United States Patent

[11] 3,623,091

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[21] Appl. No. 5,725
[22] Filed Jan. 26, 1970
[45] Patented Nov. 23, 1971
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[54] **PASSIVE RESPONDER**
10 Claims, 8 Drawing Figs.

[52] U.S. Cl. .... 343/6.8 R, 343/18 D
[51] Int. Cl. G01s 9/56
[50] Field of Search .... 343/6.8 R, 18 D

[56] **References Cited**

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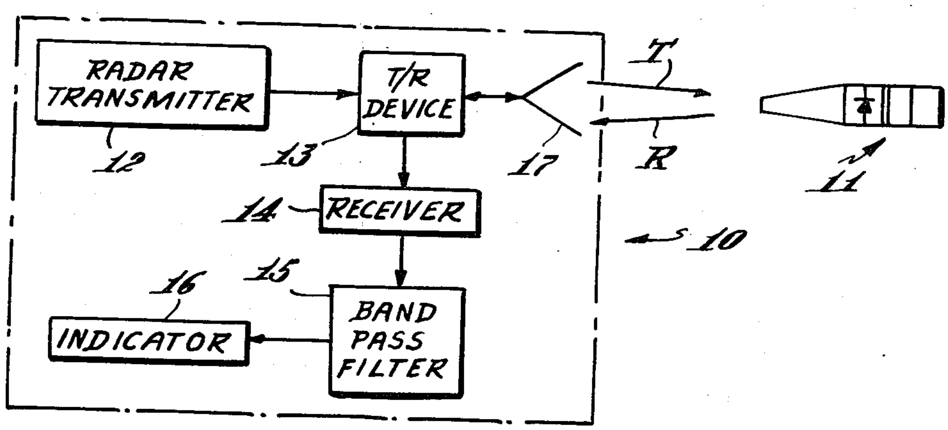
ABSTRACT: A passive responder utilizing a cylindrical waveguide and a dielectric rod element for receiving electromagnetic wave energy from an interrogating radar and for reflecting such energy back to the radar. A shorting element is used in conjunction with a pair of orthogonally mounted diode elements, all of which are positioned with the waveguide, such diode elements being suitably switched as by a multivibrator circuit to provide a phase modulated return signal. The diodes are mounted at a distance equal to an odd multiple of quarter wavelengths from the shorting element to produce a 180° phase shift of the incoming and reflected signal so as to produce a modulated return signal of the suppressed carrier type.



