United States Patent [19]

Mills

[11] **3,911,389**

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[54] **MAGNETIC GRADIENT VEHICLE DETECTOR**

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[73] Assignee: **The United States of America as represented by the Secretary of the Department of Transportation**, Washington, D.C.

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[21] Appl. No.: **453,332**

[52] **U.S. Cl.** .... **340/38 L**; 340/258 C

[51] **Int. Cl.**^{2} **G08G 1/00**

[58] **Field of Search** .... 340/38 L

[56] **References Cited**

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3,571,789	3/1971	Midlock	340/38 L

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Primary Examiner—Thomas B. Habecker
Attorney, Agent, or Firm—Herbert E. Farmer; Harold P. Deeley, Jr.

[57] **ABSTRACT**

A metallic object detection apparatus is disclosed. The detection apparatus comprises a transmitter which radiates electromagnetic energy to a receiving means which has a substantially zero voltage induced therein when a metallic object is not magnetically coupled to the transmitter and the receiving means. When a metallic object becomes magnetically coupled to the electromagnetic field radiating from the transmitter, eddy currents are induced in the metallic structure of the metallic object which in turn induce a non zero voltage within the receiving means. The transmitter is constructed from a non-distributed element which produces a dipole like electromagnetic field. The output signal produced by the receiving means is amplified and applied to either a phase responsive and/or amplitude responsive indicating means to signal when an object has caused the inducement of a non zero voltage in the receiving means.

11 Claims, 10 Drawing Figures

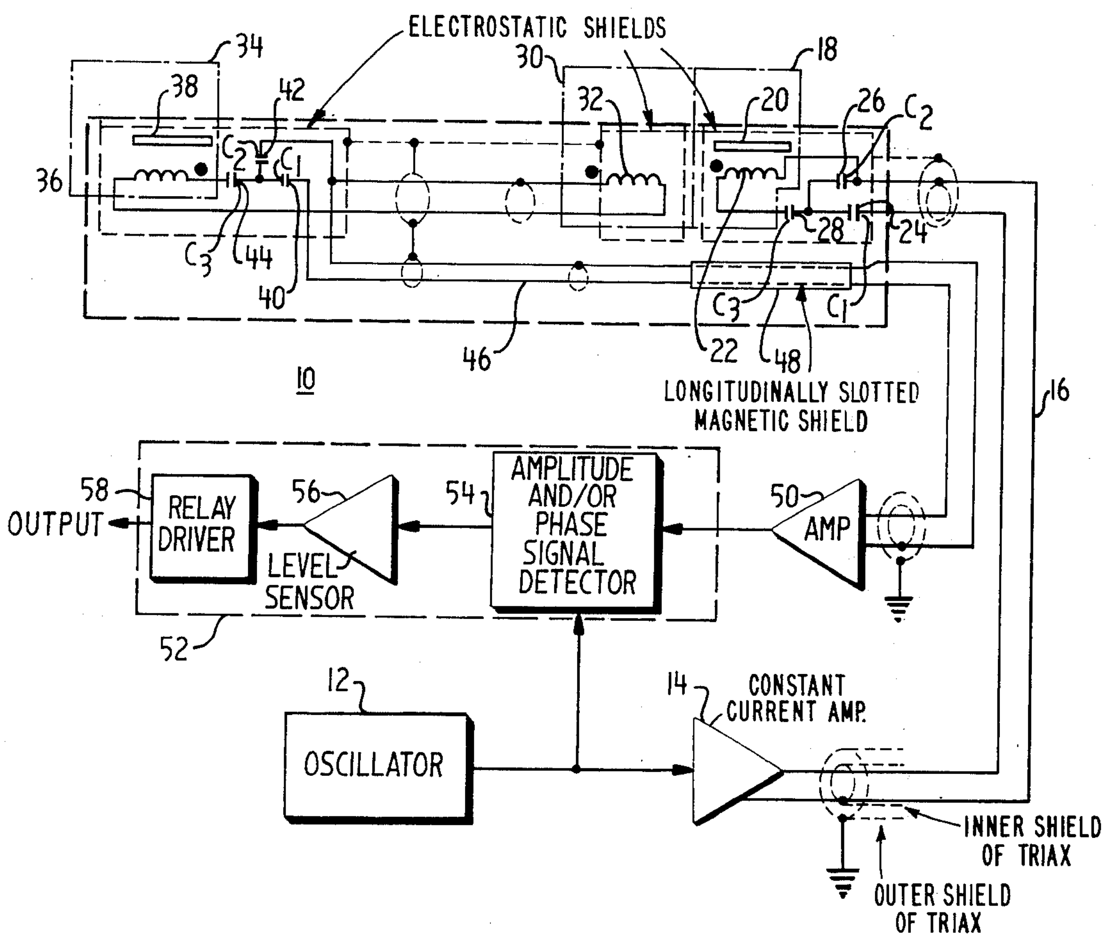
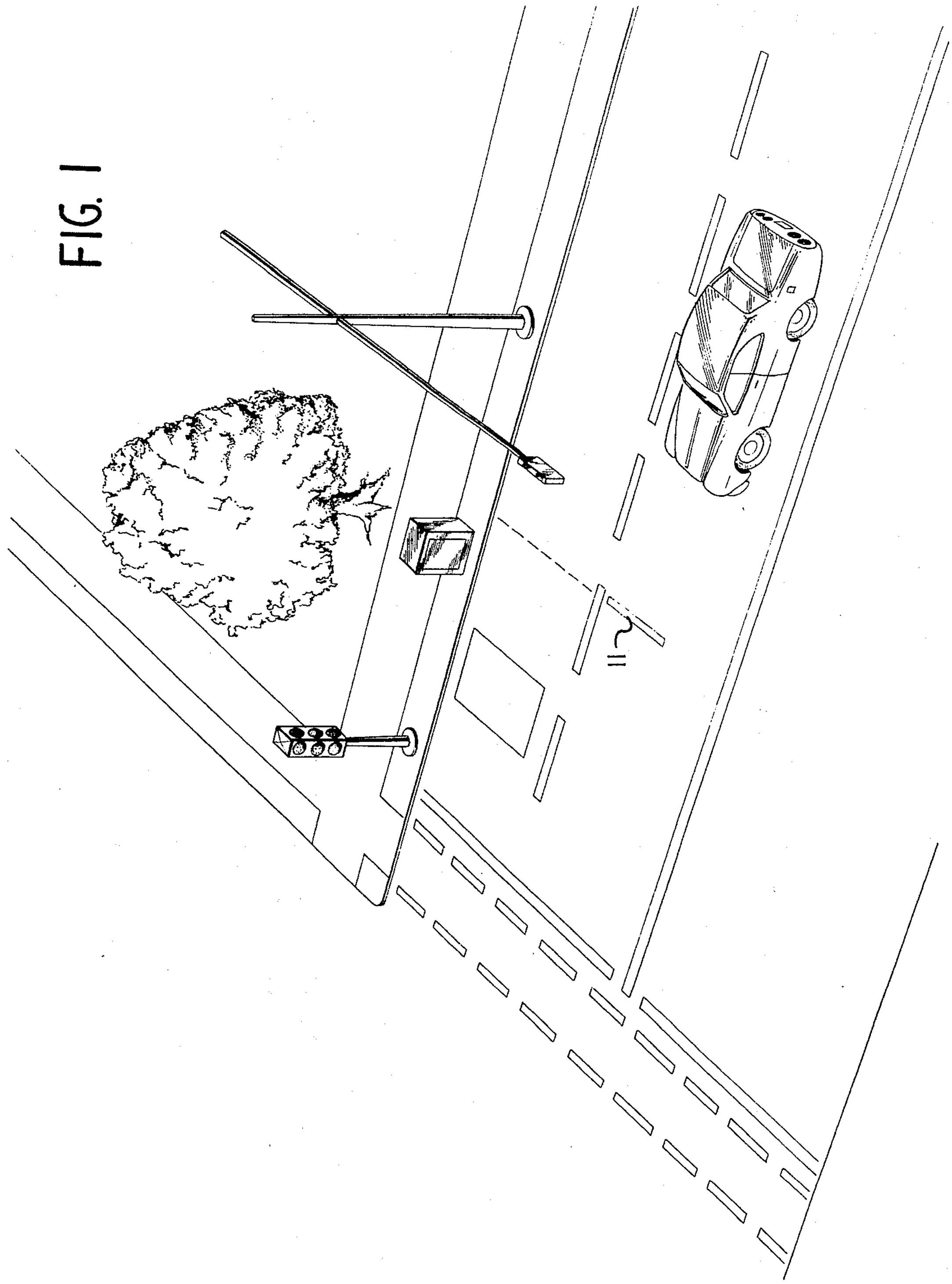


