffic Data

FIG. 12

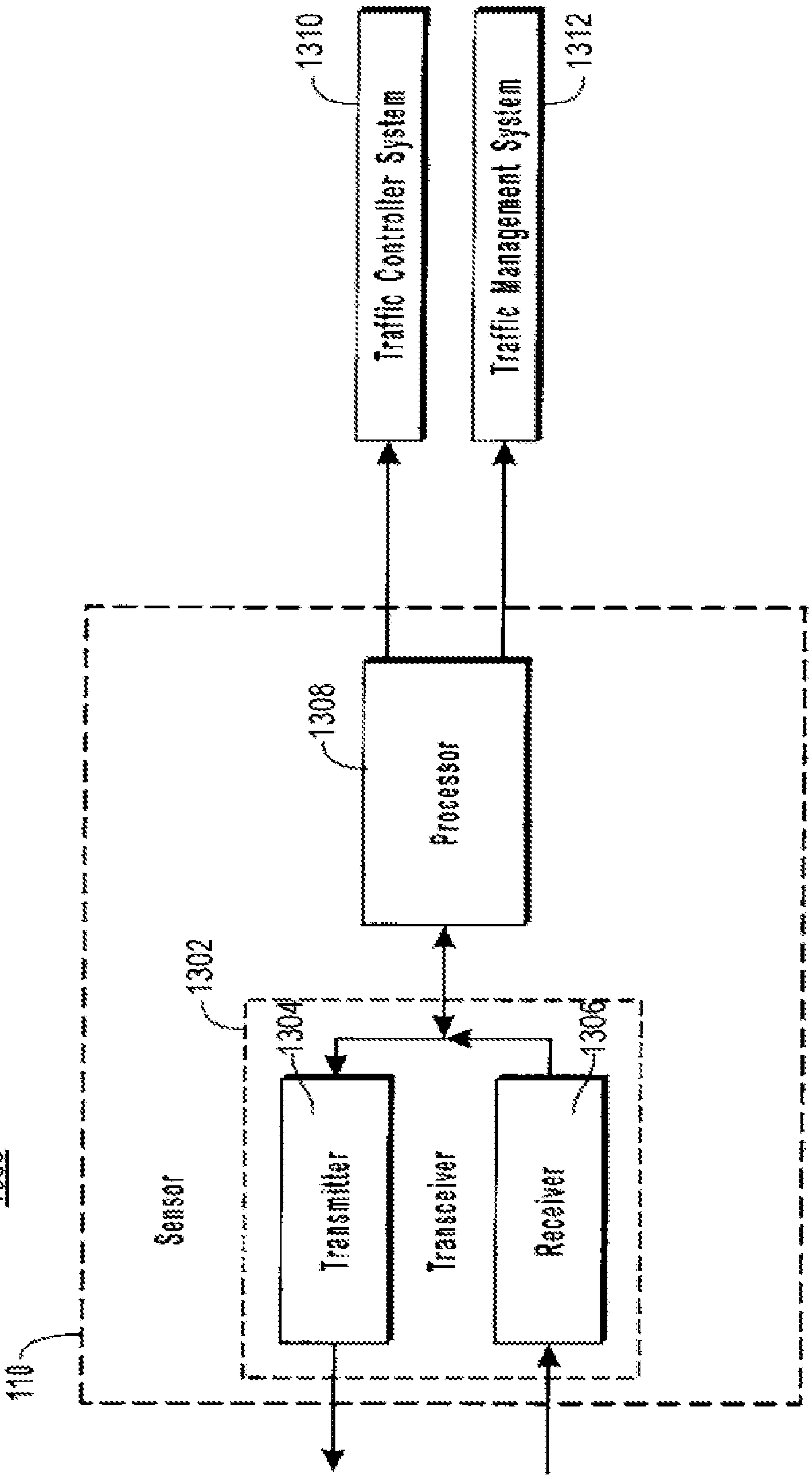

1300
110
Sensor
1302
1304
Transmitter
Transceiver
Receiver
1306
1308
Processor
1310
Traffic Controller System
1312
Traffic Management System