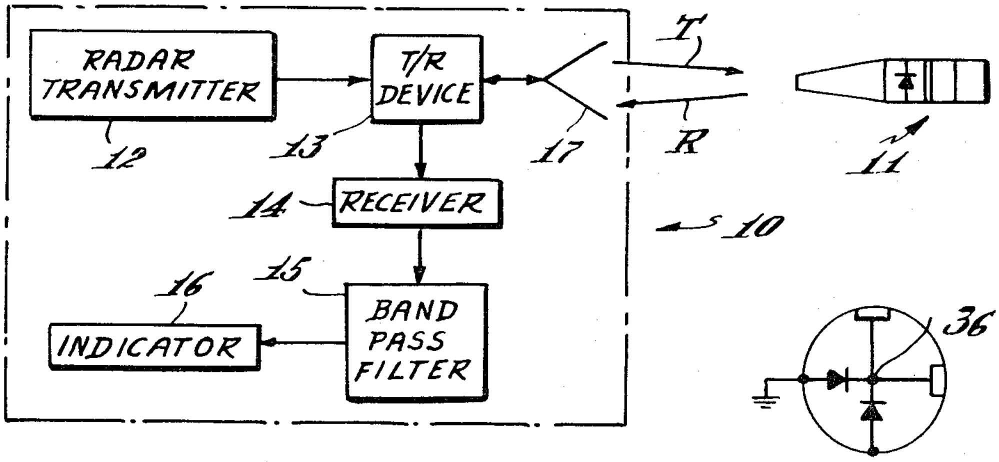


Fig. 1

Fig. 2a

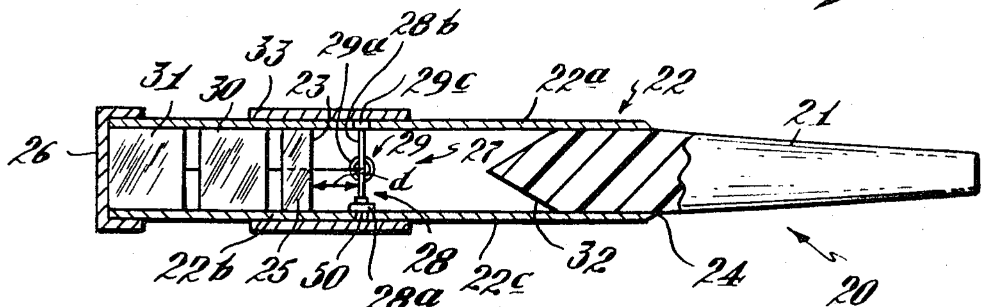


Fig. 2

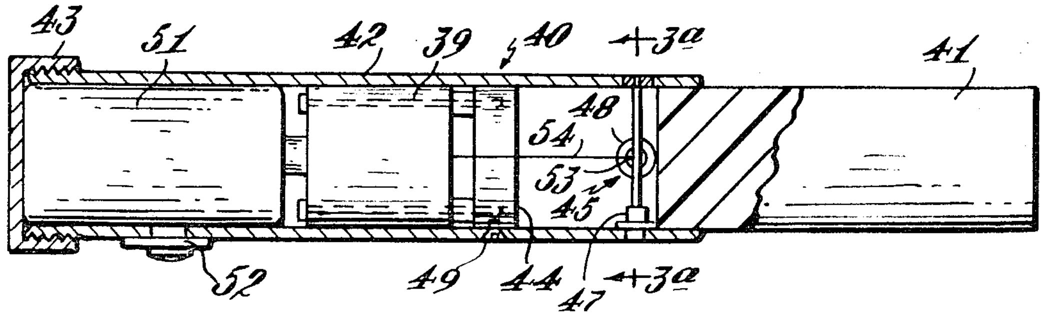


Fig. 3

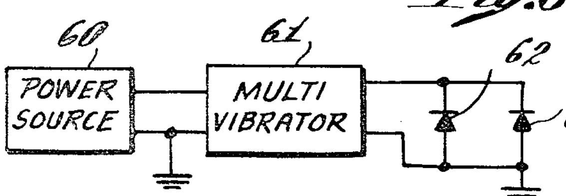


Fig. 6

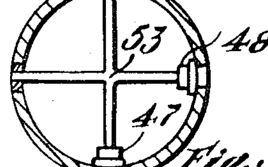


Fig. 3a

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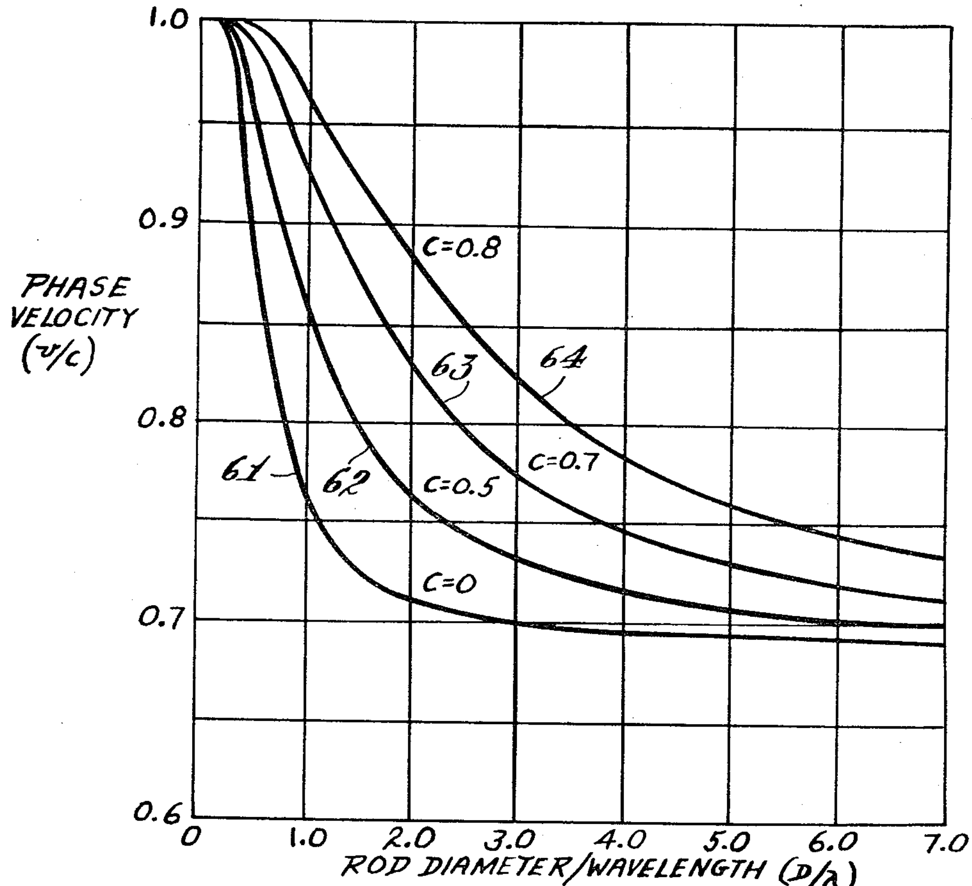
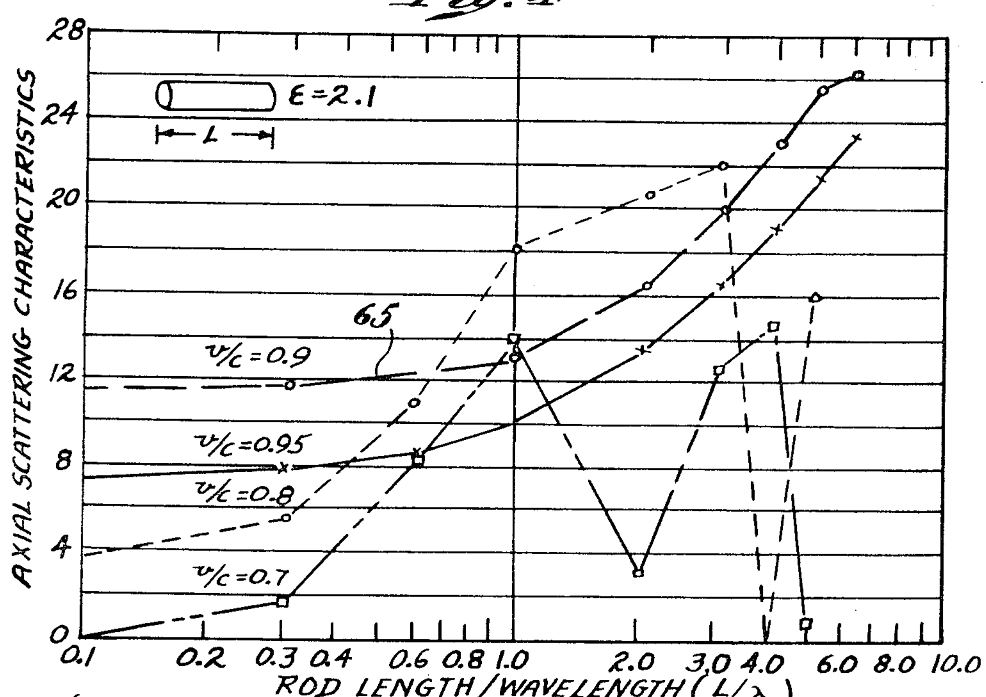

1.0
0.9
0.8
0.7
0.6
PHASE VELOCITY (v/c)
C=0.8
C=0.7
C=0.5
C=0
61
62
63
64
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
ROD DIAMETER/WAVELENGTH (D/λ)

Fig. 4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24
20
16
12
8
4
0
AXIAL SCATTERING CHARACTERISTICS
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v/c=0.95
v/c=0.8
v/c=0.7
0.1
0.2
0.3
0.4
0.6
0.8
1.0
2.0
3.0
4.0
6.0
8.0
10.0
ROD LENGTH/WAVELENGTH (L/λ)

Fig. 5

PASSIVE RESPONDER

This invention relates generally to responder devices and, more particularly, to such devices as are conventionally referred to as "passive" responders which devices do not in themselves incorporate means for actively generating and radiating electromagnetic energy signals but rather receive remotely generated electromagnetic energy signals and, after suitable processing thereof if desired, reradiate such signals by appropriate reflection from the responder.

