Jan. 14, 1975 H. STARAS ET AL Re. 28,302
HARMONIC RADAR DETECTING AND RANGING SYSTEM
FOR AUTOMOTIVE VEHICLES
Original Filed June 30, 1972 4 Sheets-Sheet 1

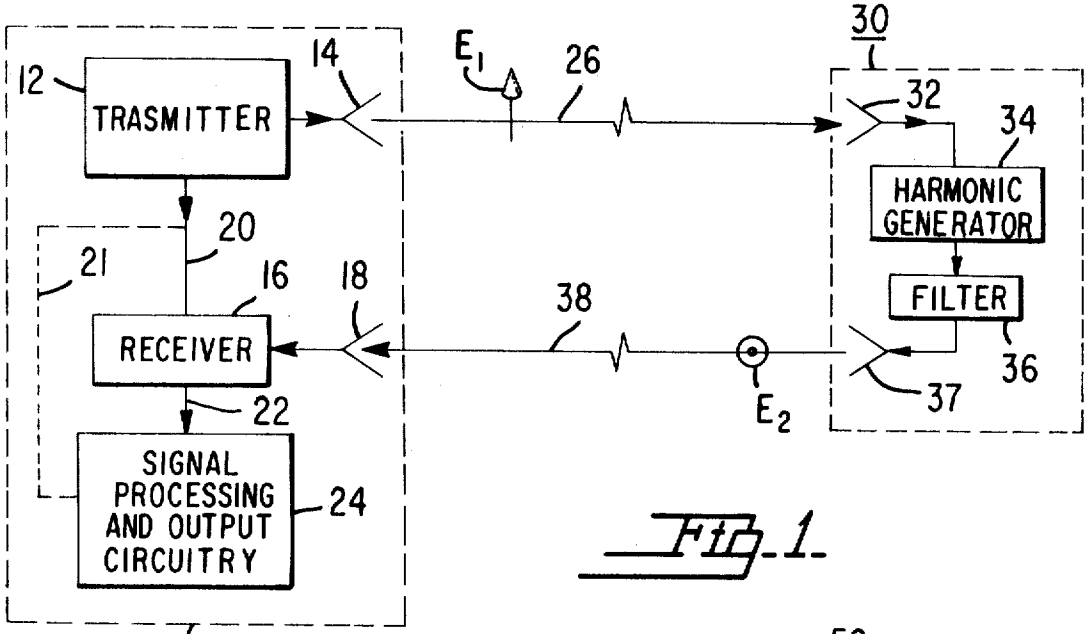


Fig. 1

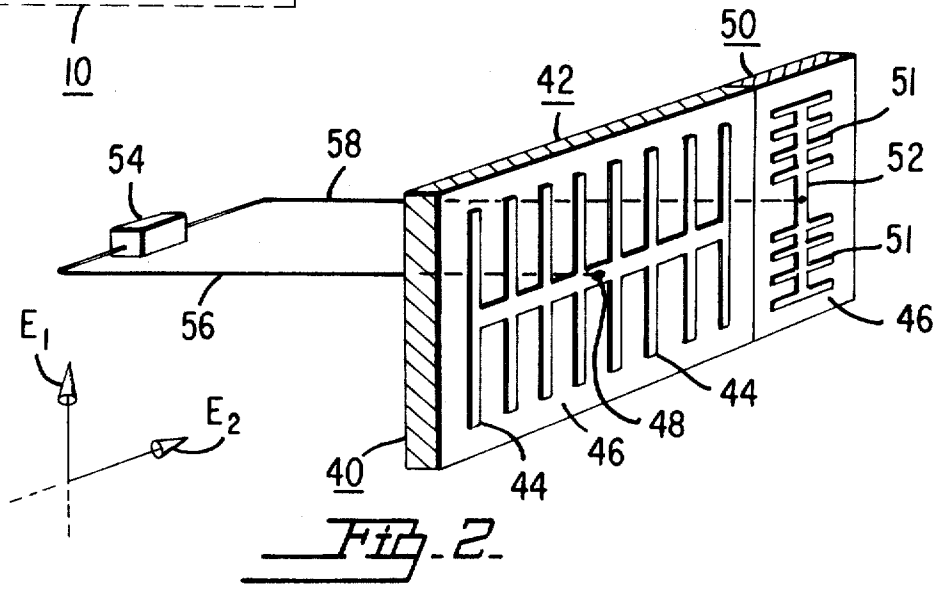


Fig. 2

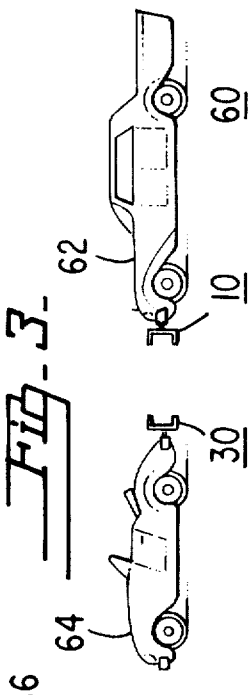

60
62
10
30
64
66
30

Fig. 3.