FIG. 1



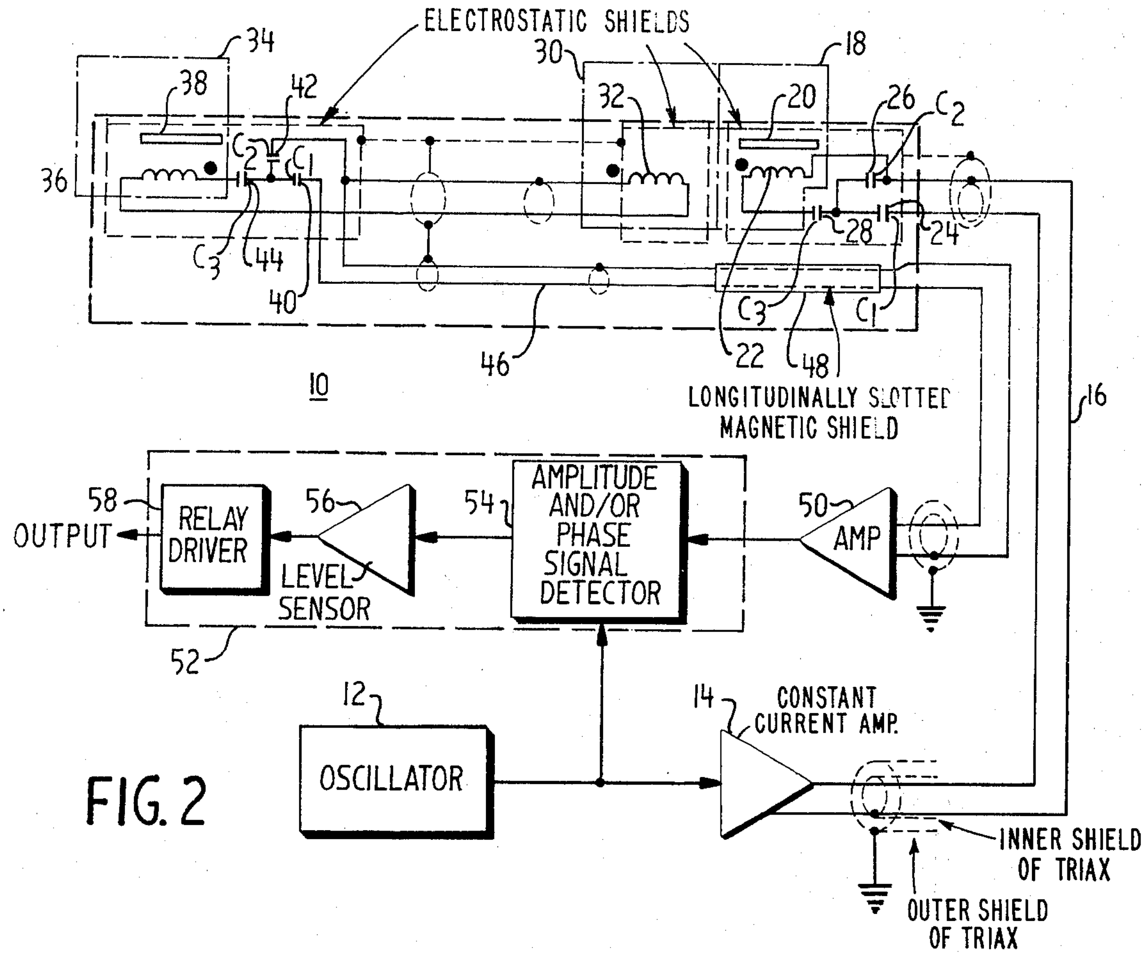

ELECTROSTATIC SHIELDS
34
38
42
C2
C1
36
C3
44
40
30
32
18
20
26
C2
28
24
C3
C1
22
48
46
10
LONGITUDINALLY SLOTTED
MAGNETIC SHIELD
16
58
OUTPUT
RELAY
DRIVER
56
LEVEL
SENSOR
54
AMPLITUDE
AND/OR
PHASE
SIGNAL
DETECTOR
50
AMP
52
12
OSCILLATOR
14
CONSTANT
CURRENT AMP.
INNER SHIELD
OF TRIAX
OUTER SHIELD
OF TRIAX