Responders, both active and passive, find use in many varied applications, particularly in identification and/or communications systems, either military or commercial. For example, responders used in military operations enable proper identification to be made in response to a probing signal and, if such responders are passive in structure and operation, they can be used without revealing the position of military personnel to the enemy. If the reflected signal is appropriately modulated by the responder with a coded signal, more specific identification can be produced.

Further, a responder device may be employed on aircraft in air traffic control indicator systems so that aircraft carrying such responders can be detected and accounted for the air traffic control center. The responders may be modulated so as to add information concerning certain operating parameters, such as barometric height, and other information which it might be desirable to provide the center in the responder's return signal. Further in this connection a responder may be utilized to permit the detection of other aircraft in the vicinity of a radar equipped aircraft so as to provide a simple pilot warning indicator. Assistance in the landing of aircraft can also be further application for such responders which devices can be located along a runway path, each responder operating at a different frequency to designate the position along the path.

The use of such responders as rescue equipment, wherein lost persons can reflect an appropriate search signal which is picked up and returned for identification by a searching aircraft, is another good application for the responder of the invention. The responder of this invention is particularly applicable in such cases where the responder reflected signal is obscured by ground clutter in that the responder herein described can be readily adapted to provide a signal which is shifted in frequency from the carrier frequency to a region of the frequency spectrum outside the ground clutter frequencies. Also, the responder may return the equivalent of a Doppler signal to an interrogating Doppler or MTI radar even though the responder itself is not moving.

Previously used responders for use in the above described, or similar, applications have either been of the active type or, if passive, have required relatively complex construction. The major disadvantage in utilizing actively generated signals lies in the requirement for a receiver design at the responder which must be capable of receiving coded signals and which must thereupon operate on such signals and retransmit them through a relatively high power transmitter, with its necessary associated power supply units and coder circuit. Moreover, the need in the interrogating radar for a separate receiver channel for receiving the return coded pulse at a separate frequency from that of the signal originally generated at the interrogating radar adds to the complexity and cost of the overall system. In addition, active generators lack location security and can be more easily detected by the enemy in military situations, for example.

Further, passive responders which have been heretofore available have not been able to provide suitable modulation of the return signal without the use of complex configurations, such as mechanical modulating means, which require relatively complicated and expensive structures having cumbersome spatial requirements. For example, certain prior art responders utilize rotating corner reflective structures which are motor driven, are relatively large in size, and are difficult to set up in the field. Moreover relatively large power sources are required to drive the motor for rotating the corner reflector structure. Other recently available responder devices, such as that which has been designated as the "Dinade" system, as manufactured by Micro Lab FXR, require a special transmitter and a special receiver in its structure and operation. Such a system is not only expensive but the diode array utilized therein is relatively large and cumbersome both to fabricate and to handle, particularly in the field.

On the other hand, the passive responder of this invention is relatively simple in construction, inexpensive to fabricate and compact in size so that it may be easily transported and utilized by individuals in the field without difficulty. It requires substantially little power and whatever is needed can be supplied by a simple battery. Its modulation system is entirely electronic and can be constructed in a very neat package either using standard components or integrated circuitry.

