April 23, 1968 L. C. FOSTER 3,379,994

ACOUSTIC INTRUDER DETECTION SYSTEMS

Filed Jan. 31, 1967

FIG. 1

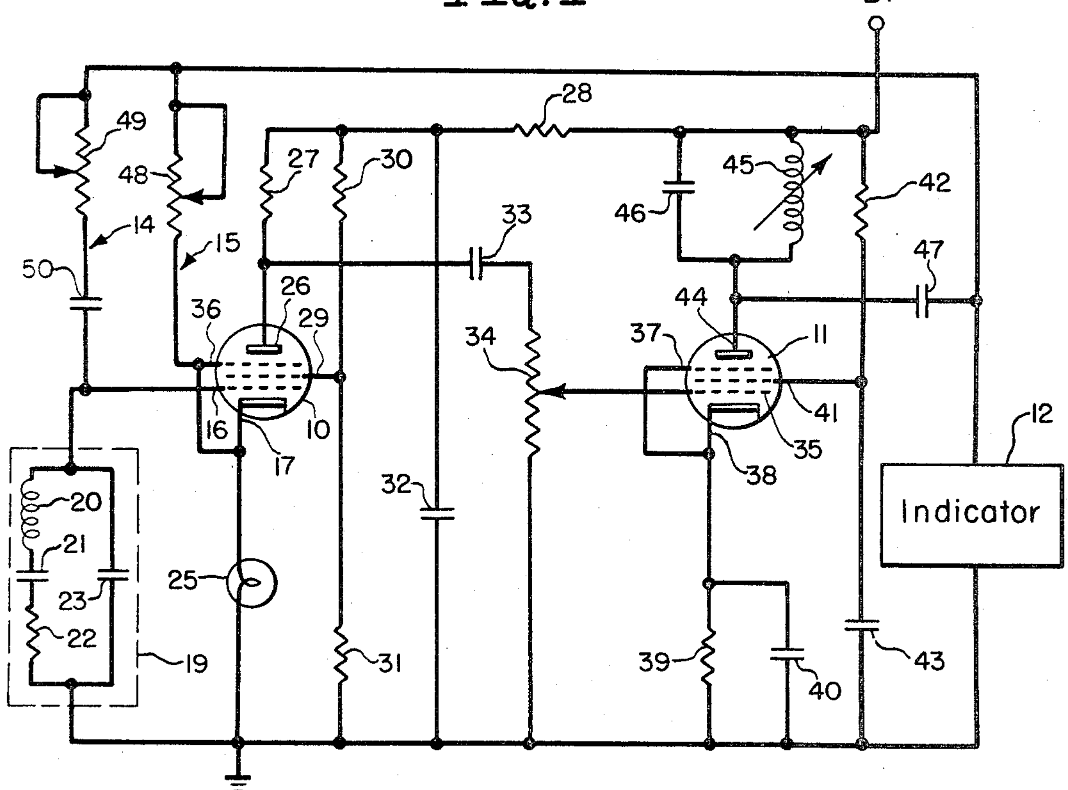


FIG. 2

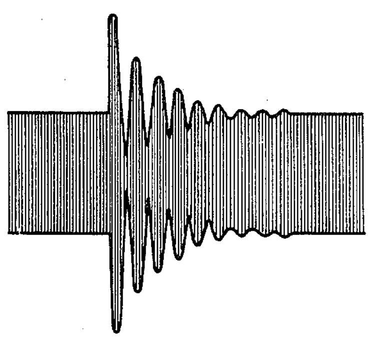
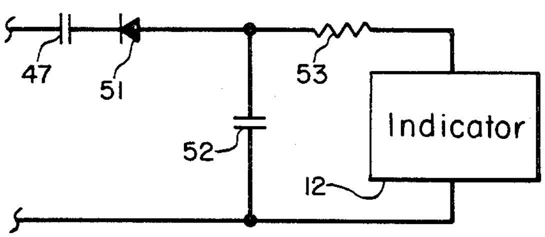