FIG. 2

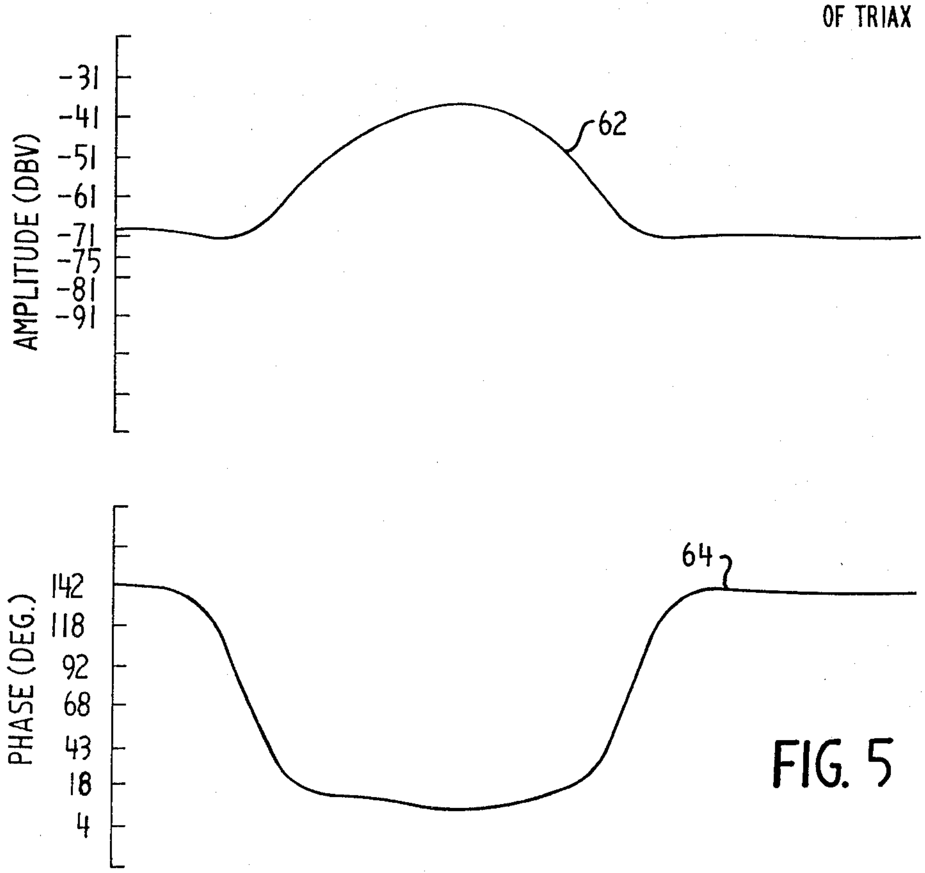

AMPLITUDE (DBV)
-31
-41
-51
-61
-71
-75
-81
-91
62
PHASE (DEG.)
142
118
92
68
43
18
4
64

FIG. 5

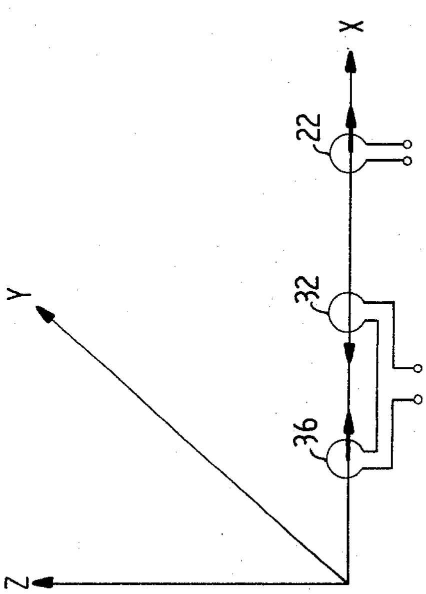


FIG. 3A