The passive responder of the invention provides a phase modulated signal and utilizes a dielectric rod radar signal reflector. The dielectric rod, partially inserted in a waveguide configuration is selected to provide an appropriate transmission of an incoming electromagnetic energy signal received thereby into the waveguide through a suitable transition structure. The rod operates in the HE_{11} mode and is arranged to provide an optimum match into the waveguide configuration which, for example, is circular in cross section and operates in the TE_{11} mode. A metallic shorting element is mounted within the waveguide and a pair of orthogonally mounted diodes are positioned within the waveguide between the shorting element and the inner end of the dielectric rod at a location such that the distance from the shorting element to the diodes is an odd multiple of quarter wavelengths at the operating frequency of the waveguide. Such positioning provides a phase shift of 180° in a received wave during its travel from the diodes to the shorting element and back again. Thus, in the modulation process such a relationship produces a maximum impedance change in the diodes so as to effect the best switching between the "off" and the "on" states thereof (i.e., as close as possible to open circuit and short circuit conditions of the diodes, respectively) during the switching operation.

Appropriate electronic switching circuitry in the form for example, of conventional multivibrator, or other relaxation oscillator circuitry operating at a frequency compatible with that of the interrogating radar system is mounted with the waveguide, such circuitry being powered by a simple battery also suitably mounted in the waveguide.

In operation the passive responder of the invention is illuminated by an appropriate electromagnetic energy signal such as that transmitted from a Doppler radar or a radar with moving target indicator (MTI) circuitry. The radar signal received at the responder is appropriately phase modulated by the responder as discussed above and reflected back to the radar source where it can be displayed with existing radar ancillary display equipment.

The structure and operation of the responder of the invention can be described most easily with the help of the accompanying drawings wherein

FIG. 1 shows a block diagram of an exemplary system in which the passive responder of the invention can be utilized:

FIG. 2 shows a view in longitudinal cross section on one embodiment of the passive responder of the invention;

FIG. 2A shows a diagrammatic view of the diode configuration used in the embodiment of the invention in FIG. 1;

FIG. 3 shows a longitudinal cross section view of an alternative embodiment of the invention:

FIG. 3A shows a lateral cross section view of the embodiment of FIG. 3 taken along the lines 3A—3A;

FIG. 4 shows a graph of phase velocity of a wave of electromagnetic energy transmitted in a dielectric rod for various coring ratios thereof;

FIG. 5 shows a graph of axial scattering of a wave as a function of the length of a dielectric rod at various phase velocities; and

FIG. 6 shows a partial block diagram, partial schematic diagram of suitable modulating circuitry for use in the passive responder of the invention.

FIG. 1 shows an exemplary environment in which the passive responder to the invention can be used. In FIG. 1 an interrogating radar system **10** comprises well-known components in the form of a transmitter **12**, a transmit/receive device **13** for providing a transmitting path to an antenna **17** during the transmitting mode of the radar operation and a receiver path from antenna **17** to receiver **14** during the receiving mode thereof. The output of receiver **14** is appropriately filtered by a band-pass filter **15** and the filtered signal to to a suitable indicator, or display, device **16**. A transmitted electromagnetic energy wave T from radar **10** is received by the passive responder of the invention shown merely diagrammatically as responder **11** in FIG. 1 and shown in more detail in the embodiments of FIGS. 2 and 3. Responder **11** appropriately modulates the received signal and reflects such modulated signal, as received wave R, to the interrogating radar system where it is appropriately received and displayed.

FIG. 2 shown one embodiment of the passive responder of the invention, shown as responder **20**, which is in the form of a waveguide portion **22*b***, and a suitable circular to square waveguide transition portion **22*c*** fabricated as an integrally formed structure in a manner well known to those in the art. A dielectric rod **21** has a portion thereof inserted into waveguide **22** at its open end **24** thereof. Rod **21** is substantially cylindrical in shape and fits snugly into the circular cross-sectional configuration of waveguide portion **22*a***. The other end of the waveguide structure is appropriately covered by a metallic cap **26**. A metallic shorting element **25** is mounted within the square waveguide portion **22*b*** so as to form a good metallic short at the front surface **23** of element **25** as shown.