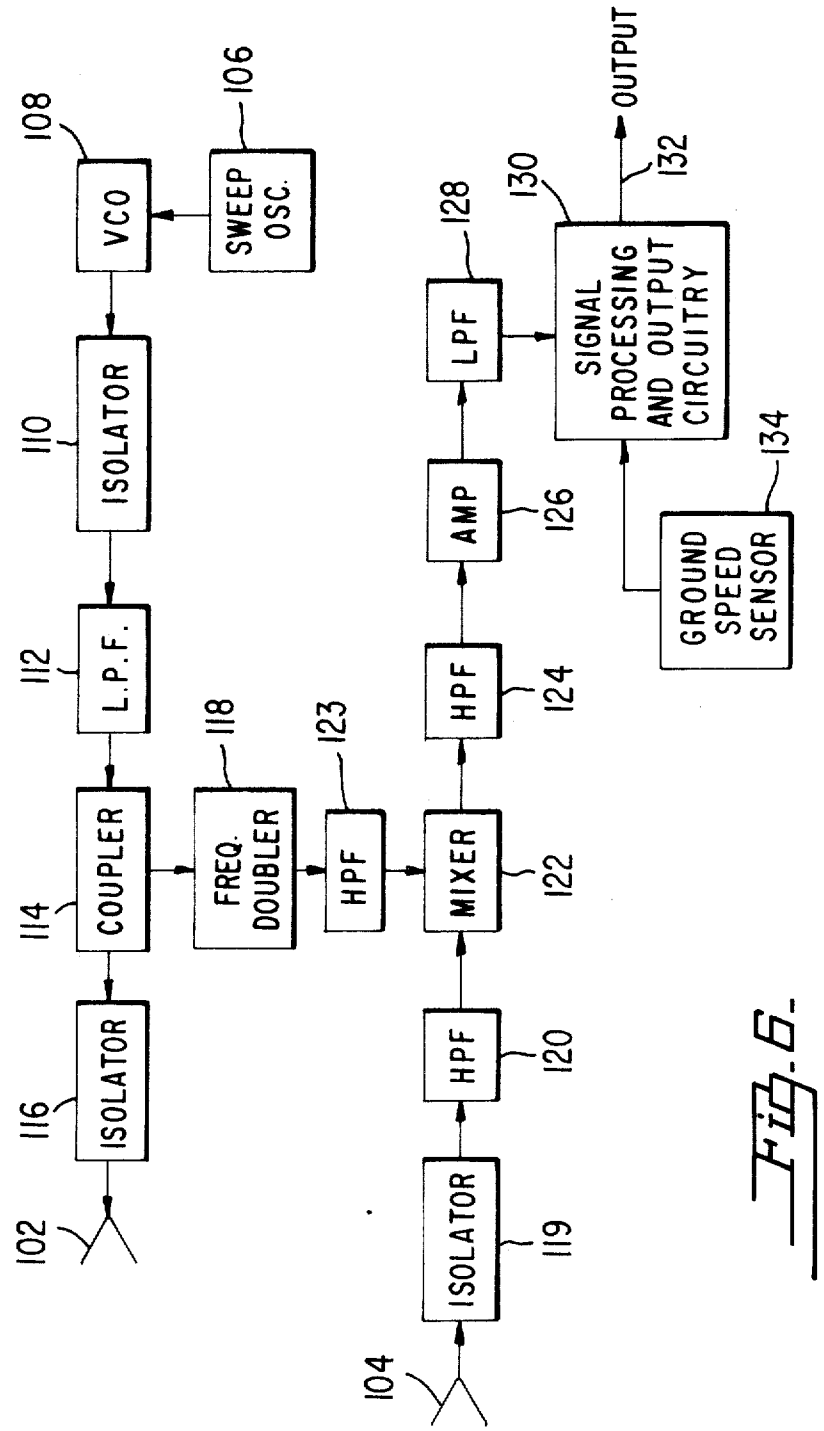

106
SWEEP OSC.
108
VCO
110
ISOLATOR
112
L.P.F.
114
COUPLER
116
ISOLATOR
102
118
FREQ. DOUBLER
123
HPF
122
MIXER
120
HPF
119
ISOLATOR
104
124
HPF
126
AMP
128
LPF
130
SIGNAL PROCESSING AND OUTPUT CIRCUITRY
OUTPUT
132
134
GROUND SPEED SENSOR

Fig. 6.

