[54] METHOD AND APPARATUS FOR PROVIDING SPACE SECURITY BASED UPON THE ACOUSTICAL CHARACTERISTICS OF THE SPACE

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[22] Filed: July 24, 1973

[21] Appl. No.: 382,192

[30] Foreign Application Priority Data
July 31, 1972 Germany.......................... 2237613

[52] U.S. Cl................................ 340/258 R; 340/276
[51] Int. Cl................................ G08b 13/16
[58] Field of Search........ 340/258 R, 258 A, 258 B,
.................................... 340/258 C, 16 R, 16 P, 276

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[57] ABSTRACT

An apparatus and method of providing securing protection for a space or a room, including the steps of generating a non-directional sound wave field to fill the room to be protected, the sound wave field being inaudible to a human intruder, and detecting the non-directional sound wave field. A security measure, such as an alarm unit, is triggered responsive to the detected non-directional sound wave field in response to a minute change in the confines of the room to be protected, but not in response to movements in the room.

11 Claims, 6 Drawing Figures
Fig. 6

TOTAL AREA OF OPENINGS (CM²)

10 30 100 300 600

FREQUENCY (CYCLES PER SECOND)

100 50 30 15 10 5

VOLUME OF SPACE (M³)

0.01 m³

0.1 m³

1 m³

3 m³

10 m³

VOLUME OF SPACE (M³)
METHOD AND APPARATUS FOR PROVIDING SPACE SECURITY BASED UPON THE ACOUSTICAL CHARACTERISTICS OF THE SPACE

The present invention relates to methods and devices for providing space or room security by means of an acoustic or non-directional sound wave field filling the space, changes in which field are detected by the acoustic conditions within the space and utilized to trigger security measures. The invention can, for example, be employed for the protection of living spaces or rooms and business premises, treasuries, banks, cars, storage spaces, or containers.

BACKGROUND OF THE INVENTION

It is well known, in the context of the provision of security for a space, to generate in said space by means of an acoustic radiator an audio frequency or ultrasonic acoustic field, the vibrations generated being reflected, from the walls of the space and changes in said field being utilized to trigger security measures. In this context, when using ultrasound, for example, the Doppler effect is exploited and utilized to indicate objects moving in the space. It is also known to utilize frequencies in the audible range and to locate the acoustic pick-up in the space in such a way that when any disturbance in the acoustic field or sound pattern occurs due to changes in reflection conditions, an alarm signal is triggered. Finally, it is known to exploit the infrasound vibrations occurring with the opening and closing of doors or windows, and to employ a flame detector or a pressure gauge to detect this and provide an indication.

When using ultrasonic vibrations or audible acoustic fields filling the space, there is the risk that inadvertent, that is, to say unwanted, triggering will be produced by the movement of animals in the space, or that when operating in the audible range, the intruder may immediately detect the alarm system and render it inoperative. Furthermore, it is necessary to carefully choose the point of installation of the acoustic beam, which operates as a directional radiator at high frequencies, and also the location of the pick-up, because dead zones can occur behind large obstacles, which adversely affect the efficiency of the installation.

The analysis of the acoustic vibrations produced by the opening or closing of doors or windows can be circumvented by methods of very slow and careful opening and closing.

The object of the present invention is to provide a method and a device which makes use of a non-directional acoustic field completely filling the space, which cannot be detected by the intruder and which responds to tiny changes in the confines of the space, but not to movements therein.

SUMMARY OF THE INVENTION

The present invention provides a method of providing security protection for a space or room comprising the steps of generating a non-directional sound wave field to occupy substantially completely the space to be protected, and detecting the non-directional sound wave field. The non-directional sound wave field is inaudible to a human intruder into the space to be protected. After detecting the sound wave field, a security measure is triggered responsive to the detected non-directional sound wave field in response to a minute change in the confines of the space to be protected, but not in response to movements therein.

The present invention also provides a device for implementing the aforesaid method. The device includes a generator which radiates frequencies which are located in the infrasound range, or are equal to or lower than the highest natural resonant frequency of the space being protected, or are located within the flanks of the resonance curve defined by the natural resonant frequency. An acoustic pick-up transmits infrasonic frequencies and, in the case of wavelengths which are longer than the dimensions of the space being protected, is arranged at an arbitrary point in the space, or, in the case of wavelengths which correspond to the space dimensions, is arranged in the neighborhood of the boundary walls.

An object of the present invention is to make it possible to secure a space without it being necessary to effect a completely airtight closure thereof, although opening of the space or any other change in the boundaries thereof will trigger an alarm.