A diode assembly **27**, in the form of diodes **28** and **29** which are mounted within waveguide portion **22*b*** in a mutually orthogonal fashion with respect to each other, is positioned at a distance *d* from surface **23** of shorting element **25**. In the embodiment shown the distance *d* is selected to be substantially equal to a quarter wavelength at the frequency of operation of the waveguide (identified as the quantity $\lambda_g/4$). It is clear that the distance *d* also may be any odd multiple of $\lambda_g/4$. Diodes **28** and **29** are conventional PIN diodes appropriately encapsulated in cases **28*a*** and **29*a***, respectively, so that diode **28**, for example, can be suitably welded to the bottom wall of waveguide **22*b*** via a bottom stud **50** attached to its case, diode **29** being welded in a similar fashion. A metallic rod extension **28*b*** extends from the case **28*a*** of diode **28** to the opposite wall of waveguide **22*b*** where it is held in a dielectric bushing **29*c*** so that the diode is appropriately supported in a vertical direction in the orientation shown. Diode **29**, also similarly welded to a sidewall of waveguide **22*b***, has a similar rod extension positioned perpendicularly to extension **28*b*** and attached to extension **28*b*** at the centers thereof, the end of the rod extension of diode **29** also being similarly supported in the opposite sidewall of waveguide **22*b*** in a dielectric bushing (not shown).

Diodes **28** and **29** are represented schematically in FIG. 2A and, as can be seen therein, they are connected at a common point **36** at the center of said extensions and, thereby, form a pair of parallel diodes from point **36** to the waveguide which is at ground potential as shown.

On the opposite side of shorting element **25**, suitable electronic circuitry is mounted in waveguide portion **22*b*** as shown by block **30**. The circuitry may be in the form of a well-known multivibrator circuit, or other relaxation oscillator circuit, which can be encapsulated in a plastic potting material, for example, and appropriately mounted within the waveguide. Power is supplied to the oscillator circuit by a battery **31** which is appropriately connected to the multivibrator circuit **30**.

Dielectric rod **21** operates as an effective antenna for receiving electromagnetic energy impinging thereon which energy is thence transmitted along rod **21** in a conventional HE_{11} mode. Rod **21** has a tapered portion **32** at its inner end for providing a good transition for the transmission of energy from the rod to circular waveguide **22*a*** where it is then propagated in a conventional TE_{11} mode.

The metallic shorting element **25** shown in FIG. 2 is mounted so as to be adjustable in its longitudinal positioning. For example, element **25** may be attached to movable slide elements **33** at the upper and lower walls of square waveguide **22*b*** via appropriate interconnecting end pieces (not shown) which extend through slots (also not shown) in such upper and lower walls so that metallic shorting element **25** can be longitudinally moved within the waveguide over a limited range of positions so as to vary the distance from waveguide surface **23** to the diode assembly **27** to adjust for frequency differences in the incoming signal.

An alternative embodiment of the responder structure of the invention is shown in FIG. 3 wherein a responder **40** is formed as a single cylindrical waveguide **42** having an appropriate end cap **43** at one end thereof and a cylindrical dielectric rod **41** having a substantially constant diameter inserted in the opening at the other end thereof. Rod **41** has substantially flat end surfaces and is adapted to be inserted so that its inner end is effectively adjacent a diode assembly **45**, comprising diodes **47** and **48**, which diode assembly is mounted within waveguide **42** in a manner similar to that discussed with reference to FIG. 2. A metallic shorting element **44** is also mounted within waveguide **42** and in the configuration shown in FIG. 3 such element is fixedly mounted via inset screw **49**. It is clear, however, that metallic shorting element **44** may also be mounted in an adjustable manner similar to that discussed with reference to the structure of FIG. 2.

Oscillator circuitry **39** is mounted on the opposite side of shorting element **44** and is connected to battery **51** via suitable leads, one of which is connected to ground and the other of which is connected to encapsulated circuitry **39** through a suitable switch **52** in any convenient manner. An ungrounded output lead **54** from oscillator circuitry **39** is connected to the common point **53** of parallel connected diodes **47** and **48**. As shown in the configuration of FIG. 3, encapsulated circuitry **39** can be appropriately mounted by attachment to shorting element **44**, although any other suitable means for mounting such structure can be used by those in the art. Such circuitry may also be formed as an integrated circuit and the overall package size compacted even more than that shown in the configurations of FIGS. 2 and 3. FIG. 3A shows a cross-sectional view of the mechanical structure of the orthogonally mounted diode elements in the diode assembly **45**. As can be seen therein, the rod extensions of the diodes can be formed as an integral cruciform structure with a common junction point **53**.