Fig. 13
NEW

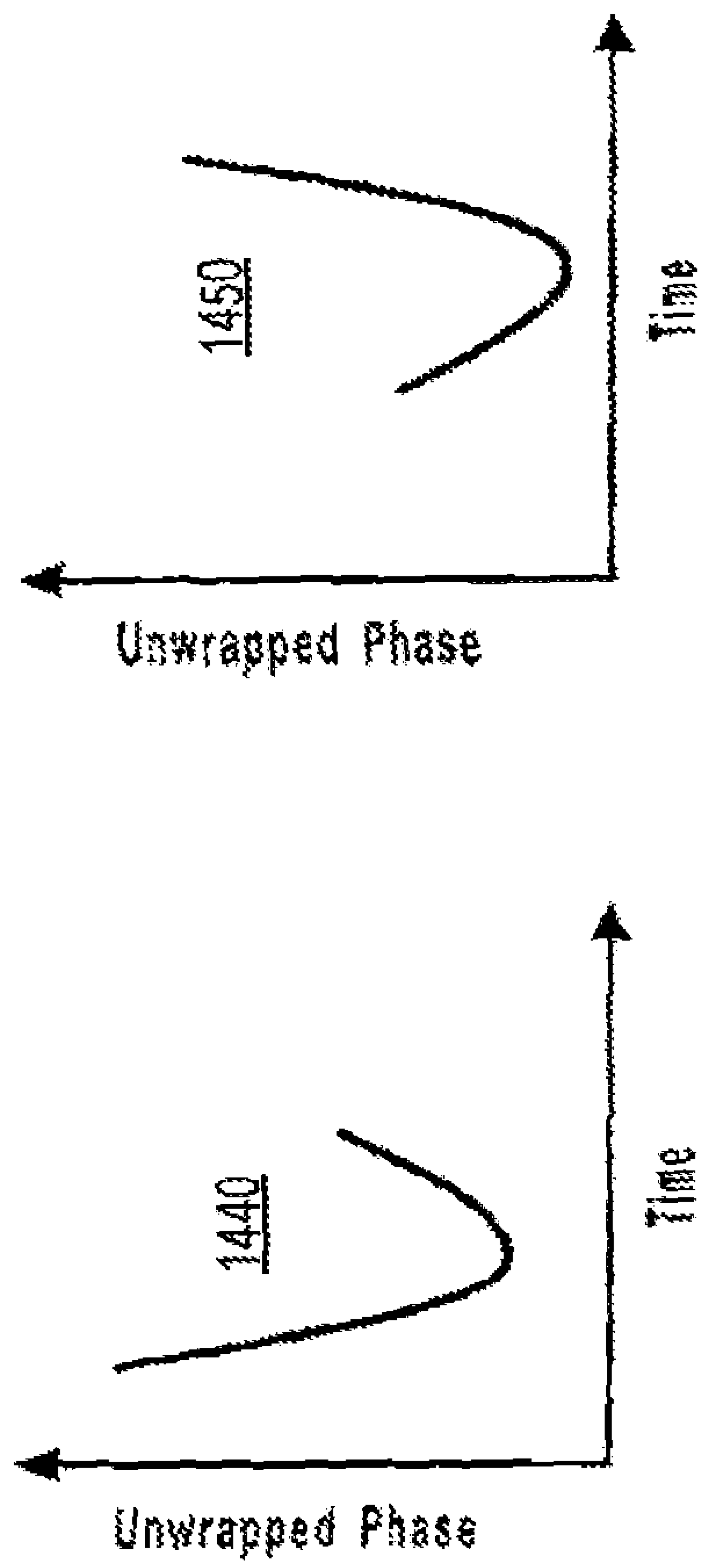


Fig. 14 NEW

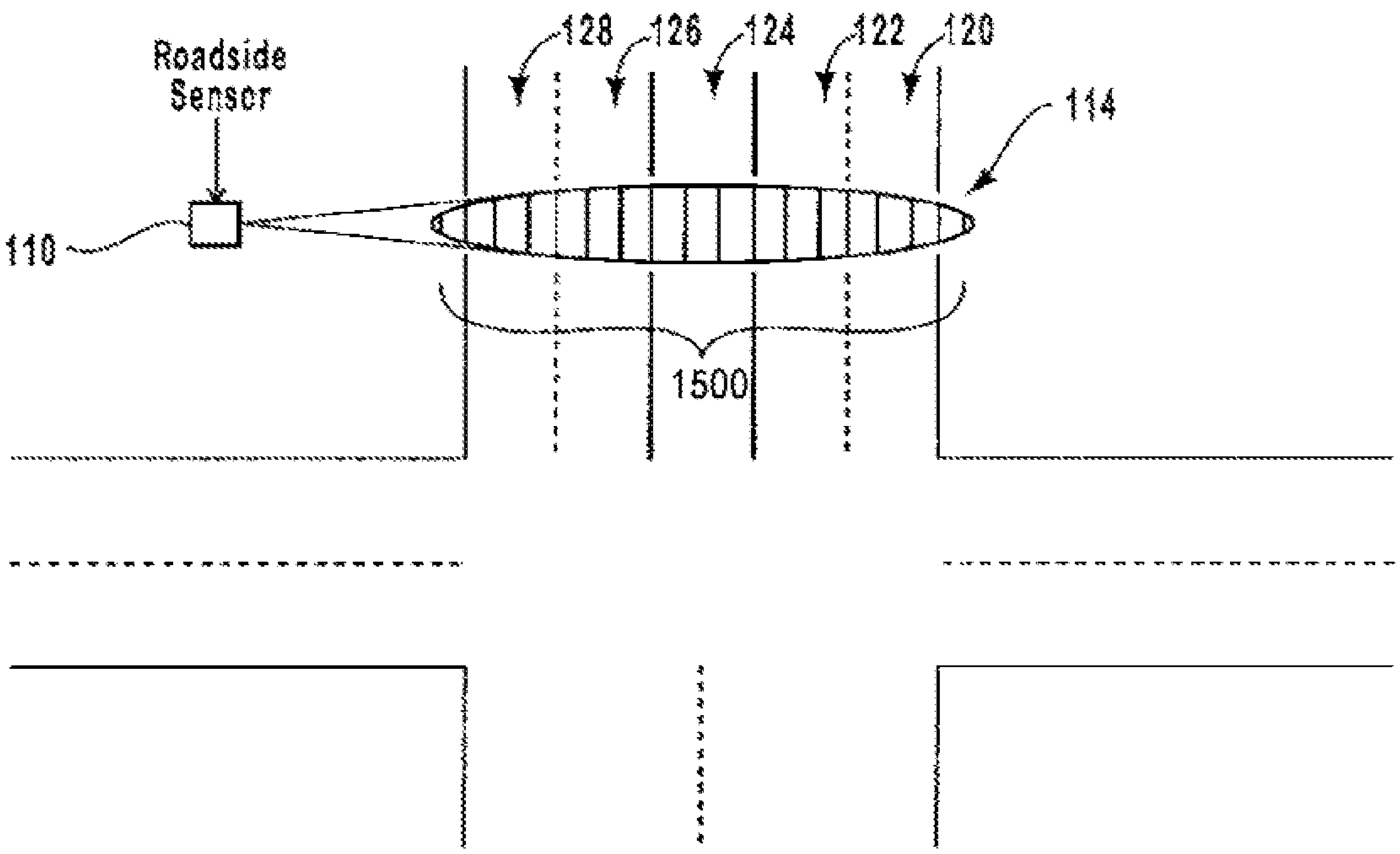


Fig. 15
NEW

VEHICULAR TRAFFIC SENSOR

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related to U.S. patent application Ser. No. 09/996,146 "System and Method of Dynamic Identification of Traffic Lane Positions," by inventors Jonathon L. Waite, Thomas William Karlinsey and David V. Arnold, filed concurrently herewith and incorporated by reference now U.S. Pat. No. 6,556,916.

BACKGROUND OF THE INVENTION

1. The Field of the Invention

The present invention relates generally to vehicular traffic monitoring systems, and more particularly relates to sensors for detecting the presence, location, speed, direction of travel, volume, and occupancy of vehicular traffic on a roadway.

2. The Relevant Technology

Controlled signalized intersections represent a key element in urban planning, public safety and traffic control. The science and engineering of traffic planning and control has long relied on the use of sensor devices designed for this specific purpose and, more recently, for the collection of traffic flow data. Some of these device technologies, such as those embedded in the roadways, have been employed for over sixty years and continue to require the same amount of attention in installation, calibration, maintenance, repair and replacement as they did decades ago. This laborious caretaking can be due to a number of factors ranging from inferior product design and poor installation to post installation disruption and migratory changes in traffic flow patterns. Reliability of these technologies is an issue to an overall traffic control plan and can prove extremely costly to maintain as an integral component to an overall traffic plan.

Traffic control devices that are embedded in roadways serve the interest of public safety, but in the event of a new installation, or maintenance/repair, they act as a public nuisance, as repair crews are required to constrict or close multiple lanes of traffic for several hours to reconfigure a device, or even worse, dig up the failed devices for replacement causing closure of the lane for several days or weeks.

While several sensor technologies are employed to assist in traffic planning and control, the oldest and most widely used technology currently employed in controlled intersections is the inductive loop. This loop is an in-pavement fixed location sensor, with the limitation of sensing only the traffic that is immediately over it. While such devices have continued history of use, failures of loops are common and at any one time as many as 20%-30% of all installed controlled intersection loops are non-responsive. Furthermore, the cost to repair these devices can be greater than the original installation cost.

As technology has developed over the decades, new sensory devices have been introduced to the traffic control industry. In recent years, there have emerged several non-intrusive technologies for traffic sensing that employ a remote sensor (i.e., not embedded in the roadway) as illustrated in FIG. **1**. While the majority of these types of sensors **110** incorporate microwave radar technology, other types including optical devices have also taken hold. For example, intersection traffic cameras may be manually configured to analyze specific user-defined traffic zones at all times. As cameras rely on optics, (i.e., the ability to visually see the traffic that is to be monitored) they are susceptible to the forces of nature that can occlude visibility. These forces include sun glare, accumulated snow or dirt and darkness. Under ideal conditions cameras would only need to be serviced or reconfigured with major intersection redesign. Presently available systems require on-site attention to improve and upgrade the capability of the unit, or complete replacement for upgrading the camera itself.

Another type of above-ground sensor includes acoustic sensors which operate as traffic sound-based listening devices. These devices employ an array of microphones built into the sensor allowing the device to detect traffic based on spatial processing changes in sound waves received at the sensor. After processing and analysis of the received sound waves, detection and traffic flow information is then assigned to the appropriate user-defined regions or lane being monitored, *thereby* forming a picture of the traffic.

When acoustic sensors are deployed, their microphone sensitivity is pre-set for normal operating conditions which include typical weather conditions. Again, the software and operating instructions to control an acoustic sensor require on-site attention to improve and upgrade the capability of the unit, or complete replacement to upgrade the sensor itself.

Other popular sensor types are based on microwave radar technology. Such sensors detect traffic based on the reflection of a transmitted electromagnetic signal depicted in FIG. **1** as signals **118**. The received signal is then processed into detection and traffic flow information which is then assigned to the appropriate user-defined lane being monitored. As illustrated in FIGS. **2** and **3**, microwave radar technology utilizes several bulky, expensive and manufacturably inefficient components to sense traffic. Most notably, microwave radar sensors are comprised of a mechanically-large horn antenna **170** and separate radio frequency components and controller boards that are individually tuned and matched in order to result in an operable system **180**. Furthermore, the unit requires on-site maintenance and attention to reconfigure, or upgrade software.

As identified above, many useful forms of technology exist to monitor and detect traffic. However, many forms of detection are obtrusively bulky, manufacturing intense, and all require on site maintenance and attention to re-configure the software, or operating instructions when traffic conditions, climate, or other operating conditions change. Without reconfiguration, the devices will continue to sense, but with reduced accuracy and in the worst case they may discard the actual flow pattern as peripheral noise. The cost to manufacture and reconfigure devices can be costly, and disruption to traffic is common.

Vehicular traffic monitoring continues to be of great public interest since derived statistics are valuable for determination of present traffic planning and conditions as well as providing statistical data for facilitating more accurate and reliable urban planning. With growing populations, there is increasing need for current and accurate traffic statistics and information. Useful traffic information requires significant statistical gathering of traffic information and careful and accurate evaluation of that information.

Additionally, the more accurate and comprehensive the information, such as vehicle density per lane of traffic, the more sophisticated the planning may become.

Roadway traffic surveillance has relied upon measuring devices, which have traditionally been embedded into the road, for both measuring traffic conditions and providing control to signaling mechanisms that regulate traffic flow. Various sensor technologies have been implemented, many of which have been "in-pavement" types. In-pavement sensors include, among others, induction loops which operate on magnetic principles. Induction loops, for example, are loops of wire which are embedded or cut into the pavement near the center of a pre-defined lane of vehicular traffic. The loop of wire is connected to an electrical circuit that registers a change in the inductance of the loops of wire when a large metallic object, such as a vehicle, passes over the loops of wire embedded in the pavement. The inductance change registers the presence of a vehicle or a count for the lane of traffic most closely associated with the location of the induction loops.

Induction loops and other in-pavement sensors are unreliable and exhibit a high failure rate due to significant mechanical stresses caused by the pavement forces and weather changes. Failures of loops are common and it has been estimated that at any one time, 20%-30% of all installed controlled intersection loops are non-responsive.

Furthermore, the cost to repair these devices can be greater than the original installation cost.