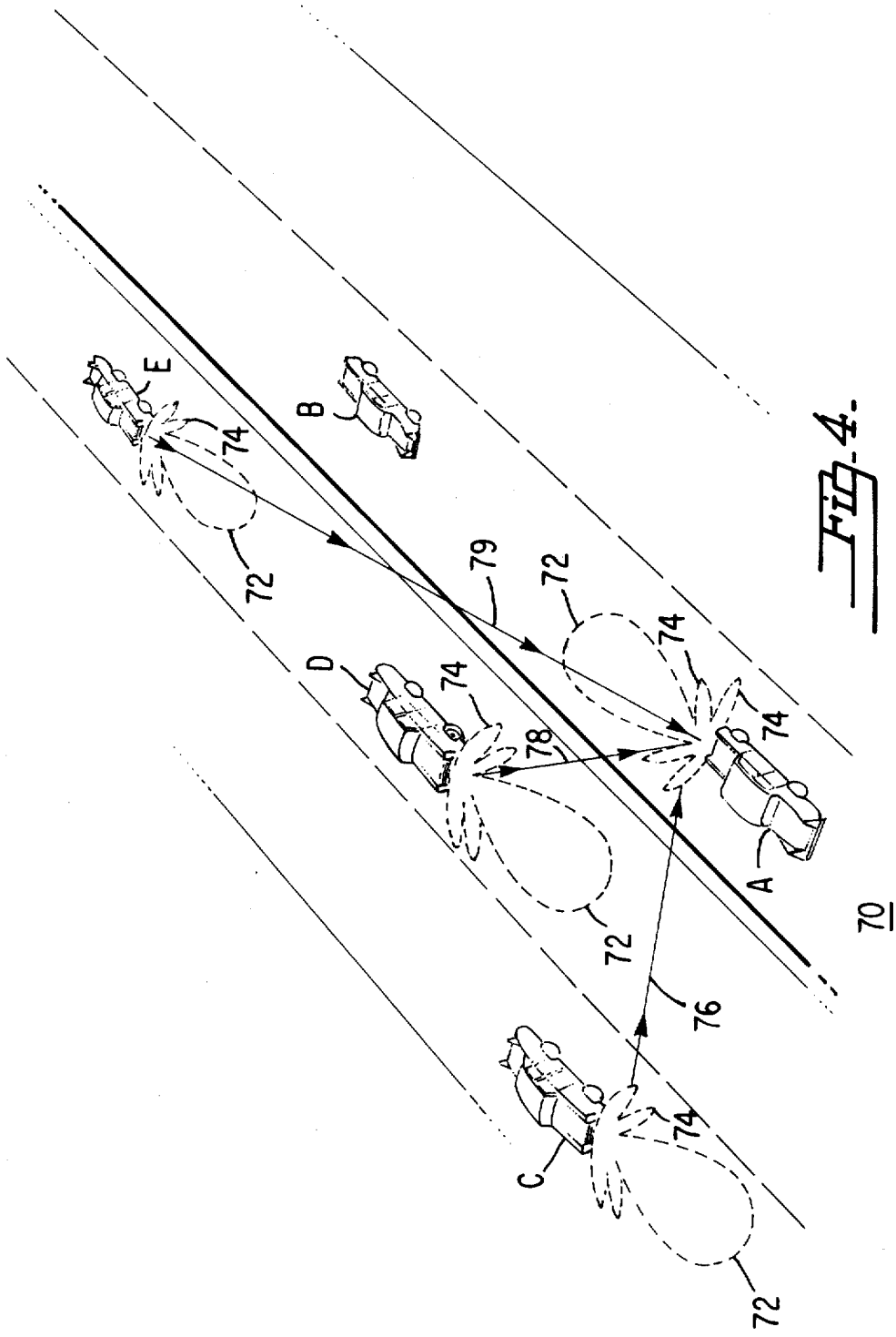


Fig. 4.

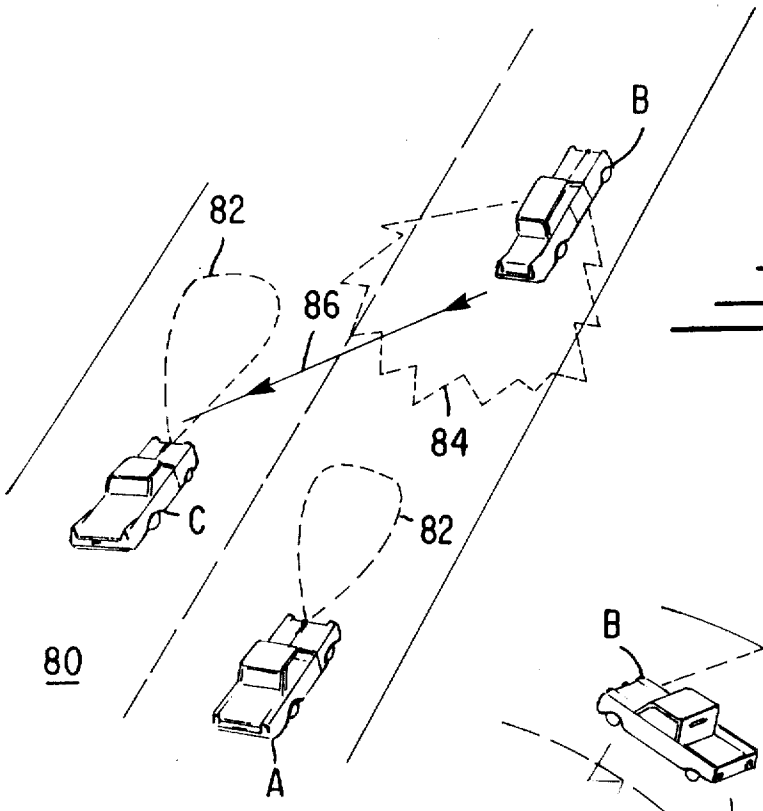


Fig. 5a

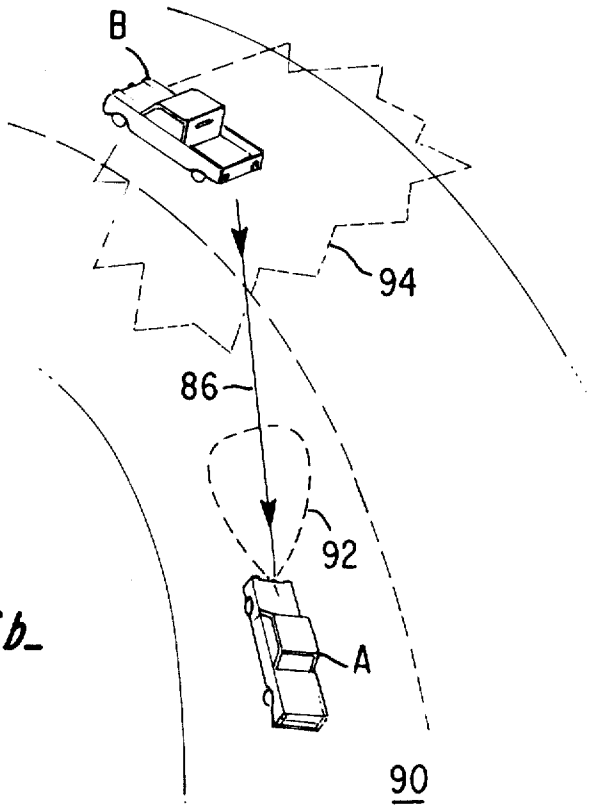


Fig. 5b

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HARMONIC RADAR DETECTION AND RANGING SYSTEM FOR AUTOMOTIVE VEHICLES

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Int. Cl. G01s 9/02

U.S. Cl. 343—5 R 11 Claims

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.

ABSTRACT OF THE DISCLOSURE

In a vehicular harmonic radar detecting and ranging system, a transmitter transmits a highly directional and polarized beam of electromagnetic energy, preferably in the microwave spectrum, toward a passive target. The passive target reradiates a beam of energy, which is harmonically related to and polarized orthogonal to the transmitted beam, directionally back toward the transmitter. A receiver by being selectively responsive *to* [the] the harmonically related and orthogonally polarized reradiated beam, is immune to blinding which would otherwise be caused by the transmitted signals of other radar equipped vehicles and to the clutter caused by extraneous targets.