FIG. 3



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3,379,994

Patented Apr. 23, 1968

3,379,994

ACOUSTIC INTRUDER DETECTION SYSTEMS

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Filed Jan. 31, 1967, Ser. No. 612,893

11 Claims. (Cl. 331—65)

ABSTRACT OF THE DISCLOSURE

A linear amplifier includes both regenerative and degenerative feedback paths. A power-sensitive element in the degenerative path stabilizes the normal oscillation of the amplifier. A resonant microphone is coupled to the regenerative path and radiates the oscillatory energy outwardly with some of the same energy being received back by the microphone. Movement of an intruder in the field of the microphone causes a perturbation of the oscillations with a resultant burst-like increase in the oscillatory amplitude. That effect is utilized to actuate an alarm indicator.

Introduction

The present invention pertains to detection systems. More particularly, the invention relates to a system applicable to the detection of an intruder within an enclosure in order to sound an alarm or otherwise signal such intrusion.

Numerous systems have been proposed for utilizing radiated electromagnetic or acoustic energy in the detection of intruders. Typically in such systems, the apparatus radiates the energy from a transmitting element so as to create a pattern of standing waves within the enclosure, such as the room of a building, and a receiver in the apparatus monitors energy present at a point in the enclosure. Upon entry into the enclosure of an intruder, the pattern of standing waves therein is disturbed and the receiver senses that disturbance in one way or another to develop an alarm signal. For example, movement through the enclosure reflects signals back to the receiver with a frequency shifted from the transmitted frequency in correspondence with the Doppler effect. Correspondingly, in some prior systems the receiver circuitry includes a filter which rejects the transmitted frequency but responds to signals at a different Doppler-shifted frequency within a range corresponding to normal movement by the intruder. Another typical prior approach seeks to balance the transmitted signal amplitude against the amplitude of the received signals under normal conditions. Movement of the intruder changes or modulates the signal energy returned to the receiver, throwing the system out of balance and resulting in the development of the alarm signal.

While certain of these prior systems have found a degree of success, they nevertheless suffer either from lack of sensitivity or undue criticality of adjustment. Usually, attempts to increase the sensitivity result in a corresponding increase in the criticality of adjustment with the overall result that the systems tend to be unduly influenced by spurious effects such as heating-system noise, movement of air through the enclosure or the operation of appliances or machines in the area.

It is a general object of the present invention to provide a new and improved intruder detection system.

Another object of the present invention is to provide a new and improved detector system which exhibits substantial stability in normal operation but which develops a strong control signal in response to ordinary movement of an intruder within the enclosure.

A further object of the present invention is to provide such a system which is capable of being used in part as a plurality of units monitoring a corresponding plurality of different enclosures and which is responsive to the presence of an intruder within any one of the enclosures in order to sound a common alarm.

A detection system in accordance with the present invention comprises a linear amplifier together with means defining a regenerative feedback path to effect oscillation of the amplifier and means defining a degenerative feedback path for normally stabilizing the amplitude of the oscillations in the amplifier to a predetermined level. Means coupled into the amplifier to radiate oscillatory energy therefrom and also receive back and deliver a portion of that energy to the amplifier. A perturbation in the received energy effects a transient increase in the amplitude of the oscillations to a level substantially greater than the predetermined level. Finally, the system includes means responsive to that transient increase for developing a control effect that is used to energize an alarm or other means to signify the presence of an intruder in an enclosure into which the oscillatory energy is radiated.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The organization and manner of operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing, in the several figures of which like reference numerals identify like elements, and in which:

FIGURE 1 is a schematic diagram of one embodiment of the present invention;

FIGURE 2 illustrates a waveform of oscillatory energy developed by the circuitry of FIGURE 1; and

FIGURE 3 is a schematic diagram of a modified portion of FIGURE 1.