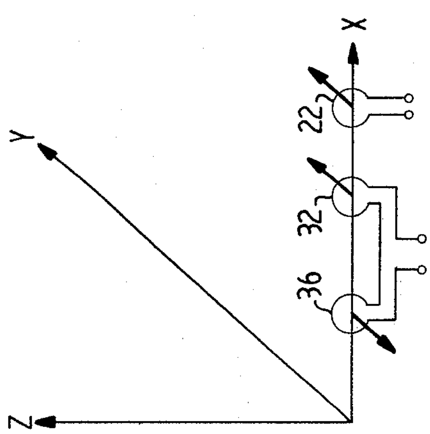


FIG. 3B

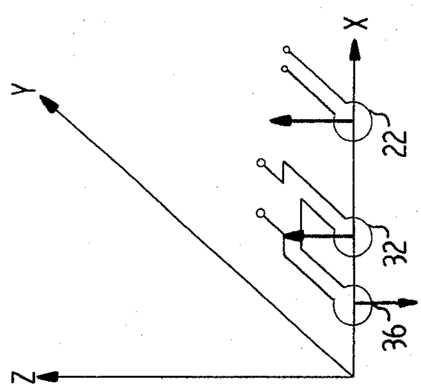


FIG. 3C

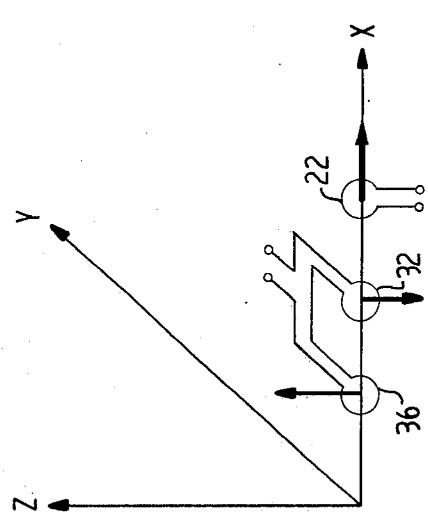


FIG. 3D

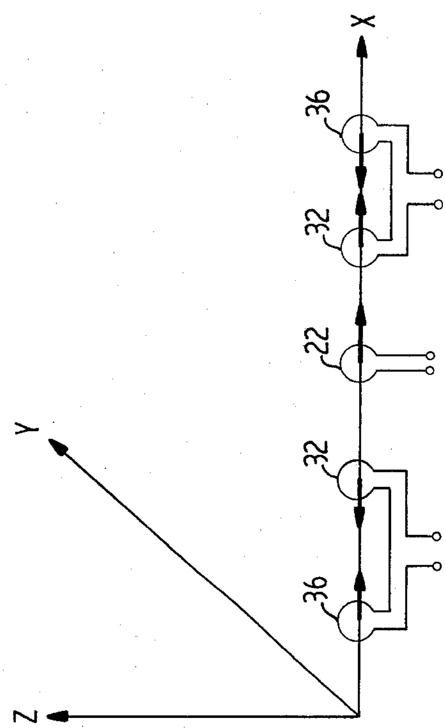
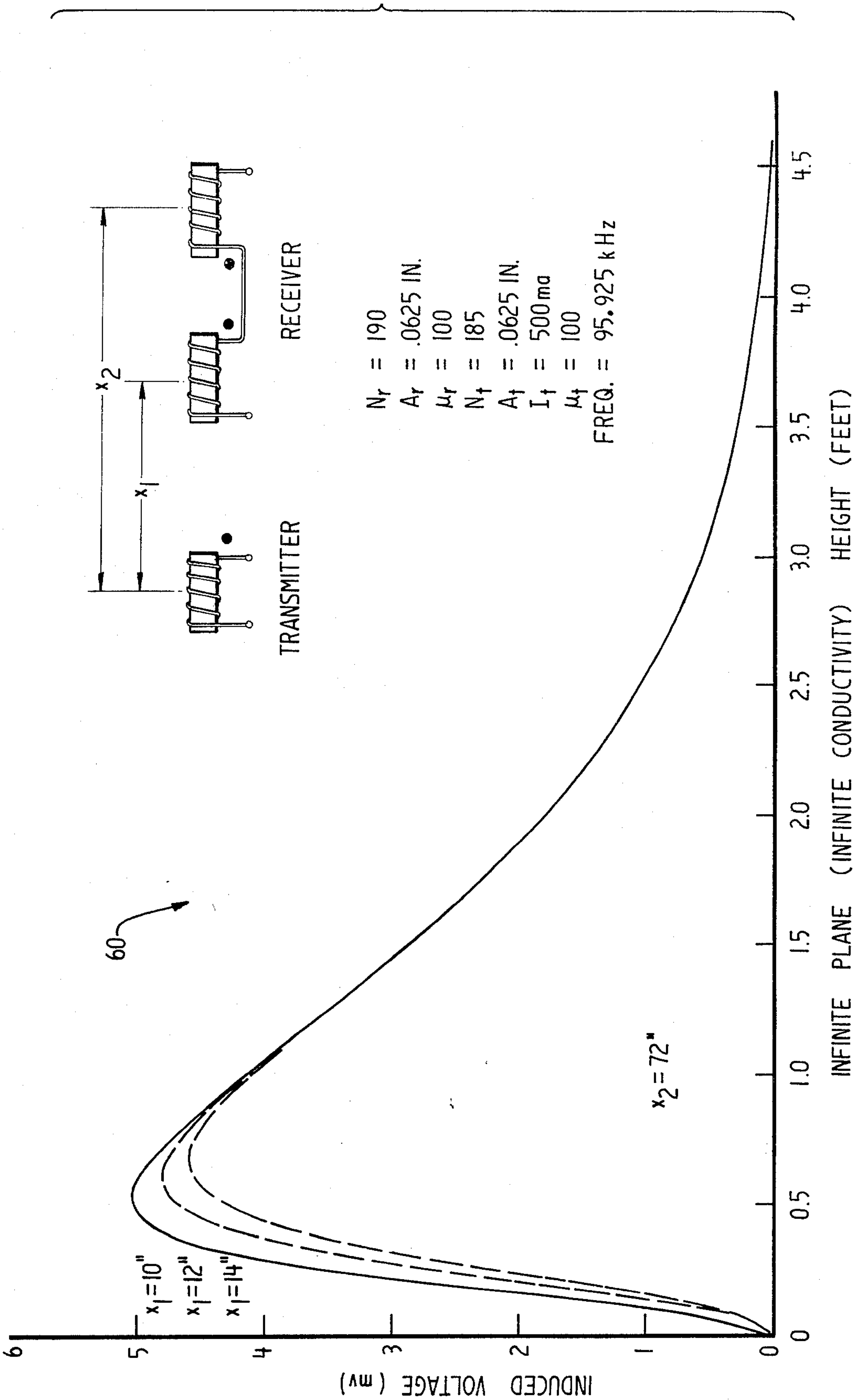