In accordance with the invention, this result is achieved in that the generator producing the acoustic field radiates frequencies which are located in the infrasound range or are equal to or lower than the highest natural resonance frequency of the space being protected, or again are located within the flanks of the resonance curve defined by the natural resonance frequency, and that in the changes in the phase alone of the acoustic field, or changes associated with the amplitude and frequency therein, are employed for monitoring.

This method has the advantage that the acoustic field which is radiated, for example, by a vibration generator at very low frequency (in the order of magnitude of at and below the audible threshold of 15 Hz), protects the entire space because any change in the confines or boundaries of the space produces a change in the acoustic conditions so that phase changes or also frequency or amplitude changes result which can be employed to trigger the alarm systems.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial illustration of a space or room which is to be protected provided with the device in accordance with the invention.

FIG. 2 is a block circuit diagram of a design using a microphone, loudspeaker and audio generator.

FIG. 3 is a block circuit diagram of a self-excited design using microphone and loudspeaker, with self-excitation through amplified feedback via microphone and loudspeaker.

FIG. 4 is a block circuit diagram of an arrangement equipped with loudspeaker and generator, the loudspeaker also doing duty as a microphone. The so-called reaction is analyzed by the discriminator comprising a differential amplifier, after differentiation of the voltage across the generator and the generator series resistor (13).

FIG. 5 is a block circuit diagram of an arrangement with a loudspeaker for example, in which the loudspeaker also does duty as a microphone (as in FIG. 4) and is self-exciting (as in FIG. 3) by feedback.

FIG. 6 is a diagram of the ratio of resonance frequency to space size, pertaining to various sizes of
areas on the part of the openings in the confines of the space.

The device 1 shown in FIG. 1 is located in a room or space 2 which is to be protected, which may, for example, include doors 3 and/or windows 4 and 4'. The device 1 can be erected or positioned at virtually any point in the space. The loudspeaker acts as a radiator and operates in the same space without any development of dead areas. If, for example, the space is one having a volume of 3 cu.m., e.g., the passenger space of a motor car, then in accordance with the diagram shown in FIG. 6, with an opening area of 200 sq.cm. (keyholes, cracks, air vents, heating vents, etc.) the natural frequency is around 15 Hz. The unit must therefore be tuned to 15 cycles/sec. (main resonance) or to a harmonic, e.g., 7.5 cycles/sec. If the space has a volume of 10 cu.m. and openings with a total area of 250 sq.cm., then preferentially a frequency of 10 cycles/sec will be used.

The device shown in FIG. 2 in the block circuit diagram contains an audio generator 11 which excites a loudspeaker 14 through an amplifier 12. The loudspeaker 14 is located in the space 15 being protected. In the same space, there is a microphone 16 which is connected through an amplifier 18 to a differential amplifier 20. To this differential amplifier 20 from the output of the amplifier 12 vibrations generated by the audio generator 11 are applied directly across an adjusting or variable resistor 17. The amplifier 20 is provided with selective negative feedback 21. The differential amplifier 20 and the negative feedback 21 together act as a discriminator vis-a-vis frequency, amplitude and phase. At the output of the differential amplifier 20, through an alarm inhibit and release switch 22, the alarm unit 24, e.g., a horn or an optical alarm signal, is connected. The alarm inhibit and release switch 22 is connected to a signal generator 23 which can be controlled by radio, using a cipher generator 25.

The device operates in the following way:

The acoustic vibrations generated by the loudspeaker 14 excite the space 15 at its resonant frequency. The acoustic vibrations picked up by the microphone 16, after amplification, are applied as differential amplifier 20, with the negative feedback 21, acting as amplitude, frequency and phase discriminator. With the help of the resistor 17, the differential amplifier 20 is so adjusted that when the space 15 is excited at its natural frequency, no output signal is produced of a kind which can trigger the alarm device 24. The operator, before leaving the space 15, sets up the device in this way, the switch 22 still keeping the unit disconnected. After the space 15 has been left, the switch 22 is so operated by means of the generator 25 that the discriminator is connected to the alarm device 24.

FIG. 3 is distinguished from FIG. 2 by the fact that instead of the audio generator 11, self-excitation is produced by a return of the output voltage from the amplifier 18 through the variable resistor or controller 17 to the input of the generator amplifier 12.

FIG. 4 is distinguished from FIG. 2 by the fact that the voltage otherwise obtained from the microphone is picked off from the loudspeaker 14 and a generator 11 alone, therefore, without any microphone 16. The so-called feedback is analyzed by the discriminator, comprising differential amplifier 20 and the selective negative feedback 21, after differentiation of the voltage across the transmitted and the transmitter series resistor 13.