Installation and repair of in-pavement sensors also require significant resources to restrict and redirect traffic during excavation and replacement and also present a significant risk to public safety and inconvenience due to roadway lane closures which may continue for several hours or days. Interestingly, some of these technologies have been employed for over sixty years and continue to require the same amount of attention in installation, calibration, maintenance repair and replacement as they did several decades ago. This can be due to a number of factors from inferior product design or poor installation to post installation disruption or changing traffic flow patterns. Subsequently this technology can be extremely costly and inefficient to maintain as an integral component to an overall traffic plan.

To their credit, traffic control devices serve the interest of public safety, but in the event of a new installation, or maintenance repair, they act as a public nuisance, as repair crews are required to constrict or close multiple lanes of traffic for several hours to reconfigure a device or even worse, dig up the failed technology for replacement by closing one or more lanes for several days or weeks. Multiple lane closures are also unavoidable with embedded sensor devices that are currently available when lane reconfiguration or re-routing is employed. Embedded sensors that are no longer directly centered in a newly defined lane of traffic may miss vehicle detections or double counts a single vehicle. Such inaccuracies further frustrate the efficiency objectives of traffic management, planning, and control.

Such complications arise because inductive loop sensors are fixed location sensors, with the limitation of sensing only the traffic that is immediately over them. As traffic patterns are quite dynamic and lane travel can reconfigure based on stalled traffic, congestion, construction/work zones and weather, the inductive loop is limited in its ability to adapt to changing flow patterns and is not able to reconfigure without substantial modification to its physical placement.

Several non-embedded sensor technologies have been developed for traffic monitoring. These include radar-based sensors, ultrasound sensors, infrared sensors, and receive-only acoustic sensors. Each of these new sensory devices has specific benefits for traffic management, yet none of them can be reconfigured or adapted without the assistance of certified technicians. Such an on-site modification to the sensors may require traffic disruptions and may take several hours to several days for a single intersection reconfiguration.

Another traffic monitoring technology includes video imaging which utilizes intersection or roadside cameras to sense traffic based on recognizable automobile characteristics (e.g.; headlamps, bumper, windshield, etc.). In video traffic monitoring, a camera is manually configured to analyze a specific user-defined zone within the camera's view. The user-defined zone remains static and, under ideal conditions may only need to be reconfigured with major intersection redesign. As stated earlier, dynamic traffic patterns almost guarantee that traffic will operate outside the user defined zones, in which case, the cameras will not detect actual traffic migration. Furthermore, any movement in the camera from high wind to gradual movement in the camera or traffic lanes over time will affect the camera's ability to see traffic within its user-defined zone. In order to operate as designed, such technology requires manual configuration and reconfiguration.

Another known technology alluded to above includes acoustic sensors which operate as traffic listening devices. With an array of microphones built into the sensor, the acoustic device is able to detect traffic based on spatial processing changes in sound waves as the sensor receives them. Detection and traffic flow information are then assigned to the appropriate user-defined lane being monitored. This technology then forms a picture of the traffic based on the listening input, and analyzes it based on user assigned zones. Again, once the sensor is programmed, it will monitor traffic flow within the defined ranges only under ideal conditions.

Like an imaging camera, the acoustic sensor can hear traffic noise in changing traffic patterns, but it will only be monitored if it falls within the pre-assigned zone. Unable to reconfigure during changes in the traffic pattern, the acoustic sensor requires on-site manual reconfiguration in order to detect the new traffic flow pattern. In an acoustic sensor, microphone sensitivity is typically pre-set at a normal operating condition, and variations in weather conditions can force the noise to behave outside those pre-set ranges.

Yet another traffic sensor type is the radar sensor which transmits a low-power microwave signal from a source mounted off-road in a "side-fire" configuration or perpendicular angle transmitting generally perpendicular to the direction of traffic. In a sidefire configuration, a radar sensor is capable of discriminating between multiple lanes of traffic. The radar sensor detects traffic based on sensing the reflection of transmitted radar. The received signal is then processed and, much like acoustic sensing, detection and traffic flow information are then assigned to the appropriate user-defined lane being monitored. This technology then forms a picture of the traffic based on the input, and analyzes it based on user-assigned zones. Under ideal conditions, once these zones are manually set, they are monitored as the traffic flow operates within the pre-set zones. Consequently, any change in the traffic pattern outside those predefined zones needs to be manually reset in order to detect and monitor that zone.

As discussed above, several sensors may be employed to identify multiple lanes of vehicular traffic. While sensors may be positioned to detect passing traffic, the sensors must be configured and calibrated to recognize specific traffic paths or lanes. Consequently, such forms of detection sen-

sors require manual configuration when the system is deployed and manual reconfiguration when traffic flow patterns change.

Furthermore, temporary migration of traffic lanes, such as during, for example, a snow storm or construction re-routing, results in inaccurate detection and control. Without reconfiguration, the devices may continue to sense, but they may discard the actual flow pattern as peripheral noise, and only count the traffic that actually appears in their user-defined zones. The cost to configure and reconfigure devices can be considerable, and disruption to traffic is unavoidable under any circumstance. Furthermore, inaccurate counting of traffic flow can result in improper and even unsafe traffic control and inaccurate and inconvenient traffic reporting.

Thus, there exists a need for a method and system for configuring and continuously reconfiguring traffic sensors according to current traffic flow paths thereby enabling improved traffic control, traffic planning and enhanced public safety and convenience without requiring constant manual evaluation and intervention.

BRIEF SUMMARY OF THE INVENTION

A vehicle sensor for detecting and monitoring vehicular targets is presented. The sensor employs a planar design resulting in a reduced profile sensor and a greatly improved sensor for manufacturing. Improvements are a result of controlled manufacturing processes for forming controlled interconnects and structures on replicable circuit boards.

The sensor of the present invention includes a multi-layer radio frequency board having a first side which includes at least a majority of the RF components. On the opposing side of the board is a ground plane providing isolation to the RF components. Additionally, the opposing side also has printed thereon array transmit and receive antennas for radiating a signal toward a vehicular target and for receiving the signal as reflected from the vehicular target. The planar antennas provide a replicable antenna structure that is easily manufactured.

The sensor device further includes logic/control functionality which may be co-located or positioned separately on at least one logic or signal processing board that is preferably populated with components on a first side with a ground plane on a second side. The second or ground plane side is preferably positioned toward the RF componentry of the RF board to form an RF shield about the RF componentry. The boards are housed within a housing that is permeable to electromagnetic waves, at least on the side through which the antenna structures radiate. To provide additional RF absorption and isolation, an RF absorber is placed between the boards to provide additional isolation of RF emanations near to the source of generation.

These and other objects and features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

To further clarify the above and other advantages and features of the present invention, a more particular description of the invention will be rendered by reference to specific embodiments thereof, which are illustrated in the appended drawings. It is appreciated that these drawings depict only typical embodiments of the invention and are therefore not to be considered limiting of its scope. The invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates an above-ground sensor employing propagation delay calculation for position calculation of vehicular traffic;

FIGS. **2**-**3** illustrate a radar sensor comprised of horn antennas and multiple modules, in accordance with the prior art;

FIG. **4** illustrates an integrated above-ground traffic sensor, in accordance with the preferred embodiment of the present invention;

FIG. **5** illustrates the mechanical integration of RF components and signal processing components, in accordance with the preferred embodiment of the present invention;

FIG. **6** illustrates planar antennas integrated into the RF module board, in accordance with the preferred embodiment of the present invention;

FIG. **7** is a detail of one of the planar antennas, in accordance with a preferred embodiment of the present invention;

FIG. **8** is a block diagram of the component side of the RF board assembly and other related functional blocks, in accordance with the present invention;

FIG. **9** is a detailed layout of the RF component side of the RF component side of the RF board, in accordance with the preferred embodiment of the present invention;

FIG. **10** illustrates an embodiment of the present invention that employs a modulated signal digital generator for generating the desired signal;

FIG. **11** illustrates an embodiment employing a mixer configuration for the digitally generated modulated signal generator, in accordance with an embodiment of the present invention; **[**and**]**

FIG. **12** illustrates direct digital signal generation of the transmit signal, in accordance with another embodiment of the present invention*;*

FIG. 13 is a block diagram of a sensor within the traffic system of the present invention;

FIG. 14 illustrates the curves associated with angular viewing of traffic with the associated differentiation of traffic direction; and

FIG. 15 is a simplified diagram of a sensor and roadway configuration, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **4** is a perspective view of a traffic monitoring sensor, in accordance with a preferred embodiment of the present invention. A sensor **500** is illustrated having a generally planar topology due to the planarization of components including planarization of a transmit and receive antenna. Sensor **500** is a generally sealed enclosure comprised of a material that is permissive to the exchange of electromagnetic propagations. Sensor **500** is also generally comprised of a housing **502** for enclosing the multi-layer radio frequency circuit board and other processing component boards such as digital signal processing and/or control assemblies. Housing **502** includes a back surface **504** and a top or front surface **506**. During deployment of sensor **500**, front surface **506** is directed generally orthogonal with the roadway or portion of roadway undergoing monitoring. In the present invention, the term "above-ground" sensor means that the sensor is not embedded into the roadway but rather may be mounted above or about the roadway at various acceptable angles.

