United States Patent [19]

Leyde et al.

[11] **3,742,442**

[45] **June 26, 1973**

[54] **ACOUSTIC OBJECT DETECTION SYSTEM**

[75] Inventors: **Warren L. Leyde; Delbert E. Marker,** both of Seattle, Wash.

[73] Assignee: **Pacific Technology, Inc.,** Renton, Wash.

[22] Filed: **Sept. 30, 1971**

[21] Appl. No.: **185,072**

[52] **U.S. Cl.** ..... **340/15,** 310/9.1, 340/8 FT

[51] **Int. Cl.** **H04b 11/00**

[58] **Field of Search** ..... 340/8 R, 8 FT, 10, 340/1 R, 15; 310/9.1

[56] **References Cited**

UNITED STATES PATENTS

2,332,541 10/1943 Turner, Jr. ..... 340/8 FT

3,672,462 6/1972 Auer, Jr. ..... 340/8 R

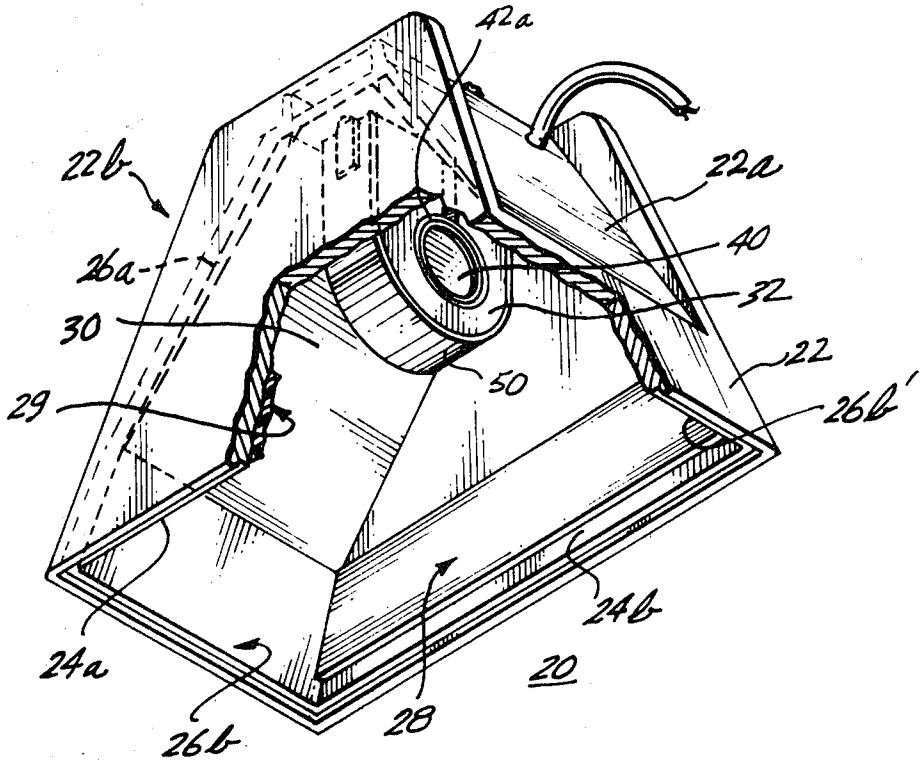
Primary Examiner—Richard A. Farley

Attorney—Christensen & Sanborn

[57] **ABSTRACT**

An object detection system is disclosed which makes use of an acoustic transducer for generating compressional waves in the air and detecting return pulses from an object lying within the detection zone. A transducer mounting system includes a transducer slug mounted for generating acoustic waves from both ends of the slug. The antenna system includes a reflector housing adapted to accommodate variable surfaces for controlling the energy pattern. Details of the electronic circuitry associated with the transducer mounting system and a door opening system are disclosed.