BACKGROUND OF THE INVENTION

In conventional radar detecting and ranging systems, the received signal which is reflected by the target exhibits essentially the same frequency as the transmitted signal. In short range detecting and ranging systems, such as automotive collision avoidance systems, this presents a severe problem since any one of a number of possible targets may provide an undesired return signal. For example, automotive radar systems have been proposed which transmit a signal in the electromagnetic frequency spectrum region and detect the return signal at the same fundamental frequency. Since these systems must respond equally well to large and small objects, the transmitter power is typically raised to accommodate the smallest possible target. However, since the radar cross section of a relatively small passenger car and a large truck differ by several orders of magnitude, the radar return from the large vehicle can mask the presence of a small vehicle. Additionally, these proposed systems exhibit two fundamental and critical disadvantages. The first being the presence of "clutter returns" from extraneous targets which may be unobtrusive, fixed objects along a roadway or moving vehicles in non-critical operating relationship to the protected vehicle. The second disadvantage is the "blinding" caused by other radar equipped vehicles operating in proximity to the protected vehicle. This blinding problem is most severe in crowded highway environments where the protection otherwise afforded by collision avoidance radar is most beneficial.

Another problem inherent to these conventional radar detecting and ranging systems occurs when there are two or more targets of equal size (or equal radar cross section) and equal speed. This situation gives rise to a fading condition and under a special condition the radar becomes inoperative. When many targets with various speeds and sizes appear in a radar beam, the detected signal will fluctuate and the output will represent either the speed of one of the targets or the average speed of all of them or a false signal not related to any desired parameter. This problem is generally discussed in Ishii, "Analysis of Target Speed Determination With Doppler Radar," IEEE Transactions on Instrumentation and Measurement, Vol. IM-19, No. 2 (May 1970), p. 86.

Systems have also been suggested which detect a reflected second harmonic of the transmitted fundamental signal rather than the reflected fundamental signal. These suggested systems also provide for the use of passive nonlinear elements which are, in turn, deployed as targets, in order to enhance the reflected harmonic signal. However, the blinding problem discussed above with reference to conventional radar systems still remains a problem since the transmitter of other similarly equipped protected vehicles includes sufficient harmonic signal content to create interference, particularly when a plurality of vehicles are operating in close proximity to one another. Additionally, the non-linear front-end characteristics of the harmonic receivers used in these prior art systems may produce enough extraneous second harmonic signal, when illuminated by an undesired fundamental signal, to create false output indications.

The present invention overcomes the disadvantages and problems present in the prior art by providing a harmonic radar detecting and ranging system for automotive vehicles which is relatively immune to blinding and clutter.

SUMMARY OF THE INVENTION

Briefly, the present invention provides a detecting and ranging system for use with an automotive vehicle comprising: a transmitter; a receiver; and output means, and a directional antenna network coupled to the transmitter and the receiver. The transmitter includes means for generating electromagnetic energy signals of a predetermined frequency. The receiver includes means adapted to detect electromagnetic energy signals which are derived from and are harmonically related to the signals of the predetermined frequency. The output means is coupled to the receiver and cooperates with the receiver to produce an output signal in response to the detected signals. The antenna network includes means for selectively transmitting the signals of the predetermined frequency into a given transmission direction while polarizing the transmitted signals into a given polarization direction. The antenna network further [include] *includes* means which are selectively responsive only to electromagnetic signals originating from the given transmission direction, which signals have been derived from and are harmonically related to the transmitted signals, and which have a polarization direction substantially orthogonal to the given polarization direction, for applying the selectively derived signals to the receiver.

BRIEF DESCRIPTION OF THE DRAWING

Many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description when taken in conjunction with the accompanying drawing wherein:

FIG. 1 is a schematic representation showing the detecting and ranging system of the present invention together with a representation of the transmitted and reflected electromagnetic energy relative to a target adapted for use with the system;

FIG. 2 is a perspective view of a preferred antenna structure adapted for use with the system of FIG. 1;

FIG. 3 is a pictorial elevation view of a protected automobile utilizing the system of the present invention in a highway environment which includes an example of two preceding vehicles in succession;

FIG. 4 is an illustrative scene view of a four-lane highway including representative examples of vehicles using conventional prior art automotive radar systems;

FIG. 5A is another scene view of conventional prior art

radar equipped automotive vehicles in a single-direction, two-lane environment;

FIG. 5B is another scene view of conventional prior art radar equipped vehicles in a single-direction, two-lane highway environment along a curved portion thereof; and

FIG. 6 is a schematic representation showing a preferred configuration of the radar detecting and ranging system of the present invention.

DETAILED DESCRIPTION

Referring now to the drawing there is shown in FIG. 1 a radar detecting and ranging system **10** having a transmitter **12** coupled to a directional transmitting antenna **14**. System **10** includes a receiver **16** coupled to a directional receiving antenna **18**. Transmitter **12** includes an output **20** which is coupled to receiver **16** for mixing a portion of electromagnetic energy generated by transmitter **12** with the electromagnetic energy received by receiver **16**. Receiver **16** includes an output **22** which is coupled to signal processing and output circuitry **24**.