As the electromagnetic signals must propagate through front surface **506** as radiated from planar printed circuit board antennas described below, front surface **506** further includes geometries that facilitate reduced distortion of the antenna radiation pattern throughout the entire beamwidth of the antennas. FIG. **4** depicts such distortion-minimizing geometries as radomes **508** and **510**.

FIG. **4** further depicts additional sensor enhancements which are structurally depicted as communication link antenna **512** which facilitates both transmission of accumulated sensor data as well as reception of commands and software upgrades. The power and serial communication link are facilitated through the connector **514**.

FIG. **5** illustrates an exploded view of sensor **500**, in accordance with the preferred embodiment of the present invention. In addition to including housing **502**, sensor **500** further includes a multi-layer radio frequency circuit board **520** which includes radio frequency components **522** disposed on a first side **524**. Circuit board **520** further includes antennas **526** on an opposing second side **528**. Such a configuration accommodates an integrated and efficient topology of a sensor since bulky horn antennas are not employed. Furthermore, the integration of radio frequency components onto a planar circuit board arrangement having the antenna also disposed thereon dramatically improves manufacturability.

Sensor **500** further includes at least one controller/signal processing circuit board **530** having a first side **532** for disposing signal processing component **534** thereon and a second side having an electrically conductive ground layer **538**. Electrically conducted ground layer **538** functions as an RF shield when it is oriented in parallel and facing multi-layer radio frequency circuit board **520** upon final assembly within housing **502**. Ground layer **538** also functions as a ground plane for the controller/signal processing circuit board. Signal processing board **530** and radio frequency circuit board **520** interact via connectors **540** and **542**, respectively.

Sensor **500** further comprises an absorber **550** located between multi-layer radio frequency circuit board **520** and signal processing board **530**. Absorber **550** comes into proximity of both the electrically conductive ground layer **538** on board **530** and the first side **524** having RF components **522** thereon of radio frequency circuit board **520**. In order to minimize the disturbance of the desired electromagnetic fields in the RF structures about and interconnecting RF components **522**, channels or cutouts preferably extending only partially into absorber **550** are incorporated within absorber **550** that provide clearance around such RF components including transmission lines located on first side **524** of radio frequency circuit board **520**.

FIG. **6** illustrates an exemplary layout of second side or antenna side **528** of multi-layer radio frequency circuit board **520**. The antenna system of the present invention is placed on the same circuit board as the other RF circuitry. The antenna system includes two coplanar loop series-fed array antennas **570** and **572** that are preferably located on opposite ends of RF circuit board **520** and on the opposite side of the circuit board from RF circuitry components **522**. Thus, in the preferred embodiment, one side of the circuit board includes antennas **570** and **572** with possibly DC interconnect lines **574** and miscellaneous bias networks **576**, while side **524** includes RF components **522**.

FIG. **7** illustrates a detailed layout of a planar printed circuit board antenna, in accordance with a preferred embodiment of the present invention. The present invention utilizes a coplanar waveguide loop antenna **580** for radiating and receiving microwave signals projected about a vehicular target. The present configuration employs a series of radiating elements. In the present implementation, areas of metal are surrounded by slots or areas with no metal. This structure can be implemented by surrounding the metal with air, or by printing it on a dielectric substrate, or on a conductor backed dielelectric substrate. This is a non-resonant element that exhibits many desirable properties such as wide bandwidth, and a low coupling between adjacent elements. The radiation from this element is polarized horizontally as oriented in FIG. **7**. In a conductor backed implementation, the elements radiate only out of the page.

FIG. **7** depicts an array of series-fed coplanar loop elements **582**-**587** and **588**-**593**. In the present invention, the coplanar waveguide traveling wave series loop antenna element exhibits the broadband qualities of a traditional coplanar loop and can be combined in a series like the series-fed microstrip patch. For an appreciation of related structures, the following articles are incorporated herein by reference: H. C. Liu, T. S. Horng, and N. G. Alexopoulos, "Radiation of Printed Antennas with Coplanar Waveguide Feed," IEEE Trans. Antennas Propgat., vol. 43 no. 10, pp. 1143-1148, October 1995; and A. G. Demeryd, "Linearly Polarized Microstrip Antennas," IEEE Trans. Antennas Propogat., pp. 846-851, November 1976.

In the present invention, since the coplanar series loop is not a resonant element, the size of the element can be readily adjusted. This size adjustment results in an alteration to the amount of radiation exhibited. Thus, tapered arrays can be designed by utilizing radiating elements with varying sizes. The coplanar waveguide series loop element is implemented using the following features: a conductor backed dielectric substrate **704**, **702** (see FIG. **9**), grounding vias **594** to prevent substrate propagation, and wide coplanar slots **595** to reduce the effects of manufacturing variations.

The use of a conductor backed dielectric substrate limits the radiation from the element to only one side of the element and also facilitates manufacturing as the element can be printed on a dielectric laminated with metal on both sides. The grounding vias **594** prevent the propagation of parallel plate modes that may exist when dielectric is laminated on both sides by metal. These parallel plate modes could cause coupling between radiating elements printed on the same substrate and could cause unpredictable antenna input impedances.

The wide coplanar slots **595** help in several ways. First, wide coplanar slots increase radiation and increase tolerance to manufacturing variations. Second, circuit boards are often coated with solder mask and conformal coating to protect the board and components. These coatings, however, fill the coplanar slots and cause unpredictable phase shifts. The widening of the coplanar slots reduces this effect. By way of example and not limitation, slots **595** in the preferred embodiment assume a width of 60 mils., which provides the needed tolerance to manufacturing and coating variations but also maintains the necessary coplanar properties. The width of the center conductor of the coplanar waveguide is chosen to achieve the desired transmission line characteristic impedance.

The detail of FIG. **7** illustrates vias **594**, that in a preferred embodiment are plated with copper to create a grounded short between the top ground plane and the bottom ground plane. In the present example, vias **594** are placed so that the edge of the via is 25 mil. from the edge of the slot which is sufficient to result in marginal influence to the transmission line characteristics but sufficiently close to effectively channel the electromagnetic energy.

A tapered antenna array **596**, **597** may be implemented through the use of varying element sizes. Series-fed arrays, such as this one in the present example, are used to replace corporate feed designs in which each element is fed by its own individual transmission line. The corporate feed approach requires an intricate feed structure that becomes more complicated when different antenna elements are used in the array or when a tapered feed is desired. Furthermore, corporate feed structures are prone to undesired radiation which results in antenna pattern distortion.

The exemplary loop dimensions given on FIG. **7** illustrate the heights of the loops and tapering towards the edges of the array. The radiating edges of the loops are the vertical sides (as oriented in FIG. **7**). Thus, variations in the height of the loop results in changes to the degree of radiation from the loop. Consequently, the tapering of the loop size results in a radiation power distribution that creates a radiation pattern with low side lobes. The dimensions shown on the array **597** illustrate the loop widths increasing towards the edges of the array. This ensures that the radiating edges of the loop are in-phase. This dimension results in the widths being larger as the heights are smaller. The exact loops dimensions were determined through simulation.

The lengths of transmission lines between the loops illustrated on array **596** are adjusted to facilitate every loop radiating in phase. As shown, these lengths are longer for smaller loops. These lengths are again determined from simulation. As illustrated in FIG. **7**, the left half of the array **596** is fed from the right and the right half of the array **597** is fed from the left. This would cause an 180° phase shift between the two sides of the array **580** if not compensated for. Since the transmission lines which feed the two sides of the array are of different lengths, the line as illustrated on the right is exactly ½ wavelength longer than the line on the left. This provides the compensation to achieve in-phase radiation from both sides of the array.

In the present example, the antenna **580** is fed from a 50 Ω transmission line that drives two 100 Ω lines, which intersect at a tee. From the tee to the edges of the array, the transmission lines are 100 Ω. Notice that the 50 Ω transmission line feeding the antenna narrows for a section **598** and then returns to the standard width. This section **598** of the line is a quarter-wave matching section used to provide an impedance match to antenna **580**. The ends of the array are terminated by short-circuited transmission lines. This termination causes a standing wave pattern throughout the antenna and causes the antenna as a whole to become a resonant structure. This has an advantage over a matched termination in that the antenna gain is higher since there are no losses in the termination. If a higher bandwidth antenna is needed, however, a matched termination, which would result in a traveling wave antenna, may be employed.