The circuitry used in either embodiment of the responder discussed above is shown in FIG. 6, wherein a power source **62**, such as batteries **31** or **51** in FIGS. 2 and 3, respectively, is connected to multivibrator circuitry **61**, such as circuits **30** and **39** in FIGS. 2 and 3 respectively, and the output thereof is connected to the common junction of diodes **62** and **63**, representative of the diode arrangements of FIGS. 2 and 3.

In the operation of the responder of the invention in either of the configurations of FIGS. 2 and 3 the electromagnetic energy wave input which is picked up by the dielectric rod of the transponder is transmitted through the rod and thence into the waveguide where it impinges either upon the diode elements (in the "on" state) and the shorting bars or it impinges upon the metallic shorting element (by passing the diodes which are in the "off" state) where it is then reflected back along the waveguide and thence along the dielectric rod to be reradiated back to the interrogating radar system. The passage from the diode assembly to the shorting element and then back to the diode assembly produces a 180° phase shift thereof. The diodes may be switched on and off as desired to produce a phase modulation of 0±180° of the received and reradiated energy in accordance with the operation of the multivibrator circuit which switches the diode impedances from maximum to minimum values at the frequency of the multivibrator, or relaxation oscillator, circuitry. The provision for such a 180° phase shift, thus, produces a signal for reradiation which is of the suppressed carrier type which operation produces sideband signals which are readily identifiable from the clutter and can be appropriately displayed by suitable filtering provided at the receiver of the interrogating radar. The signal from the responder therefore has the characteristics of a normal Doppler shifted reflected signal and is presented to the Doppler, or MTI, radar in such a form as to be appropriately processed thereby.

If desired, the electronic circuitry may be arranged to produce coded information on the reflected signal. For example, the switching rate may be arranged to impart additional information. Thus, by turning the responder appropriately on and off, the dots, dashes and spaces required for transmitting a Morse coded signal can be simulated. The audio tone obtained at the radar would then represent such a Morse coded signal.

Further, the relaxation oscillator circuitry may be set up to produce a variable frequency output for providing a reflected frequency modulated signal. Alternatively, several fixed frequencies may be employed in a prearranged sequence to code whatever information is desired to be transmitted from the responder back to the radar. Additionally, pulse code modulation or pulse width modulation circuits may be utilized and employed at suitably limited rates in order to transmit appropriate coded information.

Thus, the passive responder of the invention provides an ability to detect a nonmoving target in an area of high clutter by a conventional Doppler, or MTI, radar system. The responder produces no self-generated radiated power and so the security of its position and the identification thereof is maintained. Further, since it is a passive system, the use of such a responder eliminates saturation problems normally caused by active beacon systems.

As can be seen from the structures discussed above, the overall responder can be fabricated in a compact fashion so that it is small and light and yet substantially rugged in construction. The low power consumption from the battery element therein assures relatively long life for the responder and it is clearly easy to place into operation and can be manufactured at relatively low costs in comparison with previously used responders either active or passive. The design of the structure is relatively flexible and can be arranged to fit specific specifications and requirements. Moreover, the responder can be used directly with conventional Doppler or MTI radars without any modification of the radar systems themselves.