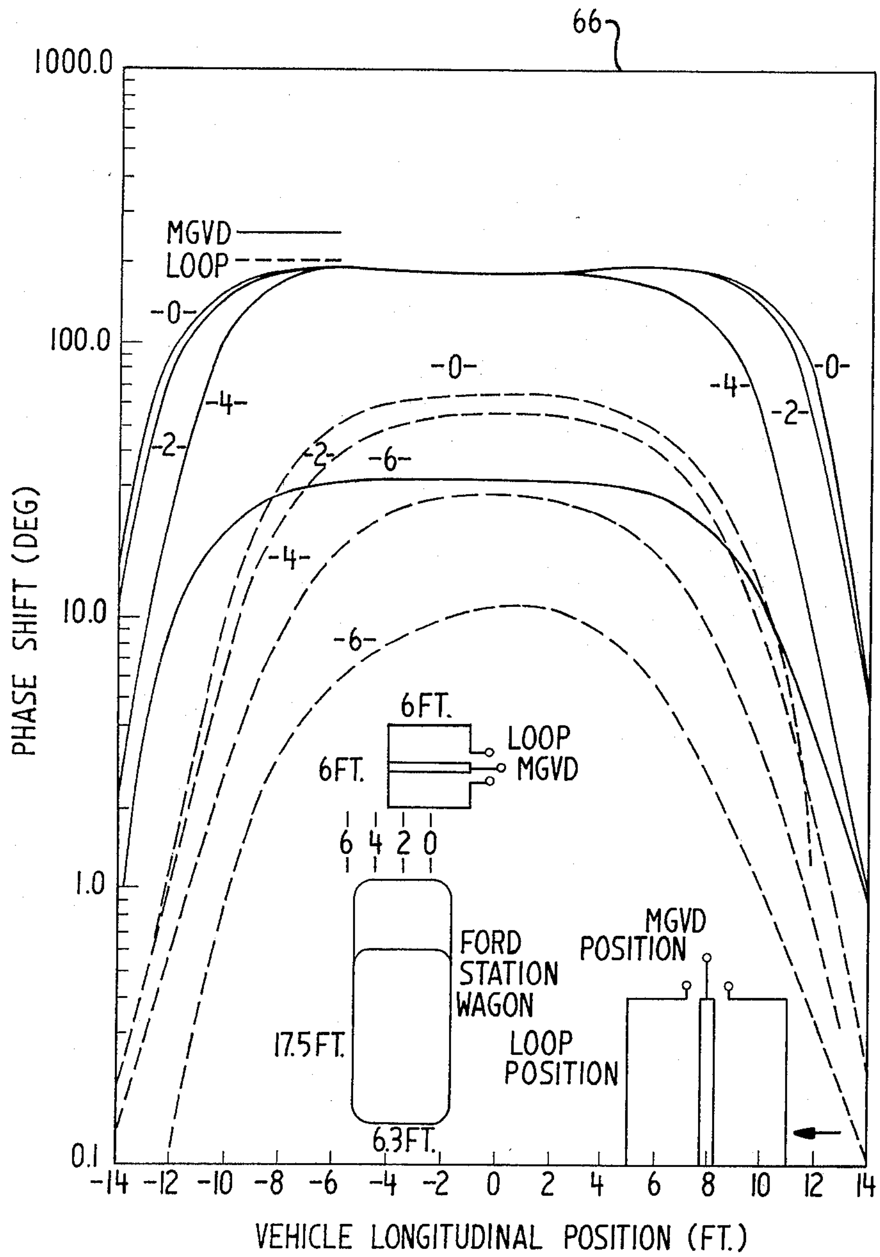
FIG. 3E



TRANSMITTER
RECEIVER
x_1
x_2
N_r = 190
A_r = .0625 IN.
μ_r = 100
N_t = 185
A_t = .0625 IN.
I_t = 500ma
μ_t = 100
FREQ. = 95.925 kHz
60
x_1=10"
x_1=12"
x_1=14"
x_2=72"
INDUCED VOLTAGE (mv)
0
1
2
3
4
5
6
INFINITE PLANE (INFINITE CONDUCTIVITY) HEIGHT (FEET)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

FIG. 4

FIG. 6


66
1000.0
100.0
10.0
1.0
0.1
PHASE SHIFT (DEG)
MGVD
LOOP
-0-
-2-
-4-
-6-
6FT.
6FT.
LOOP
MGVD
6 4 2 0
FORD STATION WAGON
17.5FT.
6.3FT.
MGVD POSITION
LOOP POSITION
-14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14
VEHICLE LONGITUDINAL POSITION (FT.)

MAGNETIC GRADIENT VEHICLE DETECTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

In its broadest sense, the invention relates to an apparatus for detecting metallic objects. In a more limited sense, the invention relates to a vehicle detection apparatus of the type which senses vehicles by detecting variations in the coupling of a magnetic field between a transmitter and a receiver caused by the induction of eddy currents within the metallic structure of the vehicle. While this apparatus has utility for detecting any metallic object, it has particular utility in the field of vehicle detection for purposes of traffic control, traffic identification and traffic classification.

2. Description of the Prior Art

One type of vehicle detection system is the inductive loop detector as disclosed in U.S. Pat. No. 3,493,954. This apparatus has a large wire loop which is embedded within pavement where it is desired to sense vehicle presence. The terminals of the inductive loop are coupled to one leg of an inductive bridge. Magnetic coupling of a vehicle to the wire loop causes a change in the inductance of the wire loop which imbalances the inductive bridge. This imbalance is detected as vehicle presence. Inductive loop detectors have a number of inherent major disadvantages. First, the installation costs are extremely high and will tend to increase with rising labor rates. Second, the signal to noise ratio of inductive loop detectors is not sufficient to allow loop detectors to be direct coupled to permit detection of stopped vehicles.

A second type of vehicle detector as disclosed in U.S. Pat. No. 3,052,869, utilizes a distributed element transmission line to radiate an electromagnetic field which is sensed by a first pair of coils disposed in close proximity to different sections of the distributed element transmission line. Unlike the instant invention, each of the receiving coils is coupled in series with a second coil and a rectification circuit. The distributed element transmission line is coupled in series with a third pair of coils, each of the third coils being magnetically coupled to a different one of the second coils. This construction has the major disadvantage of having the receiver coils nulled by combining a sample of the transmitted signal with the signal detected by each receiving coil. A slight change in the physical position of one of the receiving coils will imbalance the null since the transmitter reference voltage will not track the receiver coil voltage change. Additionally, each of the output signals from the receiving coil is detected separately for use in a speed detection system unlike the construction of the instant invention wherein a pair of receiving coils are connected in magnetic phase opposition to produce a non zero output signal when both of the receiving coils and the transmitting coil are magnetically coupled to a metallic object. The cost of installation of this apparatus is extremely high and probably would be even higher than the cost of installation of the inductive loop detector because of the larger physical size of the distributed element transmission line transmitter. A major disadvantage of the distributed element transmission line transmitter is that the conductors must be comprised of widely spaced wires similar to a long inductive loop to sense high bed vehicles (i.e., the near magnetic field of closely spaced transmission line conductors is tightly confined to the transmission line and induces negligible current in a conducting object two or more conductor spacings away). The non distributed element transmitter used in the instant invention is entirely different than the distributed element transmission line transmitter of the referenced patent. The difference in size between the two transmitters enables the much smaller transmitter of the instant invention to be installed at a much smaller installation cost.