FIG. **8** is a functional block diagram of the radio frequency circuit board with other blocks of related functionality, in accordance with a preferred embodiment of the present invention. The functionality of radio frequency circuit board **520** (FIG. **5**) may be partitioned into a transmit portion **602**, including a digitally generated modulated signal generator **603**, and a received portion **604**. Transmit portion **602** is comprised, in the preferred embodiment, of a direct digital synthesizer (DDS) **606** for creating a signal **612** that sweeps in frequency.

While the present embodiment depicts frequency generation using a DDS, it is also contemplated that other wave form generating devices, generally herein known as digitally generated modulated signal generators, including numerically controlled devices, may be employed for generating effective waveforms. In the preferred embodiment, a modulated signal is generated digitally and is thus phase-locked to a digital clock. This modulated signal is then up-converted, if necessary, to the desired band.

Various embodiments for the digital generation are depicted in FIGS. **8**, and **10-12**. FIG. **10** illustrates another embodiment for digitally generating a modulated signal. In this approach, a digitally generated modulated signal generator **780** is comprised of a modulated signal digital generator **782** and an optional up-convertor **784**. In this embodiment, the modulated signal generator provides significant advances over analog signal generators by providing enhanced phase stability over time and improved modulation control which results in lower compression sidelobes and improved detection algorithms.

FIG. **11** illustrates another digitally generated modulated signal generator **800**. This embodiment illustrates up-converting a digitally generated modulated signal by using a frequency mixer **802**. In this approach, the modulated signal **804** is mixed with an RF tone **806** resulting in a signal containing frequencies of the sum and difference of the tone and the original signal. Only the sum or the difference frequencies are desired and one or the other must be filtered out by a filter **808**. For example, the digitally modulated signal generator produces a signal ranging from 100 MHz to 150 MHz. This signal is then mixed with a 10.4 GHz tone. The resulting signal contains copies of the digitally generated modulated signal in the 10.3 GHz to 10.25 GHz range and in the 10.5 to 10.55 GHz ranges. A band pass filter **808** with a high Q can be used to filter the lower frequency copy and the higher frequency copy is then transmitted.

FIG. **12** illustrates a specific embodiment for digitally generating a modulated signal wherein the digitally generated modulated signal generator **820** is comprised of a direct digital to analog conversion generator **822** capable of direct generation of the desired signal. FIG. **12** further illustrates another implementation of the transmit and **[**receiver**]** *receive* portions wherein they share a single antenna that is multiplexed using a circulator **824** for alternating between transmit and receive modes of operation.

Each of these embodiments comprises similar additional components and the preferred embodiment, as illustrated in FIG. **8** is used to describe and define those components. In the preferred embodiment as illustrated in FIG. **8**, reference signal **612** sweeps in frequency from 10.5 megahertz to 10.55 megahertz and is generally linear with a duration of 1.25 milliseconds followed by recovery time.

The output of DDS **606** couples to a phase lock loop **608** which operates by comparing two input frequencies **612**, **614** and generates a voltage **616** which controls a voltage controlled oscillator (VCO) **610**. Regarding phase lock loop **608**, if the reference signal **612** is lower in frequency than the pre-scaler output **614**, then the output voltage **616** of phase lock loop **608** becomes lowered. Conversely, if reference signal **612** is higher than pre-scaler output **614**, then output voltage **616** of phase lock loop **608** is increased.

VCO **610** outputs a signal **618** whose frequency is determined by the input voltage **616**. Those of skill in the art appreciate that the higher the input voltage of input **616**, the higher the frequency of the RF signal output **618**, and conversely, the lower input voltage **616**, the lower the frequency of the RF output signal **618**. In a "reverse" drive

VCO, a change in input voltage yields the opposite result of that just described. By way of example and not limitation, the VCO **610** of the present embodiment generates an output signal in the 5.25 GHz to 5.275 GHz range.

Transmit portion **602** is further comprised of a pre-scaler **620** which operates as a frequency divider by reducing the frequency of VCO **610** by a factor of, for example, 4. Before comparing the two signals, the PLL further divides the signal by a factor of 250 which results in a signal in the 10.5 MHz to 10.55 MHz range, which range is near the same frequency as reference signal **612** as output by DDS **606**. Thus, output signals **612**, from the direct digital synthesizer and pre-scaler output **614** become tracking signals for comparison by phase lock loop **608**. In general, phase lock loop **608** adjusts input voltage **616** to VCO **610** until both inputs, reference signal **612** and pre-scaler output **614**, are at the same frequency. As referenced signal **612** from DDS **606** increases in frequency, phase lock loop **608** drives VCO **610** in such a manner as to also increase the frequency. Thus, output signal **618** from VCO **610** results in the same signal as reference signal **612** other than signal **618** is scaled, in the present example, by a factor of 500.

Transmitter portion **602** further includes a Wilkinson divider **622** for dividing the RF signal **618** into two paths while maintaining isolation between the two outputs, output **624** and output **626**. Those of skill in the art appreciate that Wilkinson divider **622** is a splitter in which each output path is reduced by half, or 3 dB, from input signal **618**.

Transmitter portion **602** further includes a doubler **628** for receiving signal **624** and generating a signal **630**. Doubler **628** operates as a nonlinear device for effectively doubling the frequency from input signal **624** to output signal **630**. In the present example, input signal **624** operates between 5.25 GHz and 5.275 GHz generating an output **630** ranging from 10.5 GHz to 10.55 GHz. Therefore, signal **630**, in the present example, results in a multiplication of reference signal **612** by a factor of 1,000.

Transmitter portion **602** further includes an amplifier **632** for coupling with signal **630** and for generating signal **634**. Amplifier **632** provides gain control of the signal for boosting the signal to a level sufficiently large for transmission. Amplifier **632** further couples to a Wilkinson divider **636** for partitioning a portion of the transmission power to the **[**receiver**]** *receive* portion through a signal **638** and Wilkinson divider **636** further generates an output **640** for passing to band pass filter **642**. Those of skill in the art appreciate that that pass band filter **642** filters the output signal on the transmit portion to reduce transmissions outside of the desired frequency band. Transmit portion **602** further includes a transmit antenna **644** further described below for emanating the signals generated by the aforementioned circuitry.

Received portion **604** is comprised of various components for receiving reflected signals as emanated by transmit portion **602**. Reflected signals are received by receive antenna **650** and processed by a bandpass filter **652** which reduces transmission outside of the desired frequency band. The receive filtered signal **654** is thereafter passed to amplifier **656** which generally is implemented as a low noise amplifier for boosting the received signal to a more useable level for processing.

Amplified signal **658** and signal **638** are received by mixer **660** which, in the present example, is implemented as a nonlinear device that effectively multiplies the two input signals to produce output signal **662**. Those of skill in the art appreciate that mixers operate, for example, by receiving two sinusoidal signals which may be of different frequencies which results in an output signal having the characteristics of the sum of the two input sinusoidal signals, which trigonometrically results in a first frequency corresponding to the sum of the two input frequencies and a second frequency corresponding to the difference of the two input frequencies. This principle is illustrated by the trigonometric identity:

$$\sin\alpha\cos\beta=\tfrac{1}{2}[\sin(\alpha-\beta)+\sin(\alpha+\beta)]$$

Thus, if one input signal is 10.5 GHz and a second is 10.50001 GHz then the output signal from the mixer will be the sum of the sinusoids at 21.00001 GHz and another at 10 KHz for the present exemplary implementation, the resulting difference frequency signal is employed for evaluation of the signal characteristics.

It should be appreciated that the utilization of the difference frequency is a result of ranging capabilities of a linearly sweeping transmitted frequency. For example, the present embodiment utilizes a signal transmitted that is linearly frequency modulated (e.g. chirp). If the transmitted signal is reflected by a single point source target and is received by the radar and mixed with the same linearly modulated signal, the received signal, which has been delayed in time by the propagation duration to and from the target results in a frequency difference between the two inputs to the mixer since the transmitted signal exhibits a constantly increasing frequency during the phase of the period under evaluation. Therefore, the longer the propagation time to and from the target in question, the larger the frequency difference between the presently transmitted and the received signal. For example, in the present illustration, the linearly increasing frequency increases at a rate of 50 MHz in 1.25 milliseconds. Such a linear change in frequency results in a 40 GHz per second change in frequency. Therefore, if a target is located at a distance of 100 feet, the propagation time to and from the target is approximately 203 nanoseconds. In that length of time, the transmit frequency would have changed by 8.13 KHz.

Received portion **604** is further comprised of a low pass filter **664** which eliminates undesired RF signals from the mixer output, therefore resulting in audio frequencies being present at signal **666**. Therefore, signal **666**, which is the output of the low pass filter **664**, is an audio frequency signal whose frequency corresponds to the range of the target and whose amplitude corresponds to the reflectiveness of the target.

[Receiver**]** *Receive* portion **604** further includes audio filtering and amplification as illustrated in block **668**. Such filtering and amplification conditions the signal prior to digitization to reduce any feed-through from the transmitting antenna directly coupling to the receiving antenna. Signal conditioning in the form of high pass filtering is employed since transmitter coupling appears in the received signal as a low frequency.

