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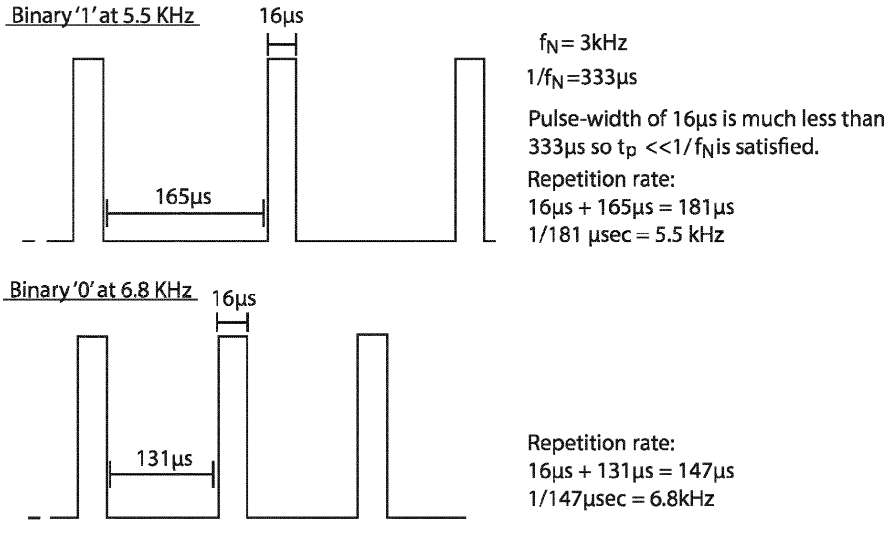
(54) AN ACOUSTIC INTERFACE FOR AN ALARM DEVICE

(57) An acoustic interface (1) is for a device such as an alarm device. It has a vibratory element piezoelectric horn (2) and a drive circuit (8, 5) with a processor (8) for delivering drive electrical signals (7) to the horn to cause it to vibrate and generate a sound signal with encoded binary data. The piezo horn (2) has a natural frequency, and the control signals are frequency encoded with pulses having pulse widths (t_p) which are significantly shorter than the vibrating member natural frequency period ($1/f_N$). The encoding processor (8) provides the control signals via a feedback transistor (5) and a voltage oscillator (6), the vibratory element (2) having at least three electrical contacts of which two are for power and a third is for feedback to the feedback transistor (5), in which mechanical oscillation of the vibratory element generates an electrical feedback signal used to amplify this control signal (7).



Example of control signals used for generating binary '0's at 6.8kHz and binary '1's at 5.5kHz, from a 3kHz piezo disc.

Fig.3

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Description

Introduction

[0001] The present invention relates to acoustic communication of information by an alarm device or other device for which status information in coded form can be advantageously communicated for pick-up and decoding by a digital processor.

[0002] Our prior patent publication EP2461299A describes an alarm device with an interface to generate encoded binary data status information concerning status of the device.

[0003] In a piezoelectric sounder or horn disc oscillation takes a certain time to build up to maximum resonance, typically more than 10 periods of the natural frequency. For a disc having a natural frequency of 3kHz, the period is 330μs, and so it may take more than 3ms before the output sound reaches a maximum. If driving the disc at resonance the disc will continue to ring even after the circuit has de-energized. This 'ring-down' time can be significant and limits the data rate since the audio output must decrease sufficiently before the next data bit can be sent. If the data rate is pushed too high it becomes difficult to discriminate where one bit ends and the next one starts, leading to decoding errors. This may limit the useful data rate to less than 25 bits per second.

[0004] The present invention is directed towards providing an improved acoustic transmitter with a lower sound intensity requirement and higher data rate.

Summary of the Invention

[0005] The invention provides an acoustic interface as set out in claim 1, an alarm device as set out in claim 10, and a system as set out in claim 13.