Antenna **14** is arranged to direct a polarized beam **26** of electromagnetic energy in a given direction. Antenna **18** is arranged to receive a polarized beam **38** of electromagnetic energy from the given direction. A suitable target **30** for radar system **10** is also shown in FIG. 1. Target **30** preferably includes a directional receiving antenna **32** which is arranged to receive polarized beam **26**. The output of antenna **32** is coupled to a harmonic generator **34**. Harmonic generator **34** may comprise a passive non-linear element such as, for example, a zero-bias silicon Schottky barrier diode. Accordingly, the output signal of harmonic generator **34** includes components of the fundamental frequency of beam **26** as well as harmonic components of the fundamental frequency signal. The output of harmonic generator **34** is coupled to a suitable filter **36** which substantially filters all but the desired harmonic component. The desired harmonic component is coupled at the output of filter **36** to a directional antenna **37**. Antenna **37** is arranged to transmit polarized beam **38** back toward radar system **10**. Thus, it can be seen that target **30** comprises a [retrodirective type] passive reflector which is adapted to reflect harmonic electromagnetic energy, in response to being illuminated by the corresponding fundamental frequency electromagnetic energy. [, back toward the source of the fundamental frequency energy.] The polarization of transmitted beam **26** is depicted by arrow E_1 which corresponds to the electric-field vector of beam **26**. It can be seen that the direction of E_1 lies in the plane of the drawing. Similarly, the polarization of reflected beam **38** is depicted by arrow E_2 which corresponds to the direction of the electric field of beam **38**. It can be seen that the direction of E_2 lies in the direction perpendicular to the plane of the drawing. The signal processing and output circuitry **24** of FIG. 1 may include a suitable logic and processing means to compute the desired parameters such as, range and/or range rate between the instantaneous location of system **10** and target **30**. In an automotive application, system **10** would be mounted on the forward portion of a protected vehicle and target **30** would be mounted on the rearward portion of the participating preceding vehicles. The respective antennas of system **10** and target **30** may comprise a unitary structure adapted to facilitate mounting on both the protected as well as the participating vehicles.

As shown in FIG. 2, the respective antenna structures may comprise a flat printed-circuit antenna **40**. A first portion **42** of antenna **40** may include a plurality of resonant dipole elements **44** formed on the surface of a low-loss dielectric circuit board **46**. The dipoles may be coupled to and fed by feedline **48** which also provides a coupling point to this portion of antenna **40**. It can be seen that dipole elements **44** are arranged to provide vertical electric-field polarization E_1. A second portion **50** of antenna structure **40** may also include an array of resonant dipole elements **51** formed on the same circuit board **46**. Dipoles **51** are fed by feedline **52** which also provides a coupling point to this portion of antenna structure **40**. It can be seen that dipoles **51** are arranged to provide a horizontal electric-field polarization E_2. First portion **42** is coupled to an external circuit **54** by way of transmission line **56**. Second portion **50** is coupled to external circuit **54** by way of transmission line **58**. Since antenna structure **40** can be utilized as the antenna means for system **10** or target **30** of FIG. 1, external circuit **54** may comprise the remaining components of either system **10** or target **30**. It has been found to be practical to operate the system **10** including transmitter **12** in the microwave region such as, for example, at X-band. Accordingly, the receiver **16** is adapted to receive a harmonic of the transmitted frequency such as, for example, the second harmonic which would be found in the Ku-band corresponding to the above-mentioned X-band. The microwave region is preferred for three primary reasons: (i) spectrum availability at these frequencies; (ii) relative freedom from electromagnetic interference (EMI) at these frequencies; and (iii) the realizable antenna gains consistent with small overall antenna size. Flat printed-circuit antennas of the type described in FIG. 2 are described and shown in greater detail in U.S. Pat. No. 3,587,110.

It should now be apparent that a flat printed-circuit antenna such as antenna **40** shown in FIG. 2 can provide a relatively high gain radiating surface embodied in a unitary structure which facilitates mounting in an automotive environment. For example, at the X-band and Ku-band frequencies mentioned above, a flat antenna exhibiting gain on the order of 25 db in both the transmit and receive directions was constructed. The overall size of the unitary structure was approximately 8 in. x 16 in. The thickness was substantially less than one inch.

Further, the isolation provided by the cross-polarization between the respective transmitting and receiving portions was on the order of 25 db. It can be seen that the profile of this unitary antenna structure is similar to that of an ordinary automotive license plate and its overall size is consistent with typical license plate mounting wells. Further, the depth or thickness of this unitary structure avoids the mounting problems commensurate with high gain microwave horn antennas as found in the prior art.

To provide, for example, a maximum effective operating range of 100 yards (300 feet) it has been found desirable that the directivity of the entire antenna system provide a resultant beamwidth on the order of three degrees. Since the average single-lane width of a typical roadway is on the order of 12 to 14 feet, the three degree beamwidth confines the operation of the radar system **10** to a single-lane operation when the maximum operating range is established at 100 yards. In this manner interference from adjacent lanes is avoided. As will be described hereinafter, the dynamic operating characteristics of system **10** can be readily controlled to further confine the operation of system **10** within the above-described parameters.

Referring now to the operation of the system in accordance with the present invention as shown in FIG. **1**, it will be assumed that a unitary structure antenna, such as antenna **40** of FIG. 2, is utilized in both system **10** and target **30**. The output of transmitter **12** is coupled to the vertically polarized portion of the unitary antenna depicted as antenna **14** in FIG. 1. Accordingly, a vertically polarized beam **26** is transmitted to antenna **32** of target **30** which in turn corresponds to the vertically polarized portion of the unitary antenna of target **30**. The output of filter **36**, representing the desired harmonic of polarized beam **26**, is coupled to antenna **37** which in turn represents the horizontally polarized portion of the unitary antenna of target **30**. Accordingly, a horizontally polarized beam **38** is reradiated back toward antenna **18** of system **10**, the antenna **18**, in turn, representing the horizontally polarized portion of the unitary antenna of system **10**. The output

of antenna **18** is applied to receiver **16** wherein it is mixed with an appropriate harmonic of a sampled portion of the output signal from transmitter **12** as provided by output **20**.

Alternatively, the sampled portion of the output signal from transmitter **12** may be directly mixed with the received harmonic signal wherein the output of receiver **16** is an intermediate frequency signal of a frequency equal to the difference between the received harmonic and the transmitted fundamental. In this case the resulting intermediate frequency can be further detected or processed by output circuitry **24** in conjunction with a second input signal coupled to circuitry **24** which is shown as dotted lead [**21'**] *21* in FIG. 1.