The following digital circuitry components may reside on a separate digital board. The output condition signal **670** is input to analog-to-digital conversion for **672**, which converts the audio frequency signal to a digital signal for processing and analysis. The digitized output signal **674** is thereafter processed by detection algorithm **676**, which performs spectral analysis on the digitized signal **674** and generates the desired traffic statistics for use in traffic analysis, control, and forecasting. Other processing within detection algorithm **676** includes automatic and continuous background estimation, automatic and continuous lane allocation and automatic and continuous detection threshold determination.

FIG. **9** illustrates a typical layout of the RF component side of the RF circuit board, in accordance with the preferred embodiment of the present invention. As discussed, RF components **522** (FIG. **5**) are populated on side **524**. The transmit portion **602** and receive portion **604** are depicted, absent antennas **570** and **572** which populate the other side of the board. The conductor backed dielectric substrates **704** and **702** for the antenna structures are depicted in FIG. **9**. Also depicted in FIG. **9** are the signal via to the transmit antenna **704** and the signal via from the receive antenna **706**.

In at least one embodiment, a traffic system sensor detects vehicles passing within the field of view and processes the data into an estimation of the position of each of the detected vehicles. A traffic monitoring system employs the traffic system sensor for monitoring traffic conditions about a roadway or intersection. As roadways exhibit traffic movement in various directions and across various lanes, the sensor detects vehicles passing through a field of view. The sensor data is input into a Fourier transform algorithm to convert from the time domain signal into the frequency domain. Each of the transform bins exhibits the respective energies with ranging being proportional to the frequency. A detection threshold discriminates between vehicles and other reflections.

In at least one embodiment, a vehicle position is estimated as the bin in which the peak of the transform is located. A detection count is maintained for each bin and contributes to the probability density function estimation of vehicle position. The probability density function describes the probability that a vehicle will be located at any range. The peaks of the probability function represent the center of each lane and the valleys of the probability density function represent the lane boundaries. The boundaries are then represented with each lane being defined by multiple range bins with each range bin representing a slightly different position on the corresponding lane of the road. Traffic flow direction is also assigned to each lane based upon tracking of the transform phase while the vehicle is in the radar beam.

Returning to FIG. 1, FIG. 1 illustrates a traffic monitoring system 100 which provides a method and system for dynamically defining the position or location of traffic lanes to the traffic monitoring system such that counts of actual vehicles may be appropriately assigned to a traffic lane counter that is representative of actual vehicular traffic in a specific lane. In FIG. 1, traffic monitoring system 100 is depicted as being comprised of a sensor 110 mounted on a mast or pole 112 in a side-fire or perpendicular orientation to the direction of traffic. Sensor 110 transmits and receives an electromagnetic signal across a field of view 114. Preferably, the field of view 114 is sufficiently broad in angle so as to span the entire space of traffic lanes of concern. As further described below, sensor 110 transmits an electromagnetic wave of a known power level across the field of view 114. Subsequent to the transmission of an electromagnetic wave front across a roadway 116, reflected signals at a reflected power level are reflected, depicted as reflected waves 118 having a reflected power, back to a receiver within sensor 110. The reflected waves 118 are thereafter processed by sensor 110 to determine and dynamically define the respective roadway lanes, according to processing methods described below.

FIG. 13 is a block diagram of the functional components of a traffic monitoring system, in accordance with the preferred embodiment of the present invention. Traffic monitoring system 1300 is depicted as being comprised of a sensor 110 which is illustrated as being comprised of a transceiver 1302 which is further comprised of a transmitter 1304 and a receiver 1306. Transmitter 1304 transmits an electromagnetic signal of a known power level toward traffic lanes 120-128 (FIG. 1) across a field of view 114 (FIG. 1). Receiver 1306 receives a reflected power corresponding to a portion of the electromagnetic signal as reflected from each of the vehicles passing therethrough. Transmitter 1304 and receiver 1305 operate in concert with processor 1308 to transmit the electromagnetic signal of a known power and measure a reflected power corresponding to the presence of vehicles passing therethrough. Processor 1308 makes the processed data available to other elements of a traffic monitoring system such as a traffic controller system 1310 and traffic management system 1312.

In at least one embodiment, to determine direction of travel automatically, the radar is preferably not mounted precisely perpendicular to the road. It is mounted off perpendicular, pointing slightly into the direction of travel of the nearest lane (to the left if standing behind the radar facing the road) by a few degrees. The vehicle direction of travel is determined by tracking the Fourier transform phase while the vehicle is in the radar beam. Many measurements are made while the car is in the radar beam. After the car has left the beam, the consecutive phase measurements are phase unwrapped to produce a curve that is approximately quadratic in shape and shows evidence of vehicle travel direction.

A vehicle entering the radar beam from the left will produce a curve similar to curve 1440 of FIG. 14 with the left end of the curve being higher than the right end. This occurs because with the radar turned a few degrees the vehicle spends more time, while in the radar beam, approaching the radar sensor than leaving the sensor. Likewise, a vehicle entering from the right will produce a curve as in curve 1450 of FIG. 14 with the right end of the curve being higher than the left. Once the direction of travel is known, the vehicle position and lane boundaries are used to determine which lane the vehicle is in. The direction of traffic flow can then be estimated by using the direction PDF estimates to determine which direction of flow is most probable in each lane.

FIG. 15 depicts a side-fired deployment of a sensor 110, in accordance with the present invention. While sensors may be deployed in a number of setups, one preferred implementation is a side fire or perpendicular configuration. In FIG. 15, a roadside sensor 110 is depicted as having a field of view 114 spread across multiple lanes of traffic. In the preferred embodiment, the field of view is partitioned into a plurality of bins 1500, each of which represents a distance or range such that a lane may be comprised of a plurality of bins which provide us a smaller and more improved granularity of statistical bins into which specific position may be allocated.

After processing the received signal, the signal reflected off the vehicles is assigned to a bin having the corresponding reflected signal parameters and shows up as an energy measurement in the range bin representing the vehicle's position. The number of vehicles in each bin is counted with the count incremented when an additional vehicle is detected the count and assigned to that bin. When a bin count is incremented, it increases the probability of a car being in that position and after many vehicle positions are recorded, a histogram of the bin count represents a PDF of vehicle position on the road. The histogram of position measurements identifies where vehicles are most probable to be and where the traffic lanes on the roadway should be defined. In *the present figure, lanes derive their specific lane positions by setting the lane boundaries between the peaks according to detection theory.*

Alternative ways of automatically assigning lane boundaries may be used but are simplifications or subsets of using PDF estimates and decision theory to set the boundaries. For a method to automatically assign lane boundaries it must have a period of training where it gathers information about vehicle position on the road and this collection of position information over time is more or less the histogram explained above. Decision theory will be used in determining lane boundaries and can vary according to desired performance. The preferred embodiment of the present invention employs statistical processing in order to determine and dynamically track the placement of lanes. While the present invention depicts a preferred statistical implementation, those of skill in the art appreciate that other statistical approaches may also be employed for dynamically defining traffic lanes.

In at least one embodiment, if vehicle position statistics change over time due to weather, road construction, or other disturbances the lane position algorithms have the ability to update lane boundaries. One example would be to have the current set of statistics averaged into the past statistics with a small weight given to older position statistics and greater weight to more recent statistics. Thus, if conditions change the overall statistics will change to reflect the current situation in an amount of time dictated by how much the current set of data is weighted.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A sensor for monitoring vehicles on a roadway comprising:

a multi-layer radio frequency circuit board for transmitting modulated radio frequency signals and for receiving reflections of the modulated radio frequency signals from said vehicles on said roadway, said multi-layer radio frequency circuit board having a first side for disposing radio frequency components thereon and a second side having a planar antenna disposed thereon, wherein the radio frequency components include a digital signal generator that digitally generates the modulated radio frequency signals; and

at least one signal processing circuit board having a first side for disposing signal processing components thereon and a second side having an electrically conductive ground layer, said second side of said at least one signal processing board oriented in parallel with and facing said multi-layer radio frequency circuit board.

2. The sensor, as recited in claim **1**, wherein said planar antenna comprises a plurality of series-configured loop elements arranged in a tapered array.

3. The sensor, as recited in claim **2**, wherein said planar antenna comprises at least a pair of tapered arrays.

4. The sensor as recited in claim **1**, wherein said digital signal generator further comprises

a direct digital synthesizer for generating a low frequency waveform for a transmitter of said sensor.

5. The sensor, as recited in claim **1**, further comprising:

an RF absorber assembled between said first side of said radio frequency circuit board having said radio frequency components thereon and said second side of said at least one signal processing board having said electrically conductive ground layer thereon.

6. The sensor, as recited in claim **1**, further comprising a housing for enclosing said multi-layer radio frequency circuit board and said at least one signal processing board therein.