FIG. 5 is distinguished from FIG. 4 by the fact that no generator 11 is used, instead simply the loudspeaker 14 on its own and the generator amplifier 12 being exciting as in FIG. 3 by feedback.

In FIG. 6, a diagram has been illustrated on the ordinate of which the frequency in cycles per second has been plotted, showing that a space with a cubic capacity V, indicated by the oblique lines, will vibrate at the natural resonant frequency, when the space has the opening area in square cms., indicated on the abscissa. If a space of 10 cu.m. has, for example, openings with a total area of about 250 sq.cm., then its natural resonant frequency is 10 cycles/sec.

If, in the wall of the space 15, a door or a window is opened even slightly or if some other opening is created, then the resonant frequency shifts, i.e., the phase and amplitude of the vibration (oscillation) applied to the differential amplifier 20 from the amplifier 18 change so that the differential amplifier 20 is displaced from the equilibrium state in which it has been set up. This deviation is detected by the discriminator 20 and is used to trigger the alarm unit 24. As can be seen from the diagram of FIG. 6, even a slight increase in the opening area in the wall of the space 2 or 15 is sufficient to produce an adequate change in the resonant conditions.

Instead of the generator 25 illustrated in FIGS. 2, 3, 4 and 5, in order to operate the switch 22 a timer switch can be used which is set up before leaving the space 2 or 15 in such a way that the unit switches itself ON after a short time, the switch OFF time being so arranged that the switch 22 is open again before the space 2 or 15 is re-entered. This design, employing a timer switch, has the advantage that no manipulation can be employed to externally render the protection inoperative.

As far as the ratio of the space size to the frequency range in which the device is preferentially to operate is concerned, the following can be said:

1. Higher frequencies and therefore shorter acoustic wave lengths.
2. This means that: acoustic vibrations whose frequency is so high that their wavelength occurs so many times within a dimension of the space, that no standing waves can develop in this dimension, and cannot be utilized for the purposes of the invention.
3. Acoustic vibrations whose wavelength is longer than the dimensions of the space to be protected cannot generate any standing waves or resonances. Then, the acoustic pressure at any point in the space is about the same. This means that an opening or an additional opening, at whatever point in the space, will produce a measurable decrease in the acoustic pressure. Because there is virtually no space which is completely airtight, instead, there usually being openings, e.g., leaks at the doors or at the window, ventilation or heating apertures, fans, ovens, oven pipes, chimney flues, and in the case of motor vehicles openings for passing the throttle and brake pedals and other ventilation openings, it is advantageous to utilize these openings (or special openings provided for the purpose) in association with the volume of the space, to act as a resonator. The data are set out in the table shown in FIG. 6.

Wind blowing through these openings from the outside can, it is true, produce a change in air pressure in
the space being detected, but cannot produce any de-
tuning of the acoustic situation.

3. Frequencies whose wavelength is identical to that
of the space dimension, so that they produce standing
waves.

On acoustic excitation of a space being monitored by
a generator, generating waves whose wavelength is
equal to or close to a dimension of the space or a small
multiple thereof, such standing waves will have the
highest acoustic pressure in the neighborhood of the
walls delimiting the space. The consequence is that
even tiny changes of only some few millimeters, as for
example the opening of a door or a window, will pro-
duce a large change in the space resonant amplitude.
At the same time, the resonant frequency changes and,
for a fixed generator frequency, this leads to a clear
amplitude and phase shift.

With space detection by means of standing waves, it
is possible to protect the space by the use of a generator
which is located in the same space, or also, for that
matter, by the use of one which is located outside the
space protected by acoustic coupling through the
space itself, i.e., produces coupling by being built into
a wall, into a ceiling, located in an air duct, in a chim-
ney flue or in a stairwell. Similarly, a generator can
monitor several spaces, provided that these can de-
velop standing waves at the same wavelength and that
there is acoustic coupling because the frequency used
is very low and in order to attenuate such low frequen-
cies acoustic absorber elements are required which are
a meter thick. Consequently, furniture, carpets, cur-
tains and the like which do not affect the geometry of
the space and its volume, are of no importance. Thus,
several spaces acoustically coupled with one another
can be protected by one unit, the generator, for ex-
ample, being located in the first space and the pick-up in
some other space. It may be convenient to distribute
several generators among several spaces to accord with
particular acoustic requirements, and to use one or
more protection frequencies for one or more spaces,
which frequencies are analyzed by one or more pick-
ups. In this context, the protection installation for sev-
eral spaces having different acoustic properties can be
arranged in a single space and contrived to carry out
the protective function from there by a remote acoustic
action.