18 Claims, 11 Drawing Figures



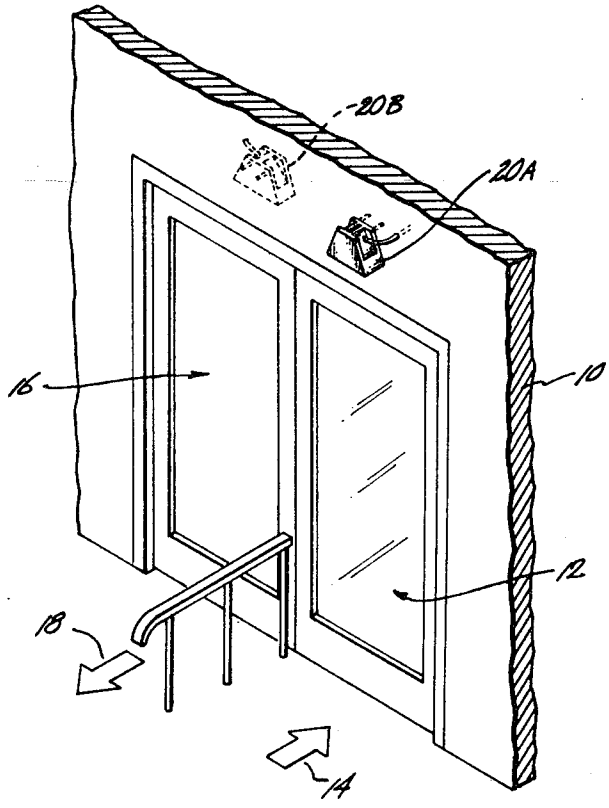

20B
20A
16
10
12
18
14

Fig. 1

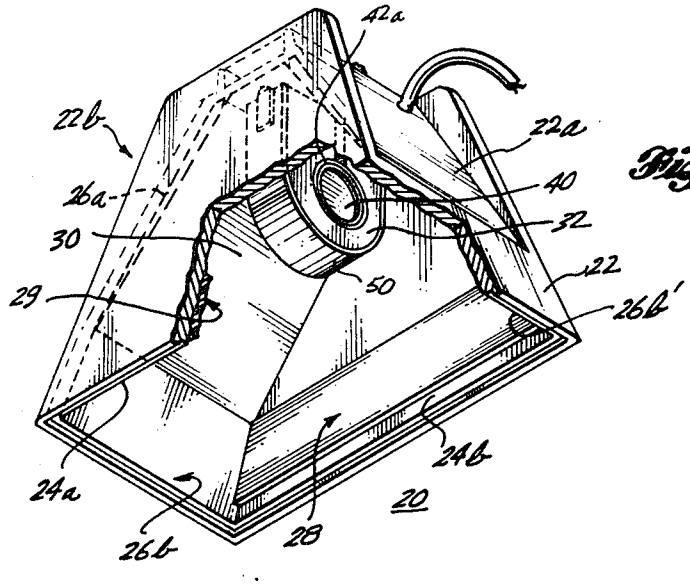

42a
22b
22a
26a
40
30
32
50
22
29
26b'
24b
24a
20
28
26b

Fig. 2.

Fig. 3.

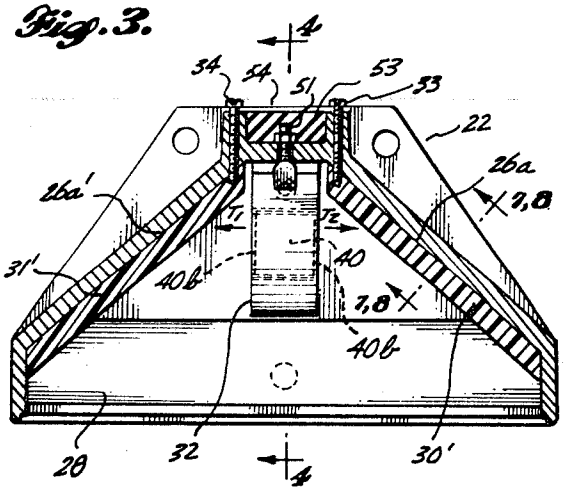
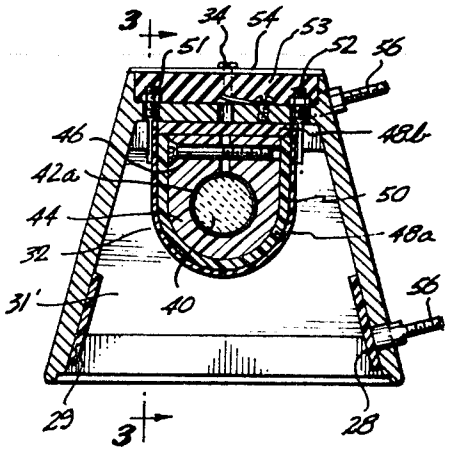


Fig. 4.



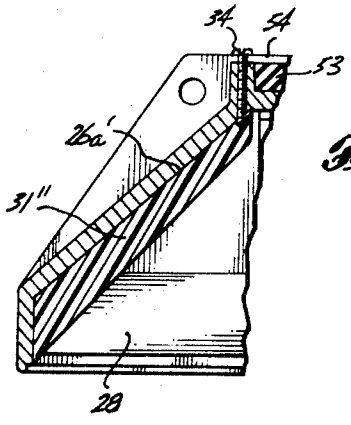


Fig. 5.

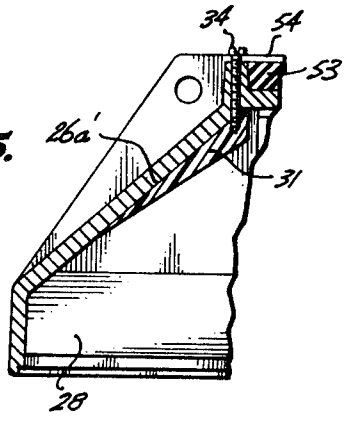


Fig. 6.

Fig. 7.

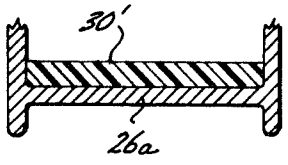
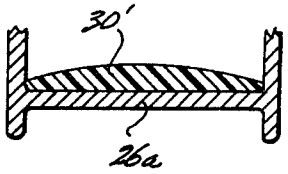


Fig. 8.



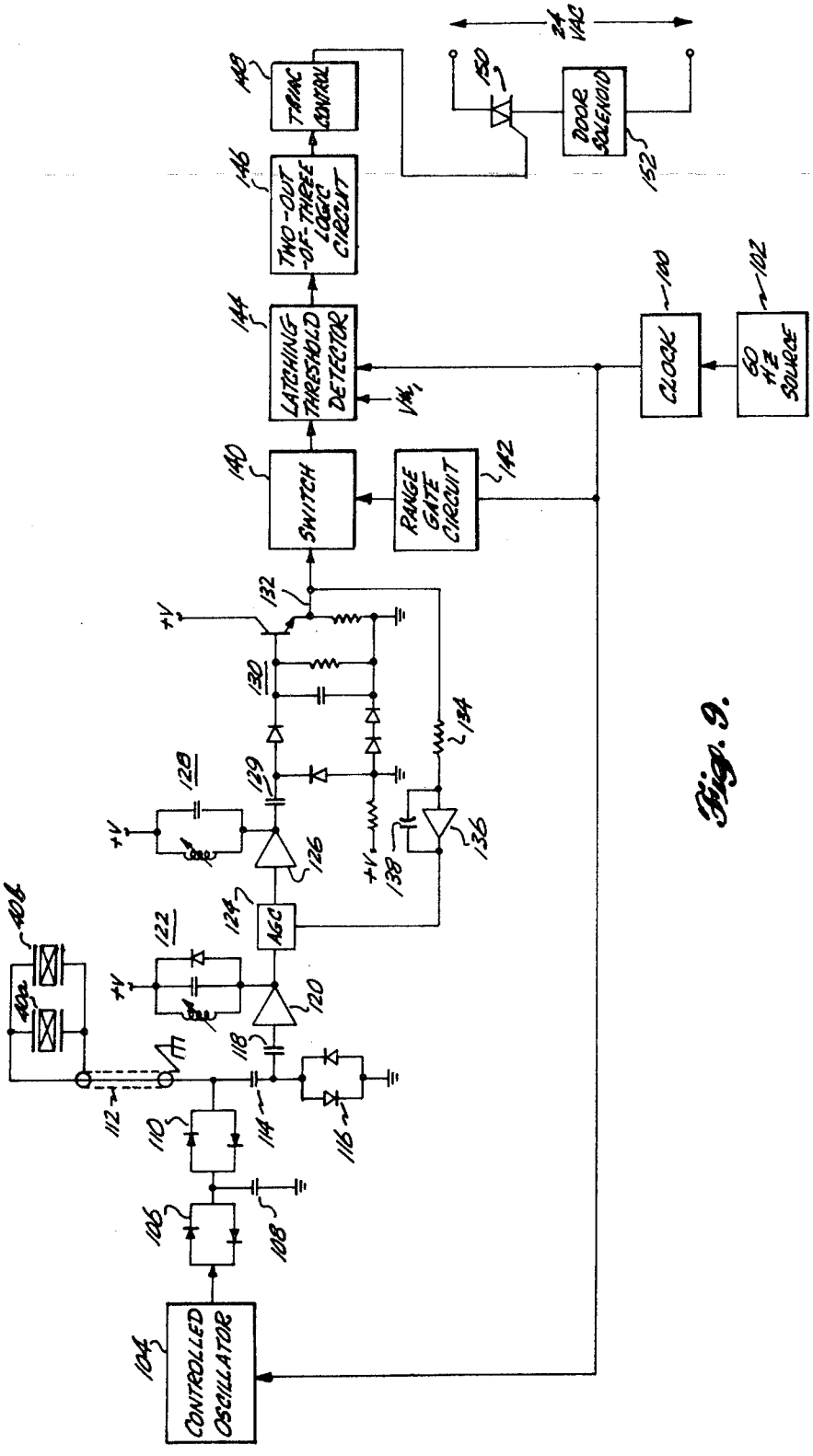

CONTROLLED OSCILLATOR
104
105
108
110
112
114
116
118
120
122
124
126
128
129
130
132
134
136
138
140
SWITCH
142
RANGE GATE CIRCUIT
144
LATCHING THRESHOLD DETECTOR
146
TWO-OUT-OF-THREE LOGIC CIRCUIT
148
TAMC CONTROL
150
152
DOOR SOLENOID
24 VAC
CLOCK
100
60 Hz SOURCE
102
AGC
+V

Fig. 9.

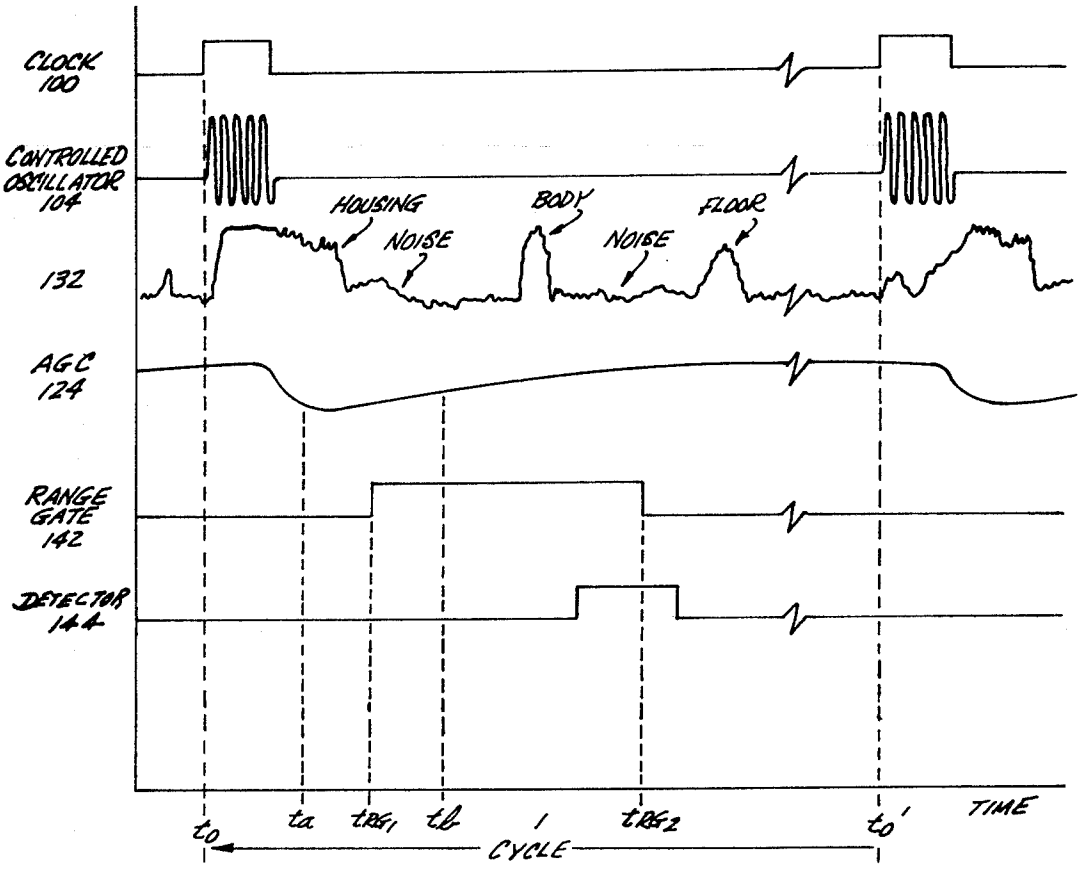

CLOCK 100
CONTROLLED OSCILLATOR 104
HOUSING
NOISE
BODY
NOISE
FLOOR
132
AGC 124
RANGE GATE 142
DETECTOR 144
TIME
t_o
t_a
t_{RG_1}
t_b
1 CYCLE
t_{RG_2}
t_o'

Fig. 10.

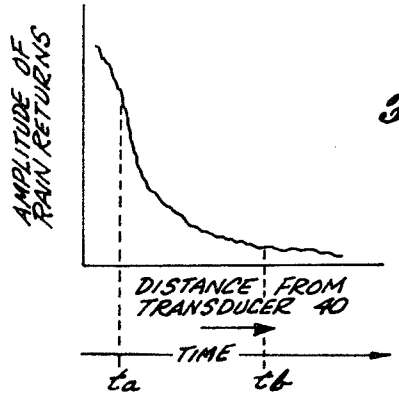

AMPLITUDE OF RAIN RETURNS
DISTANCE FROM TRANSDUCER 40
TIME
t_a
t_b

Fig. 11.

ACOUSTIC OBJECT DETECTION SYSTEM

FIELD OF THE INVENTION

This invention relates to object detection systems, and more particularly, to such systems for detecting objects by the use of acoustic waves.

BACKGROUND OF THE INVENTION

Object detection systems of the acoustic pulse-echo type have been known and used for some time, especially in traffic detection and control systems. Generally, such systems include a source of ultrasonic energy, an ultrasonic transducer coupled to the source for emitting a narrow pulse or series of pulses of ultrasonic energy, a second ultrasonic transducer for receiving return pulses from objects within a predetermined detection zone, and a detection circuit coupled to the ultrasonic transducer for providing an output signal when a predetermined criterion is met by the return pulses.

The present invention comprises an improvement in systems of this type which has applicability not only in traffic detection and control systems but also in many other fields, including door opening systems, personnel detection systems, and the like. The invention further relates to an antenna system for such an acoustic object detection system which permits a single transducer slug to be efficiently used as both a source and detector of the system.

It is another object of this invention to provide an acoustic object detection system which is particularly reliable in outdoor applications.

It is a further object of this invention to provide such an object detection system which includes the capability to distinguish between valid pulse returns and invalid pulse returns, such as might be caused by ground, wall, and precipitation surfaces.

It is yet another object of this invention to provide an object detection system which is particularly adaptable to the automatic opening and closing of doors.

It is still another object of this invention to provide an antenna system for an object detection system wherein means are provided to minimize unwanted pulse returns from the antenna system itself.

It is yet a further object of this invention to provide an antenna system for an object detection system in which control readily can be made of the beam pattern thereof.