FIGURE 1 illustrates a two-stage linear amplifier composed of a first amplifying valve **10** which drives a second amplifying valve **11**. The amplifier supplies operating energy to an indicator **12** which may simply be a warning buzzer or signal light. Coupled from the output of the amplifier back to its input is a regenerating or positive feedback path **14** and a degenerative or negative feedback path **15**. As shown, the amplifier preferably is of the differential kind having a first input terminal of valve **10** in the form of a control grid **16** and a second input terminal of that valve in the form of a cathode **17**. Regenerative feedback path **14** is coupled to deliver energy from the output circuit of valve **11** to control grid **16** while degenerative feedback path **15** feeds the oscillatory energy from the same output circuit back to cathode **17**.

Coupled into the amplifier for radiating oscillatory energy therefrom is a resonant transducer device **19** which as preferably embodied not only transmits oscillatory energy outwardly into the adjacent space within an enclosure but also is receptive to that energy to receive back and deliver the same into the amplifier. Moreover, the oscillatory energy developed in the amplifier preferably is of an ultrasonic frequency and transducer **19** is a microphone which launches acoustic waves at that frequency into the surrounding space.

A suitable microphone for this purpose is disclosed by Robert Adler in United States Patent No. 3,058,539, issued October 16, 1962, and assigned to the same assignee as the present application. Briefly, it comprises a piezoelectric element coupled to a vibratory element flexurally resonant at the frequency of the signals exciting the piezoelectric element; it constitutes a sharply-tuned transducer which exhibits a high Q. As shown in FIGURE 1, the equivalent circuit of such a resonant transducer is composed of the series combination of an inductor **20**, a capacitor **21** and a resistor **22**, representing the piezoelectric element, in parallel with a capacitor **23** representing the shunt capacitance across the terminals of the device. Microphone **19** as employed herein is coupled between control grid **16** and a point of reference potential, here shown as ground, so as in effect to be in parallel with regenerative feedback **14** which also delivers energy to the control grid.

Coupled to degenerative feedback path **15** by virtue of connection between cathode **17** and ground is a power-sensitive element which regulates the normal amplitude of the oscillatory energy developed in the amplifier. Element **25** preferably is a thermally-sensitive resistance which exhibits a positive temperature-coefficient of resistance and is coupled effectively in parallel or shunt relative to degenerative path **15**. Alternatively, element **25** may be selected to exhibit a negative temperature-coefficient of resistance in which case it is connected in series with degenerative feedback path **15**.

Completing a more detailed description of the particular embodiment illustrated in FIGURE 1, valves **10** and **11** each are pentodes although it will be apparent that equivalent operation is obtainable through the analogous incorporation of solid-state transistor devices. With respect to valve **10**, its anode **26** is connected through a load resistor **27** and a dropping resistor **28** to a source B+ of positive potential. A screen electrode **29** is connected to the midpoint of a voltage divider composed of resistors **30** and **31** connected between ground and a point intermediate resistors **27** and **28**. A coupling capacitor **32** likewise is connected between ground and that point intermediate resistors **27** and **28**. A blocking capacitor **33** is connected between anode **26** and one end of a potentiometer **34** the other end of which is connected to ground.

A variable tap on potentiometer **34** connects to the control grid **35** of valve **11**. The suppressor electrode **36** of valve **10** is connected to its cathode **17**, and similarly the suppressor electrode **37** of valve **11** is connected to its cathode **38**. Cathode **38** is returned to ground through a degenerative bias resistor **39** bypassed by a capacitor **40**. The screen grid **41** of valve **11** is connected to potential source B+ through a dropping resistor **42**, the screen also being bypassed to ground through a capacitor **43**. The anode **44** of valve **11** is connected to potential source B+ through the parallel combination of an adjustable inductor **45** and a capacitor **46**, the inductance value of inductor **45** being adjusted to be parallel resonant with capacitor **46** at the oscillatory signal frequency. Anode **44** is coupled to indicator **12** through a blocking capacitor **47**, the other terminal of the indicator being returned to ground. Feedback paths **14** and **15** are both connected to the output circuit at a point intermediate capacitor **47** and indicator **12**. Feedback path **15** includes an adjustable resistor **48**, while feedback path **14** includes an adjustable resistor **49** in series with a capacitor **50**.