In the preferred system configuration, which is discussed in greater detail hereinafter with reference to FIG. 6, the transmitted signal is frequency-modulated and the instantaneous frequency difference between the received signal and the second harmonic of the transmitted signal is detected to provide distance or range information. That is, the instantaneous frequency of the received signal will differ from the second harmonic of the instantaneous frequency signal being generated at transmitter **12** in accordance with the time delay of the received signal. This configuration has the advantage that the distance to the target is continuously detected regardless of the relative speed between system **10** and target **30**. Whereas, a system which solely detects Doppler shift or velocity information stops detecting when the relative velocity between the radar system and the target is zero.

It should now be apparent that an automotive vehicle when equipped with a system in accordance with the present information responds only to a reflected harmonic signal having a given polarization direction. Further, the transmitted output signal from other similarly equipped vehicles will not be detected by the harmonic receiver of the protected vehicle since the transmitted signal of all other protected vehicles is at the fundamental frequency and exhibits on orthogonal polarization. Thus, the blinding problem that would otherwise occur if the radar system were adapted to detect randomly polarized, reflected or return signals at the same frequency as the transmitted signal, is substantially eliminated. Additionally, virtually nothing in nature will provide a reflected second harmonic signal of sufficient level and proper polarization to be detected by the radar system receiver; except, of course, a properly designed [retrodirective] harmonic reflector.

The system in accordance with the present invention may be used in automotive applications to provide minimum safe following distance or headway control. It has been suggested that safe operation headway between operating vehicles requires one car-length of separation for each ten mile-per-hour increment of vehicle speed. A more sophisticated formula for headway control would include variables such as separation between vehicles, vehicle velocity and vehicle closing rate between the protected and participating vehicle. Accordingly, the distance information between successive vehicles as provided by the system of the present invention can be compared to the ground speed of the vehicle and processed through a relatively simple logic and control means to provide a control which responds to the actual separating distance and functions to actuate a device, such as a warning signal or the brakes of the vehicle, when a dangerous operation or headway condition exists. The preferred form of the present invention, which is discussed in greater detail with reference to FIG. 6, is particularly well suited for this headway control application since the range and range related information is continuously detected.

The present system can also be used in other collision avoidance applications. For example, having detected the range to a [retrodirective] harmonic reflector target and knowing the velocity of the protected vehicle, the signal and processing circuitry can be used to divide the detected range by the velocity to calculate the time before an imminent collision. In this example, the output circuitry can be used to deploy safety devices, such as inflatable pneumatic crash cushions or the brakes of the vehicle, when the calculated time before an imminent collision falls below a predetermined or critical value. The present invention will find particular utility in this application since the harmonic radar system is selectively responsive only to properly designed and selectively deployed targets.

The present invention provides a highly directive antenna network for use with an automotive radar system which cooperates with a similar antenna network incorporated in selectively deployed targets. By virtue of the cross polarization correspondence between the cooperating antenna networks, a unique combination of directional gain and isolation results. Accordingly, extraneous or non-critical potential targets are virtually invisible to the harmonic radar system of the present invention. The clutter-free operation which results is particularly advantageous where extraneous targets must be ignored. For example, proposed crash cushion deployment systems rely on impact detecting devices which respond to collision situations after contact is made. Consequently, these proposed systems are generally ineffective when the speed at the point of impact exceeds that speed which precludes sufficient time to deploy the safety device. Thus, it would be highly desirable to detect an imminent collision before contact is made in order to allow sufficient time for full deployment of the safety device. An automotive radar system in a collision detection configuration is the logical supplement to impact detecting devices. However, an automotive radar system that is susceptible to blinding and more importantly clutter from extraneous objects, would result in doubtful success. Additionally, certain radar targets, such as, for example, "snap-off" poles, collapsible partitions or portable metal cones may well be undesired targets to a system which would otherwise deploy such safety devices. Herein lies an important advantage of the system in accordance with the present invention; that is, through the selective deployment of properly designed [retrodirective] harmonic targets, these undesired conventional radar targets may be readily avoided.

Since all participating vehicles present the same radar cross section to the system in accordance with the present invention, the multitarget problem present in the prior art conventional radar systems is virtually eliminated. This advantage is illustrated in FIG. 3 wherein there is shown generally at **60** a pictorial elevation view including a protected vehicle **62** in a typical highway environment. Protected vehicle **62**, which includes a graphic illustration of a harmonic radar detecting and ranging system **10**, is shown following a participating vehicle **64** which in turn includes a [retrodirective] harmonic reflector **30**. Preceding the relatively small vehicle **64** is substantially larger vehicle **66** which also includes a [retrodirective] harmonic reflector **30**. It can be seen that system **10** on automobile **62** cooperates with the target **30** of vehicle **64**. Further, the target **30** of larger vehicle **66** is substantially shielded by smaller vehicle **64**. Thus, the multitarget problem of the prior art is effectively avoided.

An example of the blinding problem inherent to the prior art conventional radar systems is shown graphically in FIG. 4. FIG. 4 is a scene view of a four-lane, two-direction highway shown generally at **70**. Vehicles A and B are shown travelling in the same lane in a first direction. Vehicles C, D and E are shown travelling in the opposing lanes in a second direction. A highly directional antenna pattern which is associated with each protected vehicle is designated as pattern **72** with accompanying side lobes **74**. It can be seen that transmitted vectors designated as vectors **76**, **78** and **79** from vehicles C, D and E respectively are directed to the propagation coverage area (pattern **72**) of vehicle A. Accordingly, the receiver of the conventional radar system of vehicle A is blinded by the transmitted signals of the oncoming vehicles and is accordingly rendered inoperative with reference to the desired target represented by vehicle B in FIG. 4. More-

over, the extraneous or blinding signal may cause a false output signal. It should be noted that a harmonic radar detecting and ranging system in accordance with the present invention would continue to operate in the presence of the otherwise blinding fundamental frequency signals propagated by vehicles C, D and E. Further, the system of the present invention is relatively immune to the spuriously radiated harmonic signals of oncoming vehicles since the spuriously radiated signals also exhibit the same orthogonal or improper polarization as the transmitted fundamental signal.