7. The sensor, as recited in claim **6**, wherein said housing for enclosing said multi-layer radio frequency circuit board and said at least one signal processing board therein is configured as a planar housing surrounding said multi-layer radio frequency circuit board and said at least one signal processing board therein.

8. The sensor, as recited in claim **7**, wherein said planar housing further comprises a radome integrated into said planar housing and located adjacent to said planar antenna on said radio frequency circuit board.

[~~**9**. An above-ground traffic sensor for detecting vehicles traveling on a roadway, the traffic sensor comprising:~~

~~a radio frequency circuit board including:~~

~~a transmit portion that includes:~~

~~a digitally generated modulated signal generator that digitally generates a signal that is transmitted by a transmitter towards vehicles traveling on a roadway; and~~

~~a receiver portion that detects a reflected signal from the vehicles traveling on the roadway and that generates a data signal that represents traffic data from the reflected signal.~~]

[~~**10**. The above-ground traffic sensor, as recited in claim **9**, wherein said digitally generated modulated signal generator comprises:~~

~~a direct digital synthesizer for generating a low frequency waveform for said transmitter;~~

~~a phase lock loop coupled to said direct digital synthesizer for tracking said low frequency waveform; and~~

~~a voltage controlled oscillator coupled to said phase lock loop for generating a modulated transmit signal.~~]

11. [The above-ground traffic sensor, as recited in claim **9**, wherein said digitally generated modulated signal generator comprises] *An above-ground traffic sensor for detecting vehicles traveling on a roadway, the traffic sensor comprising*:

a radio frequency circuit board including:

a transmit portion that includes:

a digitally generated modulated signal generator that digitally generates a signal that is transmitted by a transmitter towards vehicles traveling on a roadway;

a receiver portion that detects a reflected signal from the vehicles traveling on the roadway and that generates a data signal that represents traffic data from the reflected signal;

a digitally modulated signal generator for generating a modulated signal;

an oscillator for generating an RF tone; and

a frequency mixer for mixing said modulated signal and said RF tone to form a signal [comprises] *comprised* of sum and difference frequencies.

[~~**12**. The above-ground traffic sensor, as recited in claim **9**, wherein said digitally generated modulated signal generator comprises:~~

~~a direct digital to analog converter for directly generating a modulated signal at RF frequencies.~~]

~~[13. The above-ground traffic sensor, as recited in claim 9, wherein said radio frequency circuit board further comprises a planar antenna disposed thereon for transmitting said signal and for receiving reflections of said signal.]~~

14. [The above-ground traffic sensor, as recited in claim **13]** *An above-ground traffic sensor for detecting vehicles traveling on a roadway, the traffic sensor comprising:*

a radio frequency circuit board including:

a transmit portion that includes:

a digitally generated modulated signal generator that digitally generates a signal that is transmitted by a transmitter towards vehicles traveling on a roadway;

a receiver portion that detects a reflected signal from the vehicles traveling on the roadway and that generates a data signal that represents traffic data from the reflected signal;

wherein said radio frequency circuit board further comprises a planar antenna disposed thereon for transmitting said signal and for receiving reflections of said signal, and

wherein said planar antenna comprises of a plurality of series-configured loop elements arranged in a tapered array.

15. [The above-ground traffic sensor, as recited in claim **14,]** *An above-ground traffic sensor for detecting vehicles traveling on a roadway, the traffic sensor comprising:*

a radio frequency circuit board including:

a transmit portion that includes:

a digitally generated modulated signal generator that digitally generates a signal that is transmitted by a transmitter towards vehicles traveling on a roadway; and

a receiver portion that detects a reflected signal from the vehicles traveling on the roadway and that generates a data signal that represents traffic data from the reflected signal;

wherein said radio frequency circuit board further comprises a planar antenna disposed thereon for transmitting said signal and for receiving reflections of said signal,

wherein said planar antenna comprises a plurality of series-configured loop elements arranged in a tapered array; and

wherein said planar antenna comprises at least a pair of said tapered arrays.

[**16**. An above-ground traffic sensor for detecting vehicles traveling on a roadway, comprising:

planar antennas mounted in a planar circuit board for propagating a transmit signal toward vehicles on a roadway and for receiving said transmit signal reflected from said vehicles, wherein the planar antennas further comprises:

at least one coplanar loop series-fed array antenna on the planar circuit board.]

[**17**. The above-ground traffic sensor, as recited in claim **16**, wherein said at least one coplanar loop series-fed antenna comprises:

a first coplanar loop series-fed array antenna that propagates said transmit signal toward said vehicles on said roadway; and

a second coplanar loop series-fed array antenna that receives said transmit signal reflected from said vehicle.]

18. [The above-ground traffic sensor, as recited in claim **17,]** *An above-ground traffic sensor for detecting vehicles traveling on a roadway, comprising:*

planar antennas mounted in a planar circuit board for propagating a transmit signal toward vehicles on a roadway and for receiving said transmit signal reflected from said vehicles, wherein the planar antennas further comprise:

at least one coplanar loop series-fed array antenna on the planar circuit board, wherein said at least one coplanar loop series-fed antenna comprises:

a first coplanar loop series-fed array antenna that propagates said transmit signal toward said vehicles on said roadway;

a second coplanar loop series-fed array antenna that receives said transmit signal reflected from said vehicle; and

wherein said first coplanar loop series-fed array antenna and said second coplanar loop series-fed array antenna include loop elements arranged in tapered arrays.

19. [The above-ground traffic sensor, as recited in claim **17,]** *An above-ground traffic sensor for detecting vehicles traveling on a roadway, comprising:*

planar antennas mounted in a planar circuit board for propagating a transmit signal toward vehicles on a roadway and for receiving said transmit signal reflected from said vehicles, wherein the planar antennas further comprise:

at least one coplanar loop series-fed array antenna on the planar circuit board, wherein said at least one coplanar loop series-fed antenna comprises:

a first coplanar loop series-fed array antenna that propagates said transmit signal toward said vehicles on said roadway;

a second coplanar loop series-fed array antenna that receives said transmit signal reflected from said vehicle; and

wherein said at least one coplanar loop series-fed array antenna each comprises at least a pair of tapered arrays.

20. A radar-based vehicular traffic sensor, comprising:

a digital signal generator that digitally generates a modulated electromagnetic signal;

transmitter electronic components for transmitting the modulated electromagnetic signal at a vehicle on a roadway;

receiver electronic components for receiving the modulated electromagnetic signal reflected from the vehicle on the roadway; and

at least one planar loop series-fed array antenna for transmission and/or reception of said modulated electromagnetic signal, wherein each at least one planar loop series-fed array antenna includes a plurality of loops, each loop having a height that is different from other loops in the plurality of loops.

21. A radar-based vehicular traffic sensor, as recited in claim **20**, wherein the digital signal generator further comprises one or more of:

a direct digital synthesizer that generates a modulated electromagnetic signal that sweeps in frequency; and

a modulated signal digital generator for generating a modulated electromagnetic signal that is up converted using a frequency mixer.

~~[22. A sensor for monitoring vehicles on a roadway, the sensor comprising:~~

~~a transmit portion comprising:~~

~~a digital signal generator that digitally generates a modulated signal; and~~

~~a transmit antenna for transmitting the modulated signal towards vehicles on a roadway;~~

~~a received portion comprising:~~

~~a receive antenna for receiving reflections of the modulated signal from vehicles on the roadway, wherein the reflections of the modulated signal are processed to produce traffic data representing the vehicles on the roadway.]~~

~~[23. A sensor as defined in claim 22, wherein the transmit antenna and the receive antenna are the same antenna used at different times to either transmit the modulated signal or to receive the reflections of the modulated signal.]~~

[**24**. A sensor as defined in claim **22**, wherein the transmit antenna is a first array of series fed coplanar loop elements and wherein the receive antenna is a second array of series fed coplanar loop elements.]

~~[25. A sensor as defined in claim 22, wherein the digital signal generator further comprises at least one of:~~

~~a direct digital synthesizer that is coupled with a phase locked loop;~~

~~a modulated signal digital generator and an up-converter; and~~

~~a direct digital to analog conversion generator that produces the modulate signal.]~~

26. An above-ground traffic sensor for detecting vehicles traveling on a roadway, comprising:

planar antennas mounted in a planar circuit board for propagating said a transmit signal toward said vehicles on said a roadway and for receiving said transmit signal reflected from said vehicles, wherein the planar antennas further comprises:

at least one coplanar loop series-fed array antenna on the planar circuit board, wherein each at least one coplanar loop series-fed array antenna is terminated by a short circuited transmission line.

27. The above-ground traffic sensor, as recited in claim **26**, wherein each coplanar loop series-fed array antenna includes a tapered array that includes a plurality of loops, wherein the plurality of loops are configured to generate a radiation pattern with low side lobes.

28. An above-ground traffic sensor for detecting vehicles traveling on a roadway, the traffic sensor comprising:

a radio frequency circuit board comprising:

a transmit portion that includes:

a digitally generated modulated signal generator that digitally generates and digitally modulates a signal that is transmitted by a transmitter towards vehicles traveling on a roadway;

a single receive portion that detects reflections of the signal from the vehicles traveling on the roadway and that generates, with a digital circuit that is integrated within the single receive portion, a data signal that represents traffic data from the reflected signal; and

wherein the traffic data is generated by the digital circuit that processes the reflections of the signal detected by the single receive portion to generate the traffic data about substantially all vehicles on the roadway on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway and wherein the traffic data is used in traffic control at a controlled signalized intersection.

29. The above-ground traffic sensor, as recited in claim 28, wherein said digitally generated modulated signal generator comprises:

a direct digital synthesizer for generating a low frequency waveform for said transmitter;

a phase lock loop coupled to said direct digital synthesizer for tracking said low frequency waveform; and

a voltage controlled oscillator coupled to said phase lock loop for generating a modulated transmit signal.

30. The above-ground traffic sensor, as recited in claim 28, wherein said digitally generated modulated signal generator comprises:

a direct digital to analog converter for directly generating a modulated signal at RF frequencies.

31. The above-ground traffic sensor, as recited in claim 28, wherein said radio frequency circuit board further comprises a planar antenna disposed thereon for transmitting said signal and for receiving the reflections of the signal.

32. The above-ground traffic sensor, as recited in claim 28, wherein the traffic data comprises a volume of vehicles on the roadway.

33. The above-ground traffic sensor, as recited in claim 32, wherein the volume of vehicles on the roadway is determined with respect to a fixed portion of the roadway.

34. The above-ground traffic sensor, as recited in claim 32, wherein the volume of vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

35. The above-ground traffic sensor, as recited in claim 32, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

36. The above-ground traffic sensor, as recited in claim 28, wherein the traffic data comprises an occupancy of vehicles on the roadway.

37. The above-ground traffic sensor, as recited in claim 36, wherein the occupancy of vehicles on the roadway is determined with respect to a fixed portion of the roadway.

38. The above-ground traffic sensor, as recited in claim 36, wherein the occupancy of vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

39. The above-ground traffic sensor, as recited in claim 36, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

40. The above-ground traffic sensor, as recited in claim 28, wherein the traffic data comprises a range and speed of substantially all vehicles on the roadway.

41. The above-ground traffic sensor, as recited in claim 40, wherein the range and speed of substantially all vehicles on the roadway is determined with respect to a fixed portion of the roadway.

42. The above-ground traffic sensor, as recited in claim 40, wherein the range and speed of substantially all vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

43. The above-ground traffic sensor, as recited in claim 40, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

44. The above-ground traffic sensor, as recited in claim 28, wherein the traffic data comprises a dynamic updating of the traffic data for substantially all vehicles on the roadway.

45. The above-ground traffic sensor, as recited in claim 44, wherein the dynamic updating of the traffic data for substantially all vehicles on the roadway is determined with respect to a fixed portion of the roadway.

46. The above-ground traffic sensor, as recited in claim 44, wherein the dynamic updating of the traffic data for substantially all vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

47. The above-ground traffic sensor, as recited in claim 44, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

48. The above-ground traffic sensor, as recited in claim 28, wherein the traffic data comprises a dynamic updating of a density of vehicles on the roadway.

49. The above-ground traffic sensor, as recited in claim 48, wherein the dynamic updating of a density of vehicles on the roadway is determined with respect to a fixed portion of the roadway.

50. The above-ground traffic sensor, as recited in claim 48, wherein the dynamic updating of a density of vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

51. The above-ground traffic sensor, as recited in claim 48, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

52. The above-ground traffic sensor, as recited in claim 28, wherein the traffic data comprises a direction of vehicle travel with respect to a fixed portion of the roadway.

53. The above-ground traffic sensor, as recited in claim 28, wherein the traffic sensor is mounted off-perpendicular with respect to the roadway.

54. The above-ground traffic sensor, as recited in claim 28, wherein said radio frequency circuit board comprises a printed circuit board.

55. An above-ground traffic sensor for monitoring vehicles on a roadway, the sensor comprising:

a transmit portion comprising:

a digital signal generator that digitally generates a modulated signal; and

a transmit antenna for transmitting the modulated signal towards vehicles on a roadway;

a receive portion comprising:

a receive antenna for receiving reflections of the modulated signal from the vehicles on the roadway, wherein the reflections of the modulated signal are processed to produce traffic data representing the vehicles on the roadway; and

wherein a digital circuit processes the reflections of the modulated signal to generate the traffic data such that the traffic data includes information separately identifying at least two vehicles that are traveling in adjacent lanes.

56. The above-ground traffic sensor, as recited in claim 55, wherein the traffic data comprises a volume of vehicles on the roadway.

57. The above-ground traffic sensor, as recited in claim 56, wherein the volume of vehicles on the roadway is determined with respect to a fixed portion of the roadway.

58. The above-ground traffic sensor, as recited in claim 56, wherein the volume of vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

59. The above-ground traffic sensor, as recited in claim 56, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

60. The above-ground traffic sensor, as recited in claim 55, wherein the traffic data comprises an occupancy of vehicles on the roadway.

61. The above-ground traffic sensor, as recited in claim 60, wherein the occupancy of vehicles on the roadway is determined with respect to a fixed portion of the roadway.

62. The above-ground traffic sensor, as recited in claim 60, wherein the occupancy of vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

63. The above-ground traffic sensor, as recited in claim 60, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

64. The above-ground traffic sensor, as recited in claim 55, wherein the traffic data comprises a range and speed of substantially all vehicles on the roadway.

65. The above-ground traffic sensor, as recited in claim 64, wherein the range and speed of substantially all vehicles on the roadway is determined with respect to a fixed portion of the roadway.

66. The above-ground traffic sensor, as recited in claim 64, wherein the range and speed of substantially all vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

67. The above-ground traffic sensor, as recited in claim 64, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

68. The above-ground traffic sensor, as recited in claim 55, wherein the traffic data comprises a dynamic updating of the traffic data of substantially all vehicles on the roadway.

69. The above-ground traffic sensor, as recited in claim 68, wherein the dynamic updating of the traffic data of substantially all vehicles on the roadway is determined with respect to a fixed portion of the roadway.

70. The above-ground traffic sensor, as recited in claim 68, wherein the dynamic updating of the traffic data of substantially all vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

71. The above-ground traffic sensor, as recited in claim 68, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

72. The above-ground traffic sensor, as recited in claim 55, wherein the traffic data comprises a dynamic updating of a density of vehicles on the roadway.

73. The above-ground traffic sensor, as recited in claim 72, wherein the dynamic updating of a density of vehicles on the roadway is determined with respect to a fixed portion of the roadway.

74. The above-ground traffic sensor, as recited in claim 72, wherein the dynamic updating of a density of vehicles on the roadway is determined on a lane-by-lane basis with respect to at least two different lanes on a fixed portion of the roadway.

75. The above-ground traffic sensor, as recited in claim 72, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the roadway.

76. The above-ground traffic sensor, as recited in claim 55, wherein the traffic data comprises a direction of vehicle travel with respect to a fixed portion of the roadway.

77. The above-ground traffic sensor, as recited in claim 55, wherein the traffic sensor is mounted off-perpendicular with respect to the roadway.

78. The above-ground traffic sensor, as recited in claim 55, wherein the transmit portion comprises a printed circuit board.

79. An above-ground traffic sensor for detecting vehicles traveling on a fixed portion of a roadway, the traffic sensor comprising:

a radio frequency circuit board comprising:

a transmit portion that includes:

a digitally generated modulated signal generator that digitally generates a signal that is transmitted by a transmitter towards vehicles traveling on the fixed portion of the roadway;

a receive portion that detects reflections of the signal from the vehicles traveling on the fixed portion of the roadway and a digital circuit that processes the reflected signals and generates a data signal that represents traffic data from the reflected signal,

wherein the traffic data represents information about vehicles on a lane-by-lane basis with respect to at least two different, dynamically-defined lanes on the fixed portion of the roadway.

80. The above-ground traffic sensor, as recited in claim 79, wherein the traffic data comprises one or more of a volume of vehicles on the fixed portion of the roadway, an occupancy of vehicles on the fixed portion of the roadway, or a range and speed of substantially all vehicles on the fixed portion of the roadway.

81. The above-ground traffic sensor, as recited in claim 80, wherein the traffic data is generated by the above-ground traffic sensor that is mounted to a fixed object adjacent to the fixed portion of the roadway.

82. The above-ground traffic sensor, as recited in claim 80, wherein the signal that is transmitted by the transmitter is transmitted at a known power level across multiple lanes of traffic on the fixed portion of the roadway and the signal is reflected at a reflected power level that is received by the receive portion.

* * * * *