FIGS. 4 and 5 depict graphs which are used in the selection of the appropriate dielectric rod dimensions for use in a particular application. The dielectric rod may be fabricated from a suitable plastic material, such as Teflon, or other dielectric material, such as a polypropylene material, which provides a relatively low loss dielectric. The curves shown in FIGS. 4 and 5 represent the characteristics of a cylindrical dielectric rod made of Teflon, having a dielectric constant ϵ=2.1. Curves **61**, **62**, **63** and **64** are representative curves of phase velocity, v/c, as a function of D/λ for coring ratios c of zero, 0.5, 0.7, and 0.8, respectively. D is defined the diameter of the dielectric rod and λ as the wavelength of the wave being propagated in the rod. Thus, for example, for a phase velocity of 0.9 and a ratio D/λ of 0.8 a rod having a coring ratio of 0.5 can be used. The coring ratio is defined as the ratio of the minor diameter of a centrally bored hole in the rod rod to the major diameter of the overall rod. A coring ratio of zero represents a solid rod while a coring ratio of 0.5 represents a rod in which the minor diameter of the centrally bored hole is one-half of the total major diameter of the rod. Once the rod diameter and coring ratio have been selected in accordance with a particular phase velocity, the length of the rod can be selected by the use of the curves of FIG. 5 to provide appropriate axial scattering characteristics, which characteristics are normally selected to be at a maximum. Thus, for a phase velocity of 0.9, curve **65** is utilized in FIG. 5, its maximum occurring at a ratio of rod length L to wavelength (L/λ) equal to 6.0. The rod dimensions consequently can be appropriately selected for the desired phase velocity and axial scattering characteristics which are suitable for the application in which the device is being used.

What is claimed is:

1. A passive responder comprising
   - waveguide means for permitting the transmission of electromagnetic energy therein in either direction, the wavelength of said electromagnetic energy within a range having a specified center value;
   - shorting means mounted within said waveguide means;
   - dielectric means partially inserted into said waveguide at one end thereof;
   - diode means mounted within said waveguide means at a specified distance from said shorting means and at a position between said shorting means and said dielectric means, said distance being substantially equal to an odd multiple of quarter wavelengths at said center wavelength value;
   - circuit means mounted within said waveguide and connected to said diode means for controlling the operation of said diode means;
   - whereby an electromagnetic energy wave received at said one end of said waveguide means is modulated by the operation of said diode means and said circuit means, and said modulated electromagnetic energy wave is reradiated from said one end thereof.
2. A passive responder in accordance with claim 1, wherein said waveguide means includes a circular waveguide.
3. A passive responder in accordance with claim 1, wherein said diode means are mounted orthogonally with respect to each other.
4. A passive responder in accordance with claim 2, wherein said dielectric means is in the form of a dielectric rod having a cross-sectional area substantially equal to that of said circular waveguide.
5. A passive responder in accordance with claim 4, wherein the dimensions of said dielectric rod are selected to provide a phase velocity for operation in the HE_{11} mode, the diameter of said rod corresponding to the diameter of said cylindrical waveguide operating in the TE_{11} mode.
6. A passive responder in accordance with claim 4, wherein the end of said dielectric rod which is inserted into said waveguide is tapered to provide an effective transition for the transmission of said energy between said rod and said waveguide.
7. A passive responder in accordance with claim 4, wherein the ends of said dielectric rod are substantially flat and the end inserted in said waveguide is mounted substantially adjacent said diode means.
8. A passive responder in accordance with claim 1 wherein said circuit means includes an oscillator circuit mounted within said waveguide and power supply means mounted within said waveguide for supplying power to said oscillator circuit.
9. A passive responder in accordance with claim 1 wherein said waveguide means includes
   - a circular waveguide, said dielectric means being partially inserted therein;
   - a rectangular waveguide, said shorting means, said diode means, and said circuit means being mounted therein; and
   - further waveguide means for providing a transition from said circular waveguide to said rectangular waveguide.
10. A passive responder in accordance with claim 1, wherein said shorting means is adjustably mounted within said waveguide means so as to adjust said distance between said shorting means and said diode means.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,623,091 Dated November 23, 1971

Inventor(s) John J. Mayo, Jr. and Robert L. Cavanaugh

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 22, after "for" insert--by; Column 2, line 52, after "can" insert--then--; Column 2, line 59, for "on" read--of--; Column 2, line 68, after "rod" insert--as a function of the diameter of such rod--; Column 3, line 9, for "to" (first occurrence) insert --fed--; Column 3, line 18 for "shown" read--shows--; Column 3, line 20, after "waveguide" insert--22 having a circular waveguide portion 22a, a square waveguide--; Column 5, line 59, omit "rod" (first occurrence); and Column 6, line 9, after "energy" insert --lying--.

Signed and sealed this 10th day of October 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents