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Massa

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[54] INTRUSION ALARM SYSTEM WITH
IMPROVED AIR TURBULENCE
COMPENSATION

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340/16 R

[51] Int. Cl. G08b 13/16

[58] Field of Search 340/1 R, 3 D, 16 R, 258 R,
340/258 A, 258 B

2,767,393	10/1956	Bagno	340/258 A
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2,782,405	2/1957	Weisz et al.	340/258 A
3,383,678	5/1968	Palmer	340/258 A
3,638,210	1/1972	Hankins et al.	340/258 A
3,662,371	5/1972	Lee et al.	340/258 R
3,665,443	5/1972	Galvin	340/258 A

Primary Examiner—David L. Trafton

[57] ABSTRACT

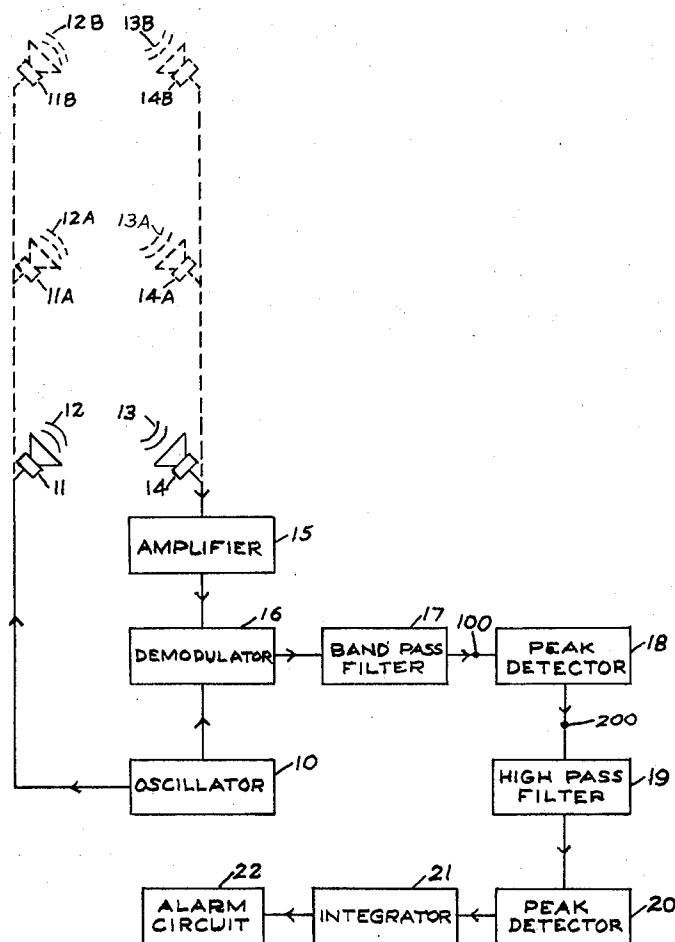
This ultrasonic intrusion alarm system responds to the Doppler shift caused by moving intruders. Instantaneous changes in amplitude are detected by peak detectors. The detected signals are filtered to reduce the sensitivity to low frequency air turbulence.

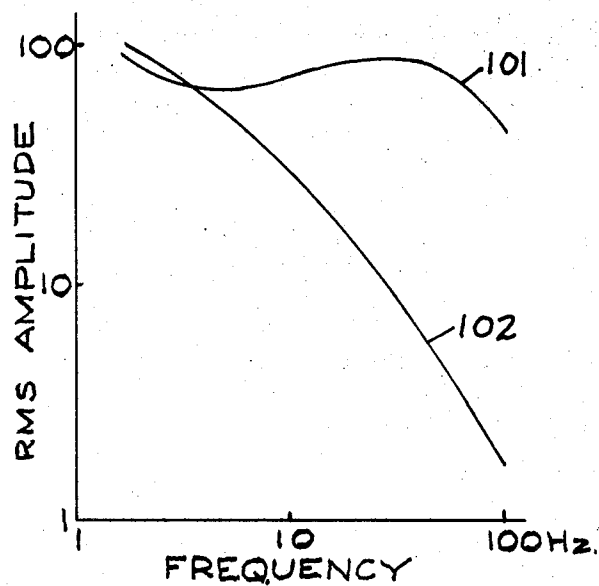
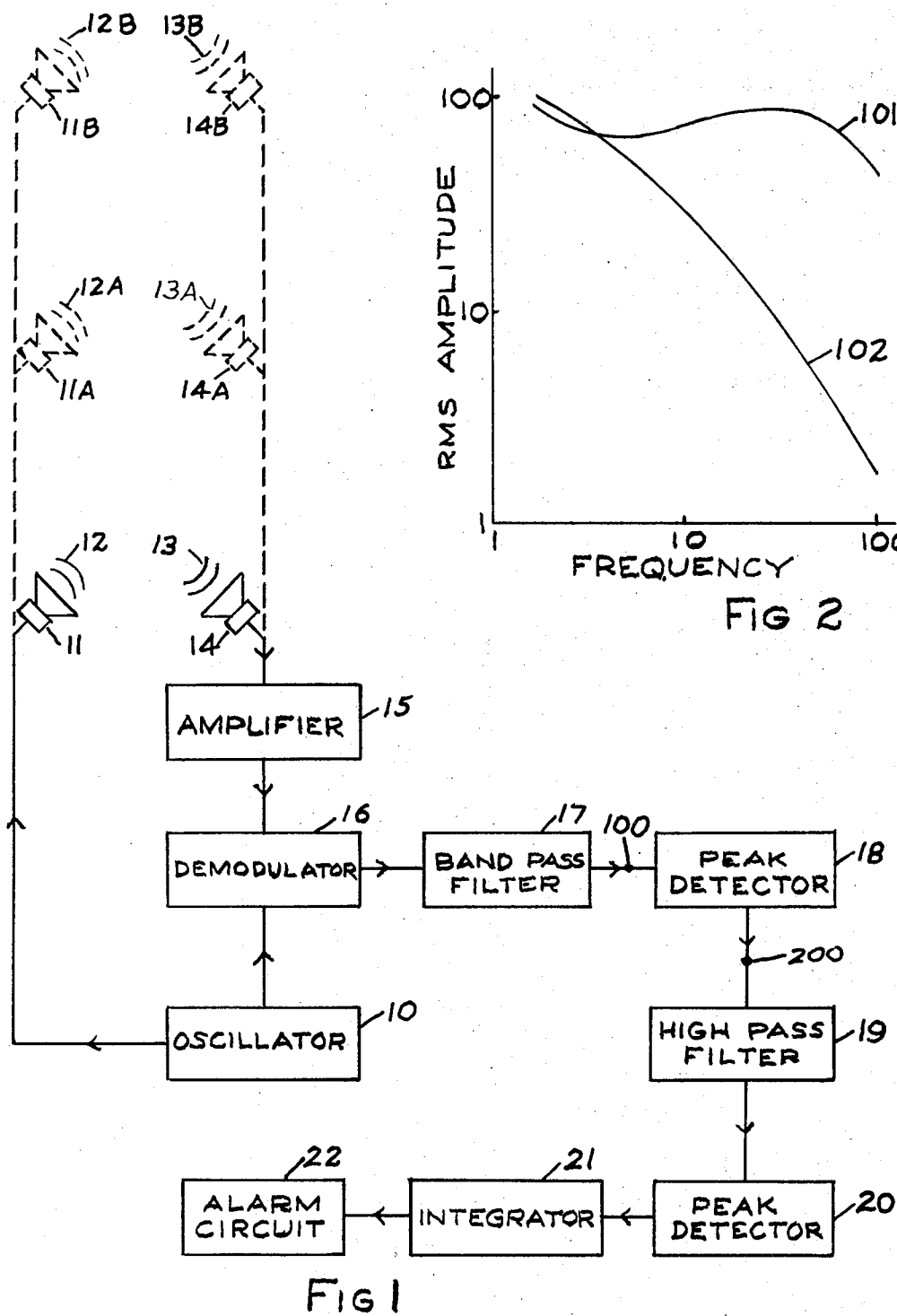
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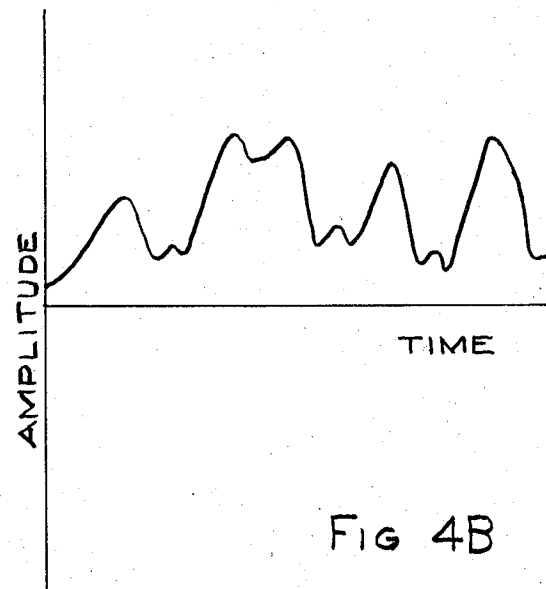
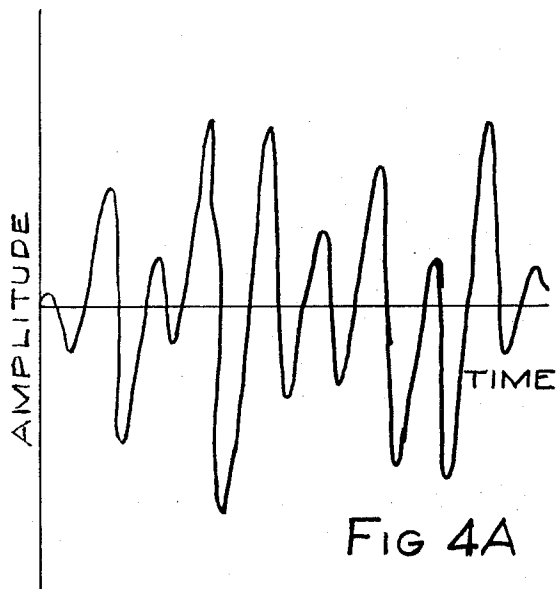
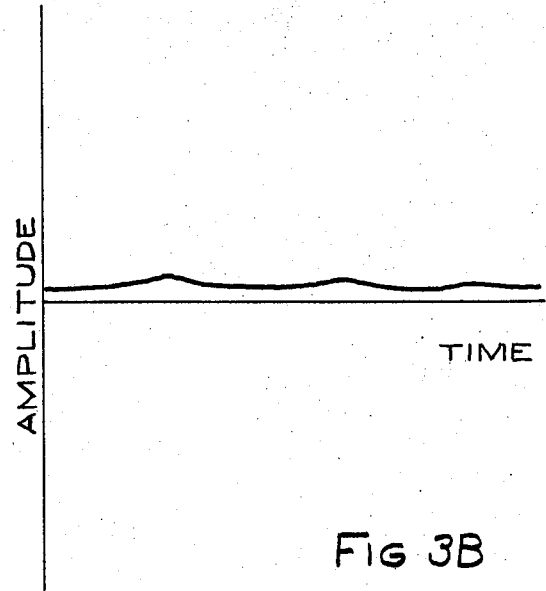
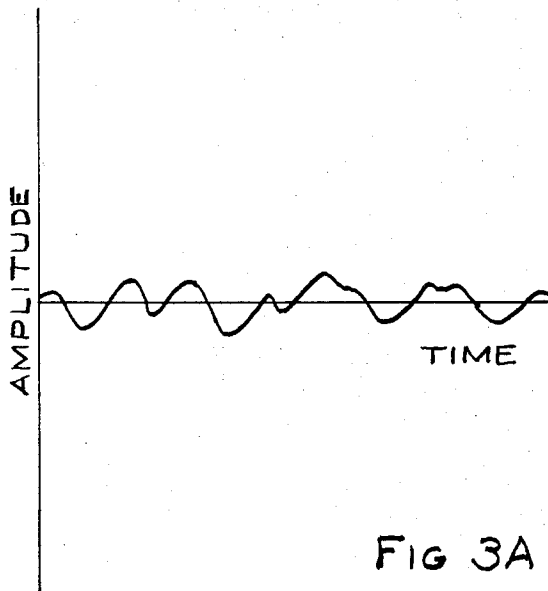
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13 Claims, 6 Drawing Figures







INTRUSION ALARM SYSTEM WITH IMPROVED AIR TURBULENCE COMPENSATION

This invention relates to intrusion detection systems and more particularly to improvements in the reliability of ultrasonic detection systems in which the presence of a moving target within secured area is detected by means of a Doppler shift in the transmitted ultrasonic frequency caused by the motion of the target. The use of ultrasonics for intrusion detection is well known. An early description of a Doppler intrusion alarm is given by Bagno in U.S. Pat. 2,655,645 issued Oct. 13, 1953 where a system is described in which the space to be protected is insonified by an acoustic signal generated by a transmitting transducer, and the sonic energy, after being reflected from the surfaces of the walls and objects within the area, is picked up by a microphone. In the absence of any motion within the room the frequency of the received signal is the same as the frequency of the transmitted signal. If a moving target enters the insonified area the signal reflected from the target will be shifted in frequency due to Doppler, and a comparison of the transmitted and received frequencies will then indicate the presence of a target.

One of the most serious problems that has persistently limited the reliability of ultrasonic intrusion detection systems has been the false alarms which occur because of ambient variables such as generally result from normal air motion within the zone of surveillance. This problem has long been recognized and numerous attempts have been made to find a practical solution but none with completely satisfactory success. In general, improvements in false alarm rates have been achieved by sacrifice of the threshold sensitivity of the system or by increased complexity and cost of the signal processing circuitry in the system. All of the prior art attempts for reducing false alarm rates due to air turbulence have utilized various circuit modifications to make the system selectively more sensitive to changes caused by a moving target as compared to changes produced by air currents within the protected zone.

The various procedures described in the prior art for reducing false alarms due to air turbulence all depend for their operation on different methods for processing the data shown by Bagno et al. in FIG. 3 of U.S. Pat. No. 2,794,974 dated June 4, 1957. This is a graphic representation of r.m.s. amplitude vs. frequency spectrum of the acoustic signals (averaged over 30 sec. periods) which appear in the microphone output in the presence of various air turbulence type phenomena in comparison to the frequency spectrum of the signals which appear when a human target is walking through the insonified area at a normal walking speed of 30 inches/second. The Bagno et al. data show that the averaged r.m.s. amplitude of the signals appearing in the microphone output in the presence of air turbulence is relatively high at the low end of the frequency spectrum and falls off approximately linearly with increasing frequency over the frequency range 2 Hz to 100 Hz. The Doppler frequencies produced by a walking human target are shown to be of approximately constant amplitude over the same frequency range. Thus the data indicates that the long time r.m.s. average amplitudes of signals introduced by air turbulence and by a walking human being are approximately equal in the low frequency region below 5 Hz whereas the signals

introduced by a walking person are very much greater in average amplitude in comparison to the corresponding air turbulence signals in the high frequency region from about 20 Hz to 80 Hz.

Bagno et al. in U.S. Pat. No. 2,794,974 utilize the differences in the amplitude vs. frequency spectrum of the signals appearing in the microphone output to discriminate against false alarms caused by air turbulence. This patent separates the demodulated signal into two channels, one for processing the low frequencies between 2 and 5 Hz and another for processing the high frequencies between 25 and 50 Hz. Then the alarm is not set off if the averaged signal amplitude appearing in the high frequency channel is "considerably less" than the averaged signal amplitude appearing in the low frequency channel. The alarm is set off when the averaged amplitude of the signal in the high frequency channel increases over a preset limit with reference to the low frequency averaged signal level.

In addition to the disadvantage of high cost introduced by the dual channel signal processing required by the Bagno et al method of compensating for air turbulence their method is not very effective in curing false alarms from air turbulence. The basic difficulty results from the fact that the high and low frequency signals as produced by air turbulence and by a walking person are very random in nature so that the smooth amplitude distribution data presented in FIG. 3 of Bagno et al. is only true when averaged over long periods of time (the averaging periods for the data in FIG. 3 of Bagno et al. is stated as 30 seconds). Obviously, with long time averaging being a necessary requirement in the Bagno et al. system for using their amplitude vs. frequency comparison method for discriminating against false alarms due to air turbulence it would be possible for an intruder to walk slowly in successive spurts of short duration and thereby escape detection.

Many other attempts have been made to use the amplitude vs. frequency spectral data disclosed by Bagno et al and avoid the serious disadvantage introduced by the requirement of long time averaging which is necessary to overcome the random nature of the amplitude variations. Bagno in U.S. Pat. No. 3,111,657 issued Nov. 19, 1963 tries to overcome the above mentioned inherent deficiencies introduced by the random nature of the signal amplitude variations which necessitates the use of long time constant averaging. He introduces further costly complications in the dual channel signal processing system of Bagno et al. and adds different time constants in the low and high frequency channels. He thus achieves a compromise between two undesirable choices of either increasing the time constants of the integrating circuits to obtain a better averaging of the random nature of the signal amplitudes which is required to reduce false alarms caused by air turbulence, or reducing the time constants which is necessary to make the system effective against the sophisticated intruder who might otherwise not be detected with the long time constants in the integrating circuits.

Hankins et al in U.S. Pat. No. 3,638,210 issued Jan. 25, 1972 are also attempting to solve the long standing problem of false alarms which occur in ultrasonic intrusion detection systems due to air turbulence. Hankins et al use a somewhat different embodiment of the dual channel, dual time constant signal processing method employed by Bagno. Bagno divides the demodulated

signal into two separate channels and introduces a long time constant in the low frequency channel and a shorter time constant in the high frequency channel whereas Hankins et al extract from the demodulated signal a single frequency band in the 40 Hz region and then split the filtered signal into two separate channels. One channel is connected to a positively phased voltage doubler and the other channel is connected to a negatively phased voltage doubler. Each channel has an integrating circuit with a different time constant for averaging the random varying amplitude of the 40 Hz signal. The time constant in one channel is made higher than in the other channel. When the outputs from the oppositely phased voltage doublers are connected together the sum voltage will be zero in the absence of an intruder. When an intruder appears as a moving target the channel with the shorter time constant will respond faster than the other channel and as a result the unbalanced signal across the voltage doublers will fire the alarm circuit. This modification of the Bagno system still has the drawbacks of employing dual channels for processing which adds to complexity and cost and because this system only looks at the average amplitude of the 40 Hz signal it still retains the disadvantages of the earlier systems which will false alarm in high turbulence air and will be subject to not detecting true targets which move slowly and thereby generate weak Doppler signals in the 40 Hz band.

Still another variation in signal processing for improving false alarm rates in turbulent air environments is proposed by Galvin in U.S. Pat. No. 3,665,443 issued May 23, 1972. Galvin makes use of the same basic spectral amplitude information originally shown by Bagno et al and he also makes use of the additional fact that the air turbulence spectrum which shows an increase in amplitude with decreasing frequency on a long time averaged amplitude basis is symmetrically distributed in both the upper and lower side bands about the ultrasonic carrier frequency. The moving target signal, however, will contain Doppler frequencies which appear only in the upper or lower side band depending on whether the target is moving toward or away from the receiving transducer, thereby causing either a positive or negative Doppler shift. Galvin splits the received ultrasonic signal into an upper side band channel and a lower side band channel and then sends the signals from the two separate channels to separate detectors; one positive and one negative. In the presence of balanced signals in each side band, both detectors generate equal voltages of opposite polarities and their sum will be zero and the alarm will not be triggered. In the presence of unbalanced side band signals such as is caused by a moving target, the unbalanced detector output will trigger the alarm circuit. This method of reducing false alarms due to air turbulence presupposes balanced upper and lower side band signals due to air turbulence which is not necessarily true in random air turbulence situations unless long time averaging of the signal amplitudes are employed. Since Galvin is required to use relatively long time constants for obtaining a stable symmetrical averaging of the random amplitude levels that are generated by the air turbulence, his system remains subject to the same limitations of the previous systems; namely, the longer the time constant the easier it is to defeat the alarm by a sophisticated intruder who can move slowly in short spurts and remain undetected. If the time constant is

made shorter, a lack of symmetry will occur in the air turbulence spectral distribution which will cause false alarms. Another major disadvantage of the Galvin system is the complex, costly multi-channel processing and the expensive ultrasonic side band splitting circuitry required.

All of the described prior art attempts to eliminate false alarms due to air turbulence have only partially achieved the desired objective. The partial improvement has been realized either at the sacrifice of threshold sensitivity or with decreased reliability of detection of a slow moving target with the long time constants necessary to integrate the randomly variable amplitudes of the air turbulence generated signals. In all cases, the complexity of the signal processing circuits, most of which require dual channels, add to the manufacturing cost of the systems which limits the potential size of the consumer market which can afford the increased price.

The present invention overcomes the drawbacks of the prior art ultrasonic intrusion alarm systems discussed above by making use of a novel principle of operation. Applicant's alarm responds to the instantaneous cycle to cycle rate of change of the amplitude of the demodulated signal and thereby eliminates the undesirable need for long time averaging which is necessary with the prior art systems which operate on the averaged amplitude vs. frequency spectrum of the turbulence and moving target generated signals. The application of this novel principle as described in this invention eliminates false alarms due to air turbulence and achieves this long sought after objective with a very simple single channel low cost circuit.

An object of this invention is to provide a new and improved ultrasonic intrusion alarm system which eliminates false alarms in the presence of high air turbulence without decreasing the threshold sensitivity of the detection system.

Another object of the invention is to improve the efficiency of detection of an ultrasonic intrusion detection system in the presence of adverse ambient conditions such as air turbulence, thermal gradients or noisy backgrounds.

A further object of this invention is to simplify the signal processing in the system thereby reducing the complexity of the system with corresponding increased reliability and decreased manufacturing cost.

A still further object of this invention is to reduce the susceptibility of the alarm system to transient disturbances.

Another object of this invention is to provide an improved system which will permit the use of multiple transmitting and receiving transducers for covering a large area to be protected without sacrificing the basic improvements in performance which are realized by the novel system.

These and other objects, features and advantages of the invention will become more fully apparent from the following detailed description of one preferred embodiment taken in conjunction with the accompanying drawings in which:

FIG. 1 is a system block diagram illustrating one embodiment of this invention.

FIG. 2 is a chart representing the amplitude vs. frequency spectrum of the signals appearing in the demodulated signal in an ultrasonic intrusion detection

system caused by air turbulence and by a moving target.

FIGS. 3A and 3B show the signals appearing respectively at the two points 100 and 200 in the circuit of FIG. 1 in the presence of air turbulence.

FIGS. 4A and 4B show the signals appearing at the same points in the circuit of FIG. 1 when a moving target is present.

Referring more particularly to the figures, FIG. 1 shows a system block diagram illustrating an embodiment of this invention. An oscillator 10 drives the transmitting transducer 11 with a frequency f_c which results in the generation of an acoustic signal 12 of the same frequency which is radiated from the transducer to insonify the area to be protected against intrusion. If the area is too large to be covered by a single transducer the transducer 11 may be supplemented by connecting additional transducers such as 11A and 11B to the same oscillator signal which supplies power to transducer 11 such as is illustrated by the dotted lines in FIG. 1. The radiated acoustic signal 12 is reflected from any objects or surfaces that may be within the range of coverage by the transmitter 11 and the reflected signal 13 will be picked up by the receiving transducer 14 as illustrated. For large areas of coverage additional receivers such as 14A and 14B may be connected together with receiver 14 as shown by the dotted lines in FIG. 1.

If there is no motion of air and no moving targets are present within the insonified zone, the reflected signal 13 that reaches receiver 14 will only contain the single frequency f_c . If a moving target is present within the area the reflected signal reaching receiver 14 will contain both the frequency f_c which is reflected from any stationary object and also a frequency which is greater or less than f_c by an amount which corresponds to the Doppler frequency shift which is generated by the movement of the target. The Doppler frequency shift f_D , which is proportional to the velocity of the moving target, increases f_c if the target is moving toward the receiver picking up the reflected signal and decreases f_c if the target is moving away from the receiving transducer.

Referring further to FIG. 1, the output of the receiving transducer 14 is applied to the input of an amplifier 15 and the amplified signal is demodulated by the demodulator 16. The demodulator also receives an input signal from the oscillator 10 which is of the same frequency f_c being supplied to the transmitter 11. Alternatively it is also possible to use the received ultrasonic signal directly and accomplish the demodulation without need for the oscillator reference signal. During the demodulation process the carrier frequency f_c is removed from the received signal and only the low frequency signals introduced by air turbulence or by the Doppler shift caused by the moving target will remain at the output of the demodulator 16. The demodulator may be any one of the many types well known in the art such as a peak detector demodulator, for example. The demodulated signal will not contain any low frequency signals other than DC if there is no moving target or air turbulence in the insonified zone. In the presence of air turbulence or a moving target the demodulator output will contain the well known spectrum of low frequency signals as shown in FIG. 2. The curve 102 is the long time average r.m.s. amplitude vs. frequency spectrum which results from air turbulence and the curve 101 is

a similar long time amplitude vs. frequency spectrum which results from the Doppler shift caused by a moving target within the insonified zone. The two curves indicate that the relative amplitudes of the two signals are approximately equal in the frequency region from 2 to 5 Hz and that the amplitude of the Doppler signal created by a moving target is about an order of magnitude greater than the air turbulence signal amplitude in the frequency region from 20 – 80 Hz. These data were taken with a carrier frequency f_c set to approximately 20 kHz which is in the vicinity of the frequency being used by many intrusion alarms. The carrier frequency could of course be changed without affecting the basic operation of the new system in this invention. If the carrier is reduced below 18 kHz, however, the signal will become audible which would generally be undesirable, and if it is increased above 50 kHz the attenuation of the ultrasonic signal will be too high; therefore, the ultrasonic carrier frequency is preferably chosen between 18 kHz – 50 kHz. If the carrier frequency is chosen in the higher portion of this range the Doppler shift curve 101 will be shifted proportionately higher in frequency, but the general relationship which is illustrated in FIG. 2 between the relatively uniform amplitude vs. frequency characteristic (curve 101) for the moving target signals and the falling off of the amplitude with increasing frequency for the air turbulence signals (curve 102) will remain unchanged.