A third type of vehicle detection system is disclosed in U.S. Pat. No. 2,144,535. The vehicle detection system disclosed therein consists of a pair of transmitter coils wound on diagonally opposite legs of a pair of elongated laminated open cores. A pair of receiver coils are wound on the remaining legs of the laminated cores. The cores are shaped with upturned ends to shorten the air gap between the ends to lower the reluctance of the magnetic circuits of each of the laminated cores. The coupling of a vehicle with the magnetic field emanating from the pair of diagonally opposed transmitter coils produces a change in the reluctance of the magnetic circuit coupling the transmitter coils to the receiver coils. This change in reluctance in the magnetic circuit coupling the transmitter and receiver windings causes the output voltage induced in the receiver coils to vary. Variation of the output voltage outside a pair of limits is detected as the presence of a vehicle. The mode of operation of the invention disclosed in the foregoing patent is fundamentally different from the instant invention. Namely, in the instant invention, eddy currents produced in the body of a vehicle are magnetically coupled to the transmitter and receiving coils to cause the induction of a non zero voltage in the magnetically phase opposed receiving coils. In the referenced patent, because of the low frequency of the current used for driving the transmitter coils, the detection of a vehicle is not based upon the induction of eddy currents within the metallic structure of the vehicle being detected. Detection of metallic objects by induction of eddy currents within the metallic structure of the object has a number of advantages over the detection of metallic objects by inducing a non zero voltage in a pair of receiver coils which function as the secondary windings of a transformer. First the physical size of the transformers required in the referenced patent is extremely large which would result in a high cost of installation in the road bed. Second, the output voltages induced in the secondary windings of the pair of transformers in the referenced patent are not in phase opposition to each other to produce a nulled output signal when a vehicle is not being detected. Third, a vehicle may induce a voltage within the secondary windings of the transformer which is between the two thresholds resulting in points of non detection.

SUMMARY OF THE INVENTION

The disadvantages and limitations of the prior art are solved by the instant invention which provides a simple and reliable means for detecting metallic objects such as vehicles. An alternating current generator is coupled to a transmitter to cause radiation of an electromagnetic field therefrom. A pair of series connected receiving coils, having their axes disposed in parallel and would in magnetic phase opposition to each other, are magnetically coupled to the transmitter. The magnetic field radiated by the transmitter induces eddy currents within the metallic structure of the object being detected. The resultant magnetic field produced by the eddy currents within the object induces unequal voltages in the receiving coils. This non zero voltage is detected by a phase responsive and/or amplitude responsive indicating means to signal the presence of a vehicle. The phase responsive system utilizes a phase detector to compare the phase of the voltage induced in the receiving coils with the phase of the signal coupled to the transmitter. The output of the phase detector is coupled to an integration circuit which sums the net output voltage from the phase detector. The output signal from the integration circuit is threshold detected to drive a relay circuit which is adapted to be coupled to a signaling device. The amplitude responsive circuit comprises a rectification circuit which rectifies the output signal of the receiving coils. The output signal from the rectification circuit is threshold detected to produce a control signal for driving a relay which is adapted to be connected to a signaling device. A longitudinally slotted magnetic shield is disposed around a section of triaxial transmission line which is located closest to the transmitter to cancel the induction of interference within the transmission line. Separate electrostatic shields may be provided around each of the receiver coils and the transmitter to prevent the displacement of charges within the pavement where the instant invention is buried to prevent the induction of interference within the receiving coils. Different sections of triaxial transmission line respectively couple the transmitter to the alternating current generator and the receiving coils to the indicating means. Appropriate impedance matching elements are respectively provided to match the characteristic impedance of the two triaxial transmission line sections with the input impedance of the transmitter and the output impedance of the series connected receiving coils. Any number of spatial orientations of the receiving coils may be used as long as a zero level output signal is produced when a vehicle is not present.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view of the environment of the preferred use of the instant invention;

FIG. 2 is an electrical schematic block diagram of the instant invention;

FIGS. 3*a*–3*e* are views of some of the possible transmitter and receiver coil orientations of the instant invention;

FIG. 4 is a graph of induced receiver coil voltage versus infinite plane height;

FIG. 5 is the measured amplitude/phase signature of the instant invention for a Volkswagon; and

FIG. 6 is an illustration of the measured vehicle phase signature of the instant invention versus that of an inductive loop detector.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows the preferred field of use of the instant invention. As may be seen from inspection of FIG. 1, the invention 11 is installed transverse to the direction of traffic flow in proximity to an intersection where it is desired to control the cycling of traffic lights or in other ways regulate the flow of traffic. While the preferred field of use for the invention is in the field of traffic control, it is to be clearly understood that the invention is no way limited to this particular field and may be used anywhere where it is desired to detect metallic objects. In its preferred field of use, the invention is buried just below the surface of the roadway in a closed box having nominal dimensions of 82 inches × 1.5 inches ×0.5 inches.