A device for implementing the method contains, for
example, an acoustic generator which generates the
acoustic vibrations filling the space, and an acoustic
pick-up, e.g., a microphone, which responds to changes
in phase alone, or to associated changes in amplitude
and frequency on the part of the acoustic vibrations in
response to changes in the conditions in the space. In
this context, the frequency of the audio generator
is chosen to be so low, or the amplitude of the radiated
sound so small, that the acoustic vibrations are located
outside the audible range. It is particularly advanta-
geous to tune the frequency of the audio generator to
the natural resonance frequency of the space being
protected. In this context, values are available, as a re-
sult of experience in this field, for completely closed
spaces, and for spaces which are partly closed and
partly open. A space which is completely closed and
contains no opening whatsoever should preferentially
be protected by means of standing waves, the wave-
length, for example, being twice that of an axis of the
space or room.

It is also possible to simultaneously utilize the loud-
speaker of the audio generator as both an acoustic radi-
ator and an acoustic pick-up and to combine the equipmen
twith a portable radio unit or car radio.

The space protection system is particularly sensitive
if the radiated sound is tuned to the space resonant fre-
quency or if the frequency is located on a flank of the
natural resonance frequency curve, because the vari-
ous changes are greatest when operating on the reso-
nance curve flank. Even the slightest opening of the
door or window, shifting the resonance frequency by
the tiniest amount, results in a change in the phase and
in a steep drop in the amplitude of the vibration. There
is radical attenuation as a consequence of pressure
compensation, and in addition to the amplitude, the
phase of the vibrations changes in a manner which is
easy to measure.

Thus, there are three acoustic parameters which can
be employed for surveillance:
1. the resonance frequency, i.e., the wavelength;
2. the amplitude, i.e., the change in level; and
3. the phase, i.e., a time shift between radiated and
received waves.

Because the phase and the other two values or their
changes, are used for surveillance or monitoring, the
equipment cannot be deceived by acoustic manipula-
tion from outside the space. For example, someone can
use a sensitive microphone (i.e., a so-called minisy)
to determine the protection frequency in order then,
when breaking into the space, to use a more powerful
generator to feed it in through a device, such as a loud-
speaker, or an amplifier amplifying the received signal
picked-up by the minisy. Although an intruder could
readily determine the protection frequency, it is very
difficult indeed for him to avoid a change in amplitude
when utilizing this procedure. Also, the change of the
same phase as that obtained at the protection device,
being encountered at the generator and pick-up, is reli-
ably excluded, this indeed for geometric reasons which
involve the transit time or delay and in so doing influ-
ence the phase. Comprehensive investigations of the
acoustic behavior and measurements upon loudspeaker
diaphragms at low and extremely low frequencies,
down too far below the audible threshold, have shown
that it is impossible to identically reproduce the phase
and the aforesaid three values, with different spaces.
Consequently, the arrangement cannot be simulated
and cannot even be rendered inoperative by the owner
of the equipment, even with a knowledge of the overall
 technique and circuitry involved, once switched ON.
However, it is also possible without further ado, as ad-
ditional protection, to modulate the radiated vibration,
this in fact in frequency, amplitude and in phase. This
modulation could also involve pulsing. There is a virtu-
ally infinite plurality of different possible modulation
ciphers.

Further security against manipulation from outside is
obtained if the arrangement is so constructed that the
voltage or applied energy (modulated or unmodulated)
is compared with the signal picked up by the pick-up,
because then the transmission factor of the pick-up is
included in the measurement. It is important that the
discriminator should respond to the change in the
phase or in frequency and level. In this way, not only
are the space conditions monitored, but at the same
time all those parts of the security installation prior to
the discriminator, inclusive of the latter itself. Thus,
with failure or only a slight change in the single element, the discriminator will be unbalanced and trigger an alarm or become impossible to balance again. It is readily possible, in order to make penetration more difficult, to additionally radiate several vibrations which serve, as it were, to camouflage the useful one, or to employ several frequencies which, for example, are tuned to the various axes or dimensions of the space and to exploit their beat tones for space protection purposes. The equipment can be designed as a portable unit, independent of the mains, yielding the particular advantage that a fixed installation in the space, as, for example, the installing of light (etc.) barriers is unnecessary. The unit can also be connected to the mains if required.