SUMMARY OF THE INVENTION

These objects and others are achieved, briefly, by providing a mounting arrangement for a ceramic transducer slug which supports the slug within a cavity of a reflector housing so as to be capable of radiation and reception at both ends thereof, and by providing means within the system for maintaining all signals corresponding to noise or returns from precipitation at a substantially constant level.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can perhaps best be understood by reference to the following portion of the specification, taken in conjunction with the accompanying drawings in which:

FIG. **1** is a pictorial view showing a typical installation of two antenna systems for permitting bidirectional control of a dobr or doors;

FIG. **2** is a cut-away, pictorial view of one embodiment of the antenna system of this invention;

FIG. **3** is a back, sectional view of the antenna system of FIG. **2**;

FIG. **4** is a side, sectional view of the antenna system of FIG. **2**;

FIGS. **5** and **6** are additional back-sectional views of the antenna system showing alternate embodiments of the side inserts shown in FIG. **3**;

FIGS. **7** and **8** are cross-sectional views of additional alternate embodiments of these side inserts;

FIG. **9** is a block diagram of the electronic circuitry of the object detection system;

FIG. **10** is a timing diagram illustrating a typical cycle of operation thereof; and

FIG. **11** is a graph illustrating a relationship between return pulses from precipitation and distance thereof from a transmitting transducer.

DESCRIPTION OF A PREFERRED EMBODIMENT

With reference now to FIG. **1**, a wall surface **10** includes doors **12** and **16**. Passage through the door **12** is made in the direction of an arrow **14** and is controlled by a first acoustic object detection system including an antenna system **20A** positioned on wall **10** so as to sense the presence of individuals desiring to pass in the direction **14**. Similarly, passage through the door **16** in the direction of an arrow **18** is controlled by a second acoustic object detection system including an antenna system **20B** located on wall **10** so as to sense the presence of individuals desiring to pass in the direction **18**.

It can be readily appreciated that acoustic object detection systems encounter many difficulties in applications such as illustrated in FIG. **1**. For example, false return pulses can be provided by the reflector housing of the antenna system, by the wall surface **10**, by either of the doors **12** or **16**, by the floor, railings and other adjacent objects, and so forth. If the acoustic object detection system is used outdoors, false return pulses can also be obtained from the surfaces of precipitation.

Therefore, the system must compensate for false returns to the extent that they do not mask desired returns from individuals or other objects within a predetermined detection zone. The embodiment of the antenna system illustrated in FIGS. **2–4** minimizes ringing of the reflector housing thereof and additionally allows variable control of the antenna's beam pattern so as to sharply define the desired detection zone, thereby further reducing false returns.

In more detail, the antenna system includes a reflector housing **22** of metallic material which preferably has a rough finish on all surfaces thereof. In one embodiment, the material comprised an aluminum alloy. The upper end of the reflector housing **22** is closed and the sides thereof are flared therefrom to define an interior cavity. The lower ends of the housing sides additionally define a substantially rectangular aperture for the transmission and reception of ultrasonic pulses. The narrower sides of the reflector housing **22** include recessed portions **22*a***, **22*b*** which are flared at a greater angle than are the corresponding sides.

As a result, the interior cavity of the housing **22** is defined by left and right, gradually-tapered surfaces **26*b***, **26*b'***, by adjoining sharply-tapered surfaces **26*a***, **26*a'***, and by front and back, gradually-tapered surfaces **24*a***, **24*b***. Energy absorbing inserts **28, 29** are affixed to sur-

faces 24*b* and 24*a*, and beam-directing inserts **30, 31** are affixed to surfaces 26*a*, 26*a'*. A transducer assembly **32** extends downwardly into the cavity and is supported in a manner to be described in more detail hereinafter.

With particular reference now to FIGS. 3–4, the reflector housing **22** is shown in back-sectional and side-sectional views, respectively. In these views, the beam-directing inserts **30, 31** have been replaced by longer embodiments thereof, **30'**, **31'**, but otherwise the device is identical to that shown in FIG. **2.** The transducer assembly **32** includes a ceramic slug **40** having left and right end surfaces **40***a*, **40***b*, respectively. In a practical embodiment, a lead zirconate ceramic was used. As can be seen, ceramic slug **40** is mounted in such a manner by the transducer assembly **32** so that transmission occurs simultaneously in opposite directions **T1, T2.** By this arrangement, the necessity for an energy-absorbing means at one end of the ceramic slug is eliminated. In addition, the power output of the transducer is practically doubled by virtue of the increased radiating surface.

Since the ultrasonic radiation occurs substantially in a direction normal to the plane of the surfaces **40***a*, **40***b*, it first comes into contact with the beam-directing inserts **31'**, **30'**. The surface configuration of these inserts and their relative orientation with respect to the directions **T1, T2,** largely determine the beam pattern of the antenna system. Therefore, choice of these inserts allows control of the system's detection zone. Additional embodiments **31''** and **31** are shown in FIGS. **5** and **6,** respectively.

As noted in FIGS. **7** and **8,** the configuration of the beam-directing inserts may also be varied in cross-section so as to vary the relative strength of the beam in planes parallel to the surfaces **40***a*, **40***b* of the ceramic slug **40.**

The beam-directing inserts are preferably composed of a plastic material having a smooth surface presented to the interior cavity. In assembly, the beam-directing inserts are positioned within the cavity adjacent inner surfaces 26*a*, 26*a'*. Fine tuning is then accomplished by adjustment of fasteners **33, 34,** which are threaded through corresponding apertures in housing **22** into each beam-directing insert. When tuning is accomplished, the inserts are then maintained in place by an adhesive.

As will be readily recognized by those skilled in the art, the beam-directing inserts function in a similar manner to direct returns of the transmitted pulses back to the surfaces **40***a*, **40***b*.

In order to minimize ringing of the antenna system itself, the design thereof must compensate for the fact that ceramic slugs commonly used have a narrow bandwidth and a high Q. The application of an ultrasonic pulse thereto causes an oxcillation therein which, if left undamped, would persist for a time sufficient to mask some returns from desired objects within the detection area. In addition, returns arising from pulse transmission from the ceramic slug **40** through the transducer arrangement **32** to the housing **22** and back must be minimized, as must those pulses returning through the air from the housing **22.**

In order to damp the slug oscillations, the slug **40** is wrapped with an inner layer 42*a* of neoprene, and an outer layer 42*b* of corprene. Layer 42*a* functions primarily to dampen the slug oscillations, whereas layer 42*b* functions primarily to isolate these oscillations from the housing **22.** In order to achieve the proper amount of damping, the slug **40** is clamped by a nylon clamp **44.** The circumferential compression force exerted on slug **40,** and thus the amount of damping, is adjusted by means of a fastener **46** passing through both legs of clamp **44.** In order to complete the isolation of the slug **40** from the housing **22,** the clamp **44** is in turn covered with separate portions 48*a*, 48*b*, of corprene. This assembly is then secured to the housing **22** by at least one nylon strap **50** whose ends terminate in adjustable tensioning fasteners **51, 52** mounted in the upper surface of housing **22.** Electrical connections are made from the ceramic slug **40** to appropriate terminal points in a cavity **53** and connections thereafter made to the remainder of the system by a cable not illustrated. The cavity **53** may be filled with a suitable potting compound and enclosed by a cover plate **54.**

To minimize ringing of the housing **22** itself, the energy-absorbing inserts **28** and **29** are provided. Preferably, these inserts are composed of a plastic material having a relatively rough finish and are secured to the inner surfaces 24*b*, 24*a*, by a suitable adhesive.

The antenna system including reflector housing **22** is mounted to an appropriate fixed surface, such as wall **10** in FIG. **1,** by a plurality of nylon fasteners **56** which serve to electrically isolate the mounting surface and the housing **22** so as to further minimize false returns.

Electronic circuitry of the acoustic object detection system suitable for use in a door opening system is seen in FIG. **9.** Reference should also be made throughout the ensuing discussion to the timing diagram in FIG. **10.** In the embodiment in FIG. **9,** timing pulses are provided by a clock source **100.** For example, these pulses may be derived from a commonly-available 60 Hz source **102** and comprise pulses having a width of one millisecond which occur at a repetition rate of 15 Hz. To avoid interference between adjacent systems, the clock pulses in one system may be phase-shifted from those in a second system.

The clock pulses from clock source **100** are applied in turn to a controlled oscillator **104,** to a range gate circuit **142,** and to a latching threshold detector **144.** Controlled oscillator **104** comprises a standard oscillator and driver stage operable to provide an output pulse of electrical energy in the ultrasonic frequency range for the duration of the input clock pulse thereto. In a practical embodiment, the frequency of oscillator **104** was 75 KHz.

The pulse of electrical energy in the ultrasonic frequency range is applied through a first portion of a duplex circuit including a first pair of reverse-parallel diodes **106,** capacitor **108,** a second pair of reverse-parallel diodes **110,** and a shielded, RF cable **112** to ceramic slug **40.** The transmitting pulse is blocked from the remainder of the electronic circuitry by a second portion of the duplex circuit including a capacitor **114** and a third pair of reverse-parallel diodes **116,** both of which are coupled from the common junction of the signal lead of RF cable **112** and diodes **110** to a source of reference potential.

Shortly after the termination of the transmitting pulse, return pulses are detected by the ceramic slug **40** and coupled by RF cable **112** to the common junction of the duplex circuit. At this time, the duplex circuit acts to couple signals corresponding to the return

pulses directly to the input of an amplifier **120** through capacitor **114** and a capacitor **118.**

The return pulses generally comprise four types. First, return pulses from the reflector housing **22** and its elements. These ringing pulses cannot be eliminated because of the proximity of the housing **22** to the ceramic slug **40,** but can be minimized and controlled by use of the antenna design previously discussed. In most cases, the ringing pulse from the housing **22** will have a longer duration than that of the transmitting pulse of ultrasonic energy, due to ringing of the housing. Second, return pulses from the body of any individual within the detection zone. These pulses will arrive at the ceramic slug **40** at some time after the first or "housing" return pulse because of the corresponding greater distance between the individual and the slug **40.** These pulses will be formed by reflections from the head and shoulder surfaces, then other, lower surfaces of the body and will comprise a relatively high-amplitude, short-duration pulse. In a door-opening system, these return pulses represent the desired object to be detected. The relative time occurrence of these return pulses will vary with respect to that of the transmitting pulse of ultrasonic energy, due to differences in the height and physical characteristics of individuals. Other objects within th detection zone will also cause large return pulses in this time period.

Third, a return pulse corresponding to a reflection from the floor. This return pulse will arrive after the "housing" and "body" return pulses. The relative time occurrence of this pulse with respect to the pulse of ultrasonic energy is substantially constant.

Fourth, miscellaneous pulses, which may be characterized as noise. As such, they may comprise either reflections of the transmitted pulse from the ceramic slug **40,** or signals arising from other sources within or without the detection zone. A special case of noise comprises those reflections from precipitation, such as from rain droplets.

Noise signals having a different frequency than that of oscillator **104** are discriminated against by tuning amplifier **120** by a circuit **122** connected from the voltage source V_s to the output terminal thereof. The output signal is then coupled through an automatic gain circuit **124** and a second amplifier **126,** which is tuned by a second circuit **128,** and a capacitor **129** to the input of a rectifying and level-shifting circuit **130.** The signal occurring on the output terminal **132** of circuit **130,** comprises a rectified version of the four types of return pulses heretofore mentioned.

Because the "noise" return pulses are random, they must be normalized prior to further signal treatment. Therefore, the system includes a feedback connection from terminal **132** to the control input of automatic gain control circuit **124** which comprises an integrator including a series-connected resistor **134** and operational amplifier **136,** and a capacitor **138** connected in feedback around operational amplifier **136.**

The combination of the integrator in the feedback connection and the automatic gain control circuit **124** functions as a noise automatic gain control and as a sensitivity time control. First, the integrator is designed to have a time constant longer than the expected duration of the "body" return pulses. In this manner, signals corresponding to these return pulses do not affect the operation of the automatic gain control. Second, as the "noise" return pulses are generally continuous, the combination averages out long-term differences therein so as to hold the envelope of the "noise" return pulses at a substantially constant level.

Third, the combination serves to discriminate against "rain" return pulses in a unique manner. With particular reference now back to FIG. **10,** a signal corresponding to the "housing" return pulse acts to substantially lower the gain of the system at time T_a, inasmuch as the "housing" return pulse is of extended duration greater than the time constant of the integrator and inasmuch as the magnitude thereof is relatively large. The gain gradually increases thereafter. With particular reference now to FIG. **11,** it has been found that the amplitude of the "rain" return pulses diminshes as the inverse of the distance of the droplets from the ceramic slug **40.** Therefore, the magnitude of the "rain" return pulses is greatest for droplets immediately adjacent the housing **22.** However, it is at this distance, or at the corresponding time t_a, that the attenuation of the automatic gain control circuit **124,** in response to the large "housing" return pulse, is greatest. At time t_b, the returns are much weaker but the gain of the system has been increased. Therefore, the "rain" return pulses are also averaged so that the resultant noise signal is substantially equivalent to the averaged "noise" return pulses.

Therefore, the signals on terminal **132** which correspond to the four types of return pulses, as modified, appear as shown in FIG. **10.** These signals are applied to the input of a normally-open switch circuit **140** whose output is coupled to the latching threshold detector **144** and which is controlled by the range gate circuit **142.** The control signal from range gate circuit **142** is seen in FIG. **10** and begins at a first predetermined time t_{RG1} after the production at t_0 of the clock pulse from clock source **100** and terminates at a second predetermined time t_{RG2} thereafter. The times T_{RG1}, T_{RG2} are chosen to block signals corresponding to the "housing" and "floor" return pulses.

The latching threshold detector **144** is normally reset at the beginning to each cycle of operation by the clock pulse from clock source **100.** In this first state, latching threshold detector provides no output signal. However, when range gate circuit **142** has opened switch **140,** latching threshold detector **144** is triggered into its second state when the magnitude of the signal presented thereto exceeds a threshold value V_{th1}. The value of V_{th1} is chosen to be greater than the average value of the signals corresponding to the "noise" and "rain" return pulses. Therefore, latching threshold detector **144** blocks noise signals from its output for a certain period of time. If an individual or other object is not within the detection zone, no "body" return pulse is provided and therefore latching threshold detector **140** remains in its first state so that no output signal is provided throughout the time that switch **140** is opened by the range gate circuit **142.**

However, if latching threshold detector **144** is placed into its second state by a large return pulse, the signals are coupled to the input of a two-out-of-three logic circuit **146.** The choice of a two-out-of-three logic circuit is predicated on the assumption that an individual or other object within the detection zone will create at least two relatively-large amplitude return pulses exceeding the threshold level V_{th1} during successive cycles determined by the clock pulses.