It must be remembered that the amplitude vs. frequency characteristics illustrated in FIG. 2 are long time averaged values and that the various prior art methods which made use of these spectral amplitude differences between the signals resulting from a moving target and from air turbulence have the distinct disadvantages previously discussed.

The present invention makes a radical departure in the basic method of operation from all the prior art ultrasonic alarm systems by making use of the differences in the instantaneous rates of change of amplitude of the demodulated signal which applicant discovered while experimentally investigating the instantaneous time variations in the amplitude of the signal appearing at the output of the demodulator 16 under various conditions of operation. By analyzing the instantaneous variations in amplitude of the demodulated signal after passing it through the band pass filter 17 applicant found that the signal, as observed on an oscilloscope connected at the point 100 in the circuit of FIG. 1, appeared as shown in FIG. 3A when intense air turbulence was generated within the insonified area. The signal due to turbulence as shown in FIG. 3A indicates a relatively slow rate of change of peak amplitude from cycle to cycle as a function of time. This general characteristic showing a slow rate of change of amplitude variation in the air turbulence signal remained essentially unchanged and was not found to be critically dependent on the response characteristic of the filter 17 provided its low frequency cut-off was set above 5 Hz. The amplitude vs. frequency spectrum of the moving target Doppler signal is shown by curve 101 with an operating frequency of 20 kHz. If an ultrasonic frequency higher than 20 kHz is used in the system the curve 101 will be shifted higher in frequency. Satisfactory results were obtained in operating the newly described system with different band pass filters 17 whose center band frequency response varied over the approximate range 20 Hz – 80 Hz. The band width of the filter 17 was also

found to be not critical. Satisfactory operation of the new system was achieved with band width variations from approximately $\frac{1}{4}$ to 2 octaves. To secure optimum system performance the pass band frequency response of filter 17 should be set within the upper broad peak response range of the moving target Doppler spectrum.

When a person walks into the insonified zone the oscilloscope signal at the point 100 in the circuit instantly appears as indicated in FIG. 4A. There was no change in the sensitivity settings of the system between the observations of FIG. 3A and FIG. 4A. The observed signal in FIG. 4A shows a very great increase in the rate of change of amplitude from cycle to cycle due to the presence of a moving target as compared to the small rate of change of amplitude caused by air turbulence as indicated in FIG. 3A. This large difference in the cycle to cycle rate of change of amplitude of the signal as caused by air turbulence in comparison to the signal caused by a moving target was observed with different center frequency settings of the band pass filter 17 ranging from 20 Hz to 80 Hz. The actual oscillographic data illustrated in FIGS. 3A and 4A were measured with a band pass filter 17 tuned at a center frequency of approximately 40 Hz and having a band width of 1 octave.

The large difference that was found to exist between the low rate of change of amplitude of the demodulated signal caused by turbulence and the high rate of change of amplitude caused by a real moving intruder is the basis of this invention and its novel application very greatly reduces false alarms even in the presence of excessive air turbulence with a simple, low cost, circuit configuration. The signal from the output of the filter 17 is connected to a peak detector 18 which may be of any conventional design as is well known in the art. This converts the air turbulence signal of FIG. 3A to the signal shown in FIG. 3B and the moving target signal of FIG. 4A to the signal shown in FIG. 4B. The detected signals shown in FIGS. 3B and 4B were observed with an oscilloscope connected at the point 200 in the circuit of FIG. 1. It is evident from FIG. 3B that the detected rate of change of the peak amplitude variations of the air turbulence signal appearing in FIG. 3A results in a low frequency signal of small amplitude superimposed on DC. The detected rate of change of the peak amplitude variations of the intruder signal appearing in FIG. 4A results in a relatively high frequency signal of relatively large amplitude as shown in FIG. 4B.

By the very simple procedure of sending the output signal from the peak detector 18 through a high pass filter 19 only the high frequency signals which result from the high rate of change of amplitude caused by a real target as shown in FIG. 4B will pass through. The low frequency signals which result from the low rate of change of amplitude caused by turbulence as shown in FIG. 3B will be blocked and cannot pass through the filter 19 to cause a false alarm. Applicant experimentally found that neither the cut-off frequency nor the rate of low frequency roll off of the high pass filter 19 is critical to the reliable operation of this new ultrasonic alarm system. As long as the cut-off frequency of the high pass filter is set above 10 Hz the system remains free from false alarms even in the presence of air turbulence of relatively high magnitudes. In an actual circuit employed by applicant for a very satisfactory operating system a high pass filter having a cut-off fre-

quency of approximately 15 Hz was used. When a signal appears at the output of the high pass filter 19 it is rectified by the peak detector 20 and the presence of a signal at the output of the detector 20 is used to activate the alarm circuit 22.