In this context, the unit can be connected through a valve device, e.g., a diode in the case of dc, (on much the same lines as in a motor vehicle), so that the plant cannot be rendered inoperative either by disconnection or by short-circuiting the external source in the plant, the equipment of course having to have its own small current source, although this is available anyway with all standard production portable car radios. In this context, the unit will conveniently be so designed that it indicates the state of its own current source and, if this is fluctuating or inoperative, cannot be switched ON. This provides protection against the possibility that an intruder may prepare for a break-in by secretly removing the current source of the protection unit, during an unprotected time.

Because of the insensitivity of this method of space security, to any external connection, it is impossible even for an authorized person to enter the space without triggering the alarm. To prevent such unwanted triggering of the alarm, there are a variety of avenues open. For example, the unit can be switched ON and OFF by a timer switch. It is also possible, for switch-ON and switch-OFF, to utilize a special lock or a short-range radiator which is tuned to a specific code incorporated into the unit and can be used to switch the unit ON and OFF.

Whilst it will be possible in many cases to employ normal loudspeakers, it may be particularly convenient to employ a loudspeaker specially designed for low frequencies, i.e., frequencies below the audible threshold, the diaphragm of which, for example, can be provided with a particularly soft suspension, or is particularly heavy.

Preferentially, four different possibilities of acoustic coupling to the space will be exploited:

1. generator (loudspeaker) and pick-up (microphone) plus vibration generator;
2. generator (loudspeaker) and pick-up (microphone) without vibration generator, self-excitation instead;
3. generator (loudspeaker) without pick-up (microphone) but with vibration generator;
4. generator (loudspeaker) without pick-up (microphone) and without vibration generator.

In this context, for the generator, any vibratory device located in the air, for example, a loudspeaker, could be used.

For the pick-up, it is possible, for example, to use a microphone, another loudspeaker or a pressure pick-up.

For the vibration generator, any device which is capable of generating vibrations in the desired wavelength could be used.

1. A method of providing a security protection for a space, comprising the steps of:
   generating compressional oscillations in the infrasonic frequency range to occupy substantially completely said space to be protected, said compressional oscillations in the infrasonic frequency range having a frequency which is no greater than half the natural resonant frequency of said space; detecting the fundamental compressional wave of said compressional oscillations in the infrasonic frequency range; and triggering a security measure responsive to the detected fundamental compressional wave of said compressional oscillations in the infrasonic frequency range in response to changes in the effective volume of said space to be protected independently of any movement within said space.

2. A method according to claim 1, further including the step of:
   detecting a node shift in the detected fundamental compressional wave of said compressional oscillations in the infrasonic frequency range occasioned by changes in the effective volume of said space.

3. The method of claim 1 further including the step of saturating said space and a second space with said compressional oscillations in the infrasonic frequency range to simultaneously protect both spaces, said second space having an effective volume which is substantially equal to said effective volume of said first-mentioned space.

4. A method according to claim 1, further including the step of:
   detecting a phase shift in the detected fundamental compressional wave of said compressional oscillations in the infrasonic frequency range occasioned by changes in the effective volume of said space.

5. A method according to claim 1, including the step of modulating said generated compressional oscillations in the infrasonic frequency range to occupy substantially completely said space to be protected.

6. A system for providing security for a space comprising:
   means for saturating said space with compressional oscillations in the infrasonic frequency range having a frequency which is no greater than half the natural resonant frequency of said space;
   means for detecting the fundamental compressional wave of said compressional oscillations in the infrasonic frequency range; and
   means responsive to said detecting means for producing an alarm when the effective volume of said space changes.

7. The system of claim 6 wherein said means for detecting is responsive to phase changes in said fundamental compressional wave of said compressional oscillations in the infrasonic frequency range when said effective volume changes.

8. The system of claim 6 wherein said means for detecting is responsive to frequency changes in the fundamental compressional wave of said compressional oscillations in the infrasonic frequency range when said effective volume changes.
9. The system of claim 6 wherein said means for detecting is responsive to amplitude changes in the fundamental compressional wave of said compressional oscillations in the infrasonic frequency range when said effective volume changes.

10. The system of claim 6 wherein said means responsive to said detecting means receives a first signal representative of the fundamental compressional wave of said first-mentioned compressional oscillations in the infrasonic frequency range, and a second signal representative of said detected fundamental compressional wave of the compressional oscillations in the infrasonic frequency range, and produces said alarm when said second signal changes in response to said effective volume changes.

11. The system of claim 6 wherein said means for detecting includes a differential amplifier and a selective negative feedback in electrical communication therewith said amplifier and said feedback cooperating to define a discriminator.

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