An example of the clutter problem inherent to conventional prior art automotive radar systems is illustrated in FIG. 5A wherein there is shown generally at **80** a scene view of a segment of a two-lane, single-direction highway. Vehicles A and B are shown in succession in one lane while vehicle C is shown in the adjacent lane. Vehicles A and C are illustrated in conjunction with their directive antenna patterns designated as **82** in FIG. 5A. The widely scattered radar return from vehicle B is illustrated by pattern **84**. It can be seen that the scattered return propagation pattern **84** provided by vehicle B in response to being illuminated by the radar signal from vehicle A somewhat resembles an irregular cardiod pattern surrounding vehicle B. As a result of the scattered propagation pattern **84** from vehicle B, return energy is also reflected to [he] *the* radar receiver of vehicle C which energy is depicted by vector **86** in FIG. 5A. It can be seen that vehicles B and C are operating in a non-critical relationship to one another. It can also be seen that the conventional radar system of vehicle C can respond to the clutter [eminating] *emanating* from vehicle B. It should be noted, however, that a harmonic radar detecting and ranging system in accordance with the present invention would be virtually immune to this prior art clutter problem since the radar return provided by participating vehicles would exhibit a well defined directional beam. Further, the radar return provided by a participating vehicle in a radar system employing selectively deployed [retrodirective] harmonic reflectors would be a well defined directional beam having a pattern somewhat resembling pattern **82** in FIG. 5A. This reflected beam would be substantially confined to the lane common to vehicles A and B and would accordingly propagate in a direction back to vehicle A only.

Another version of the clutter problem inherent to conventional prior art automotive radar systems is illustrated in FIG. 5B. There is shown generally at **90** a segment of a single-direction, two-lane highway along a curved portion thereof. A protected vehicle A with its attendant antenna pattern **92** is shown in the inner lane. A second vehicle B operating in the non-critical adjacent or outer lane is shown in conjunction with its widely scattered return signal designated as pattern **94**. Due to the relative positions of the two vehicles, the transmitted radar signal from vehicle A illuminates the rearward portion of vehicle B thereby resulting in the clutter represented by pattern **94**. It can be seen that a portion of the reflected energy, represented by vector **86**, will be detected by the radar receiver of vehicle A. As noted above, a clutter signal or other extraneous signal, such as that depicted by pattern **94** and vector **86**, could act to unnecessarily and prematurely deploy a safety device, such as a crash cushion or cause automatic braking of vehicle A. It should now be apparent that a harmonic detecting and ranging system in accordance with the present invention, operating in cooperation with a [retrodirective] harmonic reflector deployed on vehicle B in FIG. 5B would be immune to this clutter problem because of the directional characteristics of the passive target.

FIG. 6 illustrates a preferred form of the harmonic radar detecting and ranging system of the present invention. System **100** in FIG. 6 includes a transmitting antenna **102** and a receiving antenna **104**. Here again antenna **102** and **104** may form a unitary antenna structure, such as antenna **40** of FIG. 2. System **100** indicates a voltage controlled oscillator (V.C.O.) **108** which generates an electromagnetic signal. V.C.O. **108** may comprise a varactor tuned transferred electron oscillator (TEO) device wherein the frequency of oscillation is controlled by an external voltage applied to the varactor. The output signal frequency of V.C.O. **108** is modulated by a sweep oscillator **106**. Oscillator **106** provides a linearly varying output voltage, such as a triangular waveform, which is coupled to the varactor input of V.C.O. **108**. The frequency modulated output signal of V.C.O. **108** is coupled to an isolator **110** which in turn has its output coupled to low pass filter **112**. Filter **112** acts to selectively pass only the desired fundamental frequency signal. The output of low pass filter **112** is coupled to coupler **114** which in turn has its output coupled to isolator **116**. The output of isolator **116** is coupled to transmitting antenna **102**. A portion of the electromagnetic energy passing through coupler **114** is diverted to frequency doubler **118**. Isolators **110** and **116**, which may comprise ferrite isolators, provide an improved impedance match between the respective sections of system **100** while providing additional filtering.

Receiving antenna **104** is coupled to an isolator **119**. The output of isolator **119** is coupled to high pass filter **120** which in turn has its output coupled to mixer **122**. Filter **120** acts to selectively pass only the desired harmonic frequency signal which in this embodiment is the second harmonic. The output of frequency doubler **118** is coupled to mixer **122** by way of high pass filter **123**. Filter **123** acts to selectively pass only the second harmonic frequency output from doubler **118**. The output of mixer **122** is therefore a signal which represents the frequency difference between the second harmonic output of doubler **118** and the output of filter **120**. The output of mixer **122** is coupled to a high pass filter **124** which in turn has its output coupled to amplifier **126**. The output of amplifier **126** has its output coupled to low pass filter **128**. The output of low pass filter **128** is coupled to signal processing and output circuitry **130**. Filters **124** and **128** act to establish the lower and upper limits, respectively, of the difference frequency applied to circuitry **130** to thereby control the dynamic operating or response range of system **100**. A ground speed sensor **134** has its output coupled to a second input of circuitry **130**. Circuitry **130** provides an output signal on lead **132**.

Ground speed sensor **134** may comprise a speedometer cable sensor coupled to the speedometer of the protected vehicle which utilizes system **100**. Ground speed sensor **130** may alternatively comprise separate Doppler radar system which operates in a well-known manner.