Because this new invention operates on the instantaneous cycle to cycle differences in the rates of change of the amplitudes of the moving target and air turbulence generated signals it eliminates the undesirable requirement of long time constants which are necessary in prior art systems which depend for their operation on the long time averaged amplitudes of the target and air turbulence generated signals. The improved ultrasonic alarm described in this invention is inherently very fast in operation. A single step of an intruder into the insonified zone will set off the alarm and at the same time the presence of severe air turbulence will not cause false alarms. Due to the extremely fast response of this new system in which an alarm decision is made immediately upon the appearance of a signal across the output of the high pass filter 19 it was found desirable to use an integrator 21 between the detector 20 and the alarm circuit 22 to provide a small time delay in the system so that it will not respond to spurious transient signals.

While there have been shown and described several specific embodiments of the present invention, it will of course be understood that various modifications and alternatives may be made without departing from the true spirit and scope of the invention. Therefore the appended claims are intended to cover all such modifications and alternative constructions as fall within their true spirit and scope.

I claim:

1. In an intrusion alarm system, means for radiating a signal at a predetermined frequency into a space, means for receiving the signal as it is reflected from objects within the space, the received signal having a frequency differing from that of the radiated signal by amounts corresponding to the rates of movement of said objects, demodulation means for producing a difference signal having a frequency spectrum corresponding to the differences in the frequencies of the radiated and received signal, filter means connected for filtering the difference signal and passing only a selected band of frequencies lying within the upper portion of the frequency spectrum of the difference signal, signal processing means connected to the output of said filter, said signal processing means characterized in that its output contains an AC signal corresponding approximately to the envelope of the variation in the peak amplitudes of the AC signal which appears at the output of said filter, a high pass filter connected to the output of said signal processing means, and signal detection means for recognizing the presence of a signal when it appears at the output of said high pass filter.

2. The invention in claim 1 characterized in that said radiated signal is ultrasonic and said predetermined frequency lies within the approximate range 18 - 50 kHz, said filter means is a band pass filter whose pass band is centered at a frequency which lies within the upper broad peak response range of the moving target Doppler spectrum, said signal processing means includes a peak detector, and said high pass filter has a cut-off frequency greater than 5 Hz.

3. The invention in claim 2 characterized in that said demodulation means includes means for combining a

signal corresponding to the frequency of the radiated signal with the received signal.

4. The invention in claim 2 characterized in that said high pass filter has a cut-off frequency which lies within the approximate range 10 Hz - 30 Hz.

5. The invention in claim 2 characterized in that said band pass filter has a pass band centered within the approximate range 20 Hz - 80 Hz.

6. The invention in claim 2 characterized in that said signal processing means includes an integrator.

7. The invention in claim 2 and an alarm circuit operated by the output of said signal processing means when an output signal appears.

8. The invention in claim 6 and an alarm circuit operated by the output of said signal processing means when an output signal appears.

9. An ultrasonic intruder alarm comprising an ultrasonic signal oscillator, ultrasonic transmitting transducer means capable of radiating acoustic energy throughout a space to be insonified connected to said oscillator, ultrasonic receiving transducer means capable of receiving said radiated energy as it reflects from objects within the insonified space, an amplifier connected to said receiving transducer means, demodulation means, the amplifier output signal connected to said demodulator, the output from said demodulation means connected to a band pass filter, a first peak detector connected to the output of said band pass filter,

a high pass filter connected to the output of said first peak detector, a second peak detector connected to the output of said high pass filter and an alarm circuit which is activated by the output signal from said second peak detector whenever an output signal appears.

10. The invention in claim 9 characterized in that said demodulation means includes means for combining a signal corresponding to the frequency of the radiated signal with the received signal.

11. The invention in claim 9 characterized in that an integrator is included in the output circuit of said second peak detector for preventing transient signals from passing from said second peak detector to said alarm circuit.

12. The invention in claim 9 characterized in that the frequency of the ultrasonic signal generated by said oscillator lies within the approximate range 18 kHz - 50 kHz, said band pass filter is centered at a frequency within the approximate range 20 Hz - 80 Hz, said high pass filter has a cut-off frequency which lies within the approximate range 10 Hz - 30 Hz.

13. The invention in claim 12 characterized in that an integrator is included in the output circuit of said second peak detector for preventing transient signals from passing from said second peak detector to said alarm circuit.

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