By way of illustration and in no sense by way of limitation, a successful version of the FIGURE 1 apparatus included components of the following values:

Valve **10**—6SJ7
Valve **11**—6K6GT
Element **25**—7-watt, 120-volt tungsten lamp
Resistor **27**—68 kilo-ohms
Resistor **30**—33kilo-ohms
Resistor **31**—15 kilo-ohms
Resistor **28**—10 kilo-ohms
Capacitor **32**—40 microfarads
Capacitor **33**—0.001 microfarad
Potentiometer **34**—0.5 megohm
Resistor **39**—820 ohms
Capacitor **40**—0.001 microfarad
Resistor **42**—12 kilo-ohms
Capacitor **43**—0.01 microfarad
Inductor **45**—2.4 millihenries
Capacitor **46**—0.0068 microfarad

Capacitor **47**—0.015 microfarad
Resistor **48**—2.2 kilo-ohms
Resistor **49**—1 megohm
Capacitor **50**—0.001 microfarad

The frequency of operation is 40 kilocycles and microphone **19** is tuned to resonance at that frequency. Similarly, the combination of inductor **45** and capacitor **46** also are tuned to 40 kilocycles. The potential developed by a source B+ is 250 volts.

In operation, potentiometer **34** operates as an overall amplifier system gain control and during set up is adjusted to afford the sensitivity found to be necessary in a given enclosure. Potentiometer **49** in regenerative feedback path **14** is adjusted so that the output-signal waveform, the signal being fed to indicator **12** as observed for example on an oscilloscope, has an amplitude representing operation safely within the normal operating conditions for valves **10** and **11**. At the same time, potentiometer **48** in the negative feedback path is adjusted to a point intermediate its range where, absent movement within the enclosure, the output waveform remains of a very steady amplitude. With the component values above set forth, normal operation is found to occur with gain control **34** and resistor **48** adjusted so that, under stable conditions, the output signal exhibits a potential of approximately 3.2 volts RMS. Next during set up, the hand of the operator is moved back and forth slowly in front of microphone **19** while resistor **48** in the negative feedback path is adjusted so that this movement effects the initiation of a transient which is found to result in an expansion of the output waveform to an amplitude many times that previously observed under stable operation. This occurs because the microphone is coupled into the regenerative feedback path. Such action is illustrated by the waveform depicted in FIGURE 2 which represents an oscilloscope trace of the signal fed to indicator **12**. Prior to the introduction of movement within the space beyond microphone **19**, the output waveform is very uniform and stable as shown toward the left of the pattern in FIGURE 2. Upon the introduction of movement by an object in that space, however, the illustrated high-amplitude transient occurs. The transient decays comparatively quickly upon termination of the movement, as shown in the intermediate portion of the FIGURE 2 waveform. This transient has been found to result in a very large increase of oscillatory amplitude, representing a ratio of modulated oscillator power to input signal power greater than 100 db. That is, the envelope gives the impression of sort of bursting apart. It is this dramatic increase in the oscillatory level which enables but a small perturbation in the signal received by microphone **19** to cause a production of an exceedingly large control effect.

Ordinary movement of an intruder results in amplitude modulation of the oscillator, since the returned signal is Doppler shifted by the motion of the intruder. The amplitude-modulation frequency is of the value $2v/\lambda$ where v is the velocity of moving object, the intruder, and λ is the wavelength of the oscillatory energy. With the operating frequency at 40 kilocycles, an ordinarily-moving target modulates the oscillatory energy, and hence the oscillator circuitry itself upon receipt back by way of microphone **19**, at a rate of 1 cycle-per-econd for each ½-centimeter-per-second of motion. Consequently, it is necessary to be able to detect only a range of a few cycles-per-second at the bottom of the spectrum in order adequately to detect the presence of a human person walking into an enclosed space.