Referring now to the operation of system **100**, it will be understood that system **100** is adapted for use with an automotive vehicle in concert with a [retrodirective] harmonic reflector which provides a cooperating target. The target being disposed within a given distance from the vehicle and in the direction of forward movement of the vehicle. Transmitting antenna **102** radiates the frequency-modulated electromagnetic signal toward the target and in a given polarization direction. The target, in response to being illuminated by the frequency modulated fundamental signal of proper polarization, reradiates an orthogonally polarized second harmonic signal back toward orthogonally polarized receiving antenna **104** of system **100**. The received signal at antenna **104** will be delayed with respect to the corresponding transmitted signal at antenna **102** as a function of the distance between system **100** and the target. During this delay period the output signal frequency of V.C.O. **108** will continue to vary in accordance with the varying output voltage from oscillator **106**; however, the instantaneous frequency of the received signal will be the second harmonic frequency of the transmitted signal at the start of the delay period. Therefore, the instantaneous frequency of the output signal from mixer **122** which mixes the received second har-

monic with a frequency doubled sample of the transmitted signal, will be a function of [th] *the* distance or range to the target. Accordingly, the signal processing and output circuitry **130**, which may include a counter or other suitable frequency detecting means, can provide an output signal which may be readily calibrated in terms of distance to the target. If, for example, circuitry **130** provides a voltage output signal, the output signal may also be differentiated by conventional circuit means to provide a second signal which represents the rate of change of distance or range rate.

It should be noted that the dynamic operating range of system **100** can readily be controlled by selecting the desired parameters for filters **124** and **128**. In this manner only those reflected signals originating within a given range are presented to the signal processing and output circuitry. This feature may be used to complement and further facilitate the antenna network design so as to eliminate adjacent lane interference.

As previously discussed, circuitry **130** may include appropriate means to compare the detected range to the ground speed of the vehicle in order to provide the vehicle operator with an indication that a minimum safe following distance or proper headway is or is not being maintained.

An advantage of the type of harmonic radar system shown in FIG. 6 is that the distance or range between system **100** and the target is continuously detected notwithstanding the relative velocity between the protected vehicle and the target. However, given any particular system configuration, it has been found that successful system operation in view of the blinding and clutter problems of the prior art, necessitates directional antenna gain, proper isolation and particularly orthogonal polarization, in accordance with the teachings of the present invention.

Thus, there is provided in accordance with the present invention a highly effective automotive harmonic radar system facilitating, notably, headway control and collision avoidance. Further, in the event of an otherwise unavoidable collision, the present invention can provide effective pre-collision deployment of safety devices such as, for example, to inflate a pneumatic crash cushion.

What is claimed is:

1. A detecting and ranging system for use with an automotive vehicle, comprising a transmitter, a receiver, an output means and a directional antenna network coupled to said transmitter and said receiver;

said transmitter comprising means for generating electromagnetic energy signals of a predetermined frequency;

said receiver comprising means adapted to detect electromagnetic energy signals which are derived from and harmonically related to said signals of said predetermined frequency;

said output means being coupled to said receiver and cooperating with said receiver for producing an output signal in response to said detected signals; and

said antenna network including means for selectively transmitting said signals of said predetermined frequency into a given transmission direction while polarizing said transmitted signals into a given polarization direction, said antenna network further including means selectively responsive only to electromagnetic signals originating from said given transmission direction, which signals have been derived from and are harmonically related to said transmitted signals and which have a polarization direction substantially orthogonal to said given polarization direction, for applying said selectively derived signals to said receiver.

2. The system according to claim **1** wherein said receiver includes means coupled to said transmitter wherein said output signal is proportional to the difference in frequency between a preselected harmonic of said predetermined frequency and said selectively derived signals.

3. The system according to claim **1**, wherein said output means includes means coupled to said transmitter wherein said output signal is derived by comparing said predetermined frequency signal and said selectively derived signals.

4. The system according to claim **2**, including frequency modulation means coupled to said transmitter to vary the frequency of the signals generated by said transmitter about said predetermined frequency.

5. The system according to claim **1**, wherein the frequency of said selectively derived signals is the second harmonic of said predetermined frequency.

6. The system according to claim **5**, wherein said antenna network comprises a unitary antenna structure and wherein said means for selectively transmitting said signals of said predetermined frequency includes a first array of dipole elements having a resonant frequency substantially equal to said predetermined frequency and a polarization direction determinative of said given polarization direction, and wherein the selectively responsive means includes a second array of dipole elements having a resonant frequency substantially equal to the second harmonic of said predetermined frequency and a polarization direction orthogonal to said given polarization direction.

7. A detecting and ranging system for use with an automotive vehicle, comprising a transmitter, a receiver, an output means and a directional antenna network coupled to said transmitter and said receiver;

said transmitter comprising means for generating electromagnetic energy signals of a predetermined frequency;

said receiver comprising means adapted to detect electromagnetic energy signals which are derived from and harmonically related to said signals of said predetermined frequency;

said output means being coupled to said receiver and cooperating with said receiver for producing an output signal in response to said detected signals; and

said antenna network including means for selectively transmitting said signals of said predetermined frequency in the direction of forward movement of the vehicle and onto a target comprised of a [retrodirective] harmonic reflector mounted on the rearward portion of a preceding vehicle, while polarizing said transmitted signals into a given polarization direction, said antenna network further including means selectively responsive only to the reflected electromagnetic energy signals which are harmonically related to said transmitted signals and have a polarization direction substantially orthogonal to said given polarization direction for applying said harmonically related and orthogonal signals to said receiver.

8. The system according to claim **7**, wherein said [retrodirective] harmonic reflector includes a harmonic generating means coupled between a first and second directive antenna, said first antenna having a polarization direction corresponding to said given direction and a resonant frequency substantially equal to said predetermined frequency, said second antenna having a polarization direction which is substantially orthogonal to the polarization direction of said first antenna and a resonant frequency substantially equal to a preselected harmonic frequency of said predetermined frequency.

9. The system according to claim **8**, wherein said preselected harmonic frequency is the second harmonic of said predetermined frequency.

10. The system according to claim **8** wherein said harmonic generating means comprises a diode.

11. The system according to claim **7**, including frequency modulation means coupled to said transmitter to vary the frequency of the signals generated by said transmitter about said predetermined frequency; and

wherein said receiver includes means coupled to said transmitter to provide an output signal which is pro-

portional to the difference in frequency between a preselected harmonic frequency of said predetermined frequency and said selectively derived signals.

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