Therefore, logic circuit **146** comprises a counter which furnishes an output signal for a predetermined period of time when return pulses are detected during the range gate period for two out of three successive cycles. This output signal is applied to a Triac control circuit **148** which is of a standard configuration. In response, Triac control **148** provides a control signal to the gate electrode of a Triac **150** which is connected in series with a door solenoid **152** across a suitable alternating current voltage source. The time period of conduction of Triac **150**, after passage of an individual is on the order of one second, so as to hold the door open to allow passage of the individual therethrough and so as to prevent oscillation of the door in response to secondary detections of the individual within the detection zone at the next and succeeding clock pulses from clock pulse source **100**.

While the invention has thus been described in terms of the preferred embodiment, it is to be fully understood by those skilled in the art that the invention is not limited thereto, but rather is intended to be bounded only by the limits of the appended claims.

What is claimed is:

1. For an antenna system useful in an acoustic object detection system, the antenna system including a reflector housing defining an interior cavity, and a communicating aperture for the transmission and reception of acoustic waves and a substantially cylindrical slug transducer situated within the interior cavity, an improvement in a mounting assembly for the transducer slug, said assembly comprising a first layer of acoustic insulating material wrapped around the circumferential surface of said transducer slug, clamp means for exerting a compressional force on said circumferential surface, a second layer of acoustic insulating material surrounding said clamp means, and resilient strap means passing around said second layer and terminating in the reflector housing for securing said assembly to said housing.

2. An improvement as recited in claim **1**, wherein said first layer of acoustic insulating material comprises an inner layer of material suitable for damping vibrations of the transducer slug, and an outer layer of material suitable for isolating vibrations of the transducer slug from said clamp means.

3. An improvement as recited in claim **1**, wherein said clamp means and said strap means are composed of nylon.

4. An improvement as recited in claim **1**, wherein said second layer comprises a corprene.

5. An antenna system useful in ultrasonic detection systems, said antenna system comprising:

a. a reflector housing having a closed upper end and front, back and side surfaces flaring out from said closed upper end to define an interior cavity which terminates in a substantially rectangular aperture for the transmission and reception of ultrasonic waves,

b. an elongated ceramic transducer slug having first and second wave-generating surfaces at opposite ends thereof,

c. assembly means supporting said ceramic transducer slug from said reflector housing in said interior cavity so that the longitudinal axis thereof is substantially parallel to said front and back surfaces and substantially normal to said side surfaces,

d. means within said assembly means for damping vibrations of said ceramic transducer slug occurring in the direction of said longitudinal axis, and

e. insert means affixed to each of said side surfaces including a surface for directing ultrasonic waves to and from said first and second wave-generating faces.

6. An antenna system as recited in claim **5**, wherein each of said insert means covers all of its corresponding side surface and wherein its surface has a greater angle of slope with respect to said longitudinal axis of said ceramic transducer slug than does said corresponding side surface.

7. An antenna system as recited in claim **5**, wherein each of said insert means only covers an upper portion of its corresponding side surface.

8. An antenna system as recited in claim **7**, wherein the surface of each of said side insert means has a lesser angle of slope with respect to said longitudinal axis of said ceramic transducer slug than does said corresponding side surface.

9. An antenna system as recited in claim **5**, wherein the surface of each of said insert means is planar.

10. An antenna system as recited in claim **5**, wherein the surface of each of said insert means is convex.

11. An antenna system as recited in claim **5**, further comprising second insert means affixed to each of said front and back surfaces for absorbing ultrasonic waves within said interior cavity.

12. An antenna system useful in ultrasonic detection systems, said antenna system comprising:

a. a reflector housing having a closed upper end and front, back and side surfaces flaring out from said closed upper end to define an interior cavity which terminates in a substantially rectangular aperture for the transmission and reception of ultrasonic waves,

b. an elongated ceramic transducer slug having first and second wave-generating surfaces at opposite ends thereof,

c. assembly means supporting said ceramic transducer slug from said reflector housing in said interior cavity so that the longitudinal axis thereof is substantially parallel to said front and back surfaces and substantially normal to said side surfaces, said assembly means comprising a first layer of acoustic insulating material wrapped around the circumferential surface of said ceramic transducer slug, clamp means for exerting a compressional force on said circumferential surface, a second layer of acoustic insulating material surrounding said clamp means, and resilient strap means passing around said second layer and terminating in the reflector housing for securing said assembly to said housing, and

d. insert means affixed to each of said side surfaces including a surface for directing ultrasonic waves to and from said first and second wave-generating surfaces.

13. An antenna system as recited in claim **12**, wherein each of said insert means covers all of its corresponding side surface and wherein its surface has a greater angle of slope with respect to said longitudinal axis of said ceramic transducer slug than does said corresponding side surface.

14. An antenna system as recited in claim 12, wherein each of said insert means only covers an upper portion of its corresponding side surface.

15. An antenna system as recited in claim 14, wherein the surface of each of said side insert means has a lesser angle of slope with respect to said longitudinal axis of said ceramic transducer slug than does said corresponding side surface.

16. An antenna system as recited in claim 12, wherein the surface of each of said insert means is planar.

17. An antenna system as recited in claim 12, wherein the surface of each of said insert means is convex.

18. An antenna system as recited in claim 12, further comprising second insert means affixed to each of said front and back surfaces for absorbing ultrasonic waves within said interior cavity.

* * * * *