Referring to FIG. 2, 10 designates the electrical schematic block diagram of the invention. A crystal oscillator 12 having a preferred frequency of oscillation of 100 KHz has its output coupled to a constant current power amplifier 14 of conventional construction. The output of power amplifier 14 which is a conventional construction is coupled to transmitter 18 via a section of triaxial cable 16. It is to be emphasized that transmitter 18 comprises a "non-distributed element transmitter". In terms of the specification and the appended claims, non-distributed element transmitter defines a type of transmitter which physically is not used for the function of transferring electrical energy between different transmitter locations which have magnetic fields isolated from each other. The only function of the non-distributed element transmitter used in the invention is to radiate electromagnetic energy from a single location. The respective physical ends of transmitter 18 have magnetic fields which are coupled to each other. Because of the small physical size of the non-distributed element transmitter 18 (preferrably four inches in length), the electromagnetic energy radiates therefrom in a field pattern similar to that produced by a dipole. The non-distributed element transmitter is superior to a distributed element transmission line transmitter because of its small size and concomitant small installation cost. The transmitter 18 comprises a ferrite core 20 having a coil wound thereon. Capacitors 24, 26 and 28 are provided to match the characteristic impedance of triaxial transmission line 16 to the input impedance of transmitter 18. The outside sheath of triaxial transmission line 16 is grounded only at amplifier 14 to couple any charges flowing therein to ground. A pair of receivers 30 and 34 respectively having coils 32 and 36 serially connected and wound in magnetic phase opposition to each other are magnetically coupled to the field radiating from trasmitter 18. The coils 32 and 36 have their axes parallel to each other. Receiver 30 consists of a RF choke 32. Receiver 34 consists of coil 36 and associated ferrite core 38. Capacitors 40, 42 and 44 are used to match the output impedance of the serially connected coils 32 and 36 to the characteristic impedance of triaxial cable 46. Transmitter 18 and coils 32 and 36 are individually enclosed in electrostatic shields as shown in FIG. 2. Grounded conducting rings are provided at one or both ends of the electrostatic shields in a position located away from the coils and thus do not represent a shorted turn. A magnetic shield 48 is disposed around the section of triaxial transmission line 46 which comes closest to the transmitter 18 to prevent the induction of interference within triaxial cable 46. Magnetic shield 48 consists of a longitudinally slotted aluminum tube which has each section of the tube between the slots electrically isolated from other sections. This construction induces eddy currents within the aluminum sections to cancel coupling of any magnetic field with the sheaths of the triaxial cable 46. Triaxial transmission line 46 is coupled to receiver amplifier 50 which is of conventional construction. The outside sheath of the triaxial transmission line 46 is grounded only at amplifier 50. The output of receiver amplifier 50 is coupled to an indicating means 52 which may be either phase responsive and/or amplitude responsive depending upon the construction of the roadway in which the invention is employed. The phase responsive curcuit **54** comprises a phase comparator which has inputs derived from receiver amplifier **50** and crystal oscillator **12**. An integration circuit is included within the phase comparator to store the level of the signal produced by the comparator. The output of the integration circuit is applied to level sensor **56** which comprises a threshold detector. Threshold detector **56** produces an output signal of a first level when the amplitude of the charge stored in the integration circuit is below the threshold of the threshold detector and produces an output voltage of a second value when the level of the charge stored in the integration circuit is above the threshold of threshold detector **56**. The output of threshold detector **56** is applied to a relay driver **28** which may be used to control the activation of a suitable signaling means to signal the presence of a vehicle within the intersection. On the other hand if an amplitude responsive circuit is used, the output of receiver amplifier **50** is coupled to a rectification circuit also designated by number **54**. Rectification circuit **54** is not responsive to an input derived from crystal oscillator **12**. The resulting DC signal produced by rectification circuit **54** is applied to level sensor **56**. As in the case of the phase responsive circuit, level sensor **56** comprises a threshold detector. The output of the level sensor **56** is coupled to a suitable relay driver **58**. Threshold detector **56** and relay driver **58** are of the same construction as discussed in the description of the phase responsive circuit. The sections of triaxial cable **16** and **46** are respectively coupled to transmitter **18** and series connected receiver coils **32** and **36** via transformers (not shown). The longest section of conductor connecting receiver coils **32** and **36** has been connected to receiver coil **32** because of the small distributed capacitance of receiver coil **36**. This construction produces cancellation of the voltages induced therein when a vehicle is not magnetically coupled therewith. The receivers **30** and **34** are DC coupled to the signal indicating means **52** to provide the capability of detecting stopped vehicles. The use of sections **16** and **46** of triaxial transmission line is necessary in those environments where shielding is required to prevent the inducement of noise in the output signal from the receivers **30** and **34**. When the invention is used for traffic control, placement in pavement inherently subjects the output signal to the inducement of noise in response to change flow within the pavement, vehicle ignition noise, etc. If the invention was located above ground for metal detection, sections of transmission line **16** and **46** are unnecessary.

OPERATION

The 100 KHz signal produced by oscillator **12** is amplified by power amplifier **14**, and transmitted to transmitter **18** via triaxial transmission line **16**. Because receivers **30** and **34** have their coils **32** and **36** connected in series and wound in magnetic phase opposition to each other, the electromagnetic field, radiating from transmitter **18** induces equal and opposite polarity voltages in coils **32** and **36** when a metallic object is not magnetically coupled to the electromagnetic field emanating from transmitter **18**. When a metallic object is coupled to the electromagnetic field radiating from transmitter **18**, eddy currents induced therein magnetically couple with receiver coils **32** and **36** producing a non zero output voltage. The non zero output voltage is applied to indicating means **52** to signal the presence of a vehicle via triaxial transmission line **46**. The indicating means is either amplitude responsive and/or phase responsive as explained above.

FIG. 3 shows some of the possible coil orientations which may be used with the transmitter and receiver coils of the instant invention. The same numerals which were used in FIG. 2 to identify the transformer and receiver coils have been used in FIG. 3. It should be noted that different coil orientations may be used with different applications of the instant invention. The choice of the particular coil orientation must be empirically determined from the desired field of use. FIG. 3*e* shows that multiple receiver coils may be used with the instant invention. It should also be noted that multiple transmitting coils could be used with equal facility. In addition, the functions of the transmitter and receiving coils are reciprocal in that the receiving coils could be used to transmit or to receive depending upon the desired mode field of operation.

FIG. 4 is a graphical analysis of induced receiver coil voltage versus infinite plane height. The spacings between the transmitter and receiving coils are the relevant electrical parameter values are given in the top and right hand portions of the graph. Although it is not shown in the graph, vehicle heights above 4½ feet will produce an inverted mirror image in the voltage response. Given the physical heights of the various types of vehicles present in traffic today, the invention is designed to utilize only the positive half of the receiver response characteristic.

FIG. 5 is the magnetic gradient vehicle detector amplitude versus phase signature for a Volkswagon sedan using a transducer optimized for amplitude detection mode. Curve **62** represents amplitude response of the invention to the passage of a Volkswagon sedan. It has been found that the phase signature is superior for vehicle detection where structural steel is not prevalent in the road bed. The amplitude signature has been found to be superior for vehicle detection where there is a large amount of structural steel in the road bed. Accordingly, the choise of using either the amplitude responsive and/or phase responsive indicating means **52** must be determined from the construction of the road bed in which the invention is buried. It also should be understood that the transducer coil geometry can be changed to optimize the phase detection mode when the transducer is installed near structural steel.

FIG. 6 is a graph of the vehicle phase signature of the magnetic gradient vehicle detector optimized for the amplitude detection mode versus the inductive loop detector. Comparison of the curve of the respective systems shows that the instant invention has a much more uniformly shaped phase response curve as a function of lateral displacement of vehicle position than the response of the inductive loop detector. The slope of the phase signature of the instant invention as a function of vehicle lateral position is approximately equal to a constant whereas the slope of the inductive loop detector is not equal to a constant. The range of phase response of the instant invention is much greater than the corresponding phase response of the inductive loop detector. Unlike the variable slope of the inductive loop detector, the constant slope characteristic of the vehicle phase signature of the instant invention may be used to determine the speed of a vehicle independent of its lateral displacement with respect to its position.

It should be apparent from the foregoing description that the instant invention has many advantages not present in the prior art vehicle detection systems. Accordingly, it will be apparent to those skilled in the art that many modifications and changes may be made to the instant invention without departing from the spirit and scope of the invention. The many advantages and cost saving of a passive vehicle identification and/or classification method can also be appreciated where the signature of the vehicle is measured using the invention, stored and features thereof compared to real time measured signature information. It is to be understood that although the invention has been described with specific reference to a preferred field of use, it is not to be so limited since changes in alterations therein may be made which are within the full scope of this invention as defined by the appended claims.

I claim:

1. In an object detection system of the type which senses metallic structure of objects, the combination comprising:

an alternating current generator comprising oscillator means having a predetermined oscillation frequency and constant current amplifier means;

a non-distributed element transmitter radiating electromagnetic energy at the predetermined frequency, said transmitter being electrically coupled to said alternating current generator;

receiving means being electromagnetically coupled to said transmitter, said receiving means producing a substantially zero magnitude output signal when a metallic object is not magnetically coupled with said receiving means and said transmitter and producing a non-zero level output signal in response to eddy currents induced in a metallic object magnetically coupled with said receiver; and

indicating means responsive to the output signal produced by said receiving means for signalling when a non zero output signal is produced by said receiving means.

2. In an object detection system as recited in claim **1** wherein said receiving means comprises at least one pair of series connected receiving coils wound in magnetic phase opposition to each other to produce a zero magnitude output signal when a metallic object is not magnetically coupled with said transmitter and said coils and producing a non zero level output signal when eddy currents induced in the object are magnetically coupled with said transmitter and said coils.

3. In an object detection system as recited in claim **2** further comprising:

a triaxial transmission line electrically coupling said transmitter and said alternating generator;

a triaxial transmission line electrically coupling said receiving means with said indicating means and;

separate electrostatic shielding means enclosing said transmitter and said receiving means.

4. In an object detection system as recited in claim **3** further comprising:

a longitudinally slotted magnetic shield disposed around the section of said triaxial transmission line coupled between said receiving means and said indication means which is located closest to said transmitter to minimize the induction of interference in said triaxial transmission line.

5. In an objection detection system as recited in claim **2** wherein each coil of said at least one pair of receiving coils has its axis substantially parallel to the other coils within said at least one pair of receiving coils.

6. In an object detection system as recited in claim **2** wherein said indicating means comprises:

a phase detector having two inputs and an output, the first input of said phase detector being coupled to said receiving means, said second input being coupled to an output of said alternating current generator;

a threshold detection circuit having an input and an output, the input being coupled to the output of said phase detector, said threshold circuit producing an output signal of a first level when the level of the signal of said phase detector is below the threshold of said detection circuit and producing an output signal of a second level when the level of the signal of said phase detector is above the threshold of said detection circuit; and

a relay having an input and an output, said input being coupled to the output of said threshold detector, the output of said relay driver being adapted to be connected to a signalling device.

7. In an object detection system as recited in claim **2** wherein said indicating means comprises:

a threshold detection circuit having an input and an output, said input being coupled to the output of said receiving means, said threshold circuit producing an output signal of a first level when the level of the output signal produced by said receiving means is below the threshold of said detection circuit and producing an output signal of a second level when the level of the output signal produced by said receiving means is above the threshold of said detection circuit; and

a relay having an input and an output, said input being coupled to the output of said threshold detector, the output of said relay driver being adapted to be connected to a signalling device.

8. An object detection device as recited in claim **4** wherein said object detection device is buried in the pavement of a roadway, said object detection device having a longitudinal axis oriented transverse to the direction of traffic flow of the roadway.

9. In an object detection device as recited in claim **2** wherein each of said at least one pair of series connected receiving coils has a distributed capacitance, said coil of said at least one pair of coils which is disposed closest to said transmitter comprising an RF choke, said coil disposed farthest from said transmitter having a ferrite core, said series connection of receiving coils having a pair of terminals with said terminals located closest to said receiving coil disposed farthest from said transmitter, and said transmitter comprising a coil and an associated ferrite core.

10. In an object detection system as recited in claim **3** further comprising:

impedance matching means coupled between said transmitter and output terminals of said triaxial cable at said transmitter; and

impedance matching means coupled between output terminals of said receiving means and terminals of said triaxial transmission line at said receiving means.

11. An object detection system as recited in claim **1** wherein said electromagnetic energy is radiated from said transmitter in a dipole like spatial field pattern.

* * * * *