For these reasons, the output circuitry of valve **11** feeding indicator **12** may include a detector for deriving from the oscillatory energy only the low-frequency amplitude modulation with the output of that detector feeding indicator **12** through a low-pass filter unit having a cut-off frequency of only a few cycles-per-second. This aids in discriminating against spurious reaction to higher frequency perturbations such as those caused by wind noise and machinery operation. Such a low-pass filter is shown in FIGURE 3 wherein the detector is in the form of a diode **51** coupled to the output end of capacitor **47** and the low-pass filter takes the form of a shunt capacitor **52** followed by a series resistor **53**. Its cut-off preferably is below 10 cycles-per-second to avoid response to spurious effects of hum, for example, and is greater than 1 cycle-per-second to permit response to typical intruder movement.

The illustrated type of amplifier, as such and exclusive of indicator **12** and microphone **19**, is described in the Hewlett-Packard Journal for April–June 1960, vol. 11, Nos. 8–10, pages 1–8, published by the Hewlett-Packard Company, 1501 Page Hill Road, Palo Alto, Calif., in an article entitled "The Effect of μ-Circuit Non-Linearity on the Amplitude Stability of RC Oscillators" by B. M. Oliver. As noted in that article, element **25** is operated at a temperature high enough to be on the sloping portion of its resistance-power characteristic and yet low enough so that its cut-off frequency is well below the frequency of operation. As a result, its normal time constant prevents appreciable resistance changes during an oscillation cycle. The authors noted that, with the circuit so designed and the amount of negative feedback selected to achieve linear operation of the amplifier, the amplifier exhibits poor phase margin and a highly oscillatory transient response.

In the environment there considered, such a response was undesirable and therefore was purposely avoided by introducing a non-linearity into the amplification characteristic in order to obtain unconditionally stable waveform envelope amplitude. In the environment of the present application, that same transient response characteristic is just as purposely obtained and, in combination with microphone **19** serving to propagate the oscillatory energy into an enclosed space and at the same time to monitor that oscillatory energy, the result is a system particularly advantageous as an intruder alarm. That is, the system herein disclosed takes advantage of a heretofore unwanted characteristic of a known amplifier by combining such an amplifier with other elements so as to create a detection system capable of operating with high sensitivity while yet developing a very large control effect in response to but a small perturbation of the received signal energy. Because of the very narrow and low-frequency range of the signal modulation which is to be detected, the system is capable of rejecting all other frequency components throughout the spectrum and hence of being essentially nonresponsive to spurious signals.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. A detection system comprising:

a linear amplifier;

means defining a regenerative feedback path for effecting oscillation of said amplifier;

means defining a degenerative feedback path for normally stabilizing the amplitude of the oscillations in said amplifier to a predetermined level;

means, including a device coupled into said amplifier to radiate oscillatory energy therefrom and receive back and deliver a portion of said energy to said amplifier for effecting a transient increase in the amplitude of said oscillations to a level substantially greater than said predetermined level in response to a perturbation in the received energy;

and means responsive to said transient increase for developing a control effect.

2. A system as defined in claim **1** in which said responsive means responds only to components of said transient having frequencies below approximately 10 cycles-per-second.

3. A system as defined in claim **1** in which said amplifier is of the differential type with said regenerative path delivering signal energy to a first input terminal thereof and said degenerative path delivering signal energy to a second input terminal thereof differentially related to the first.

4. A system as defined in claim **1** in which said degenerative path includes a power-sensitive element regulatory of said oscillation amplitude.

5. A system as defined in claim **4** in which said element is a thermally-sensitive resistance.

6. A system as defined in claim **5** in which said element exhibits a positive temperature coefficient of resistance and is coupled in shunt with said degenerative path.

7. A system as defined in claim **1** in which said radiated and received oscillatory energy is in the form of acoustic waves.

8. A system as defined in claim **1** in which said device is a transducer resonant at substantially the frequency of said oscillations.

9. A system as defined in claim **8** in which said device is coupled into said regenerative feedback path.

10. A system as defined in claim **1** in which said responsive means includes a unit for detecting only very-low-frequency amplitude modulation signal energy modulated upon the higher-frequency oscillatory energy.

11. A system as defined in claim **10** which includes a low-pass filter transmissive of the signal energy detected by said unit.

No references cited.

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