[0006] We describe an acoustic interface for a device such as an alarm device, the acoustic interface comprising a vibratory element, and a drive circuit with a processor for delivering drive electrical control signals to the element to cause it to vibrate and generate a sound signal with encoded binary data, wherein the vibrating element has a natural frequency and the control signals are frequency encoded with pulses having pulse widths t_p which are shorter than the vibrating element natural frequency period $1/f_N$ and a frequency which is greater than said natural frequency.

[0007] Preferably, the processor provides the control signals via a feedback transistor and a voltage oscillator, the vibratory element having at least three electrical contacts of which two are for power and a third is for feedback to the feedback transistor, in which mechanical oscillation of the vibratory element generates an electrical feedback signal used to amplify this control signal.

[0008] Preferably, the processor (8) is configured to generate the control signals according to a Frequency Shift Keying scheme.

[0009] Preferably, the processor is configured to generate the control signals according to a Binary Frequency Shift Keying scheme, in which one frequency is used to represent a binary '0' and a different frequency is used to represent a '1'.

[0010] Preferably, the processor is configured to generate the control signals with a frequency difference between binary 0 and 1 representations of at least 1kHz.

[0011] Preferably, the processor is configured to generate the control signals having a pulse width t_p less than 8% of said natural frequency period.

[0012] Preferably, the processor is configured to generate the control signals having a frequency which is greater than said natural frequency by at least 40%.

[0013] Preferably, the processor is configured to generate the control signals having a frequency which causes at least one additional vibratory element harmonic of double or treble the drive control signal frequency for encoding a binary value a said at least one harmonic.

[0014] We also describe an alarm device comprising a condition sensor and a controller, and a sound emitter with a vibrating element, and an acoustic interface of any example described herein, in which the controller is configured to encode alarm status data in the acoustic output of the interface. Preferably, the acoustic interface vibrating element is also the alarm sound emitter.

[0015] We also describe a system comprising an interface of any example described herein or an alarm device of any example described herein, and a decoding device having an acoustic pickup and a decoding processor configured to decode acoustic signals and provide a user data output.

[0016] Preferably, the encoding processor is configured to provide the control signals to generate a strong second harmonic, and the decoding processor is configured to decode at double or treble the drive control frequency.

[0017] Preferably, the second harmonic decoding is used for only one of a binary 0 or 1 decoding.

Detailed Description of the Invention

[0018] The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings in which:

Figs. 1(a) and 1(b) are diagrams showing the audio components of an alarm device of the invention,

Fig. 2 is a plot of microprocessor control signals for driving a piezoelectric disc sounder, indicating parameters of these signals in one example,

Fig. 3 is a set of further control signals, with specific detail of control signals for generating sound for a binary "0" and a binary "1",

Fig. 4 represents the audio output frequency spectrum, with output intensity in dB over the audible range of frequencies, demonstrating that the output is dominated by a high amplitude 3kHz tone when driven conventionally, such that resonance at 3kHz is established,

Fig. 5 is another plot of the audio output spectrum, showing decibel level vs. sound (disc vibration) frequency arising from a control signal drive frequency f_d = 6.8kHz and control signal pulse width $t_p << 1/f_N$, showing that the output audio signal shows a dominant peak at 6.8kHz, which is approximately 5dB larger than the output generated at the natural frequency of the disc(3kHz), and also of note is that the output at 3kHz is now significantly less than that in Fig. 4, a decrease of approximately 30dB,

Fig. 6 is a further plot of output audio signal decibel level vs. output sound frequency resulting from a binary-FSK control signal in which data was transmitted by alternately driving at frequencies of 5.5kHz and 6.8kHz, representing binary 1's and 0's respectively,

Fig. 7 is a plot of background noise decibel level plotted against frequency of such noise, demonstrating the tendency for acoustic background noise to decrease at higher frequencies, and

Figs. 8 and 9 are plots showing audio output decibel peaks which arise at sound frequencies which are multiples of the control signal drive frequency, allowing decoding at higher frequency bands where background noise is less.

[0019] Referring to Fig. 1(a) an acoustic interface 1 suitable for an alarm device or any other device for which acoustic encoded information is required to be outputted is shown in block diagram form in Fig. 1(a) and in Fig. 1(b) with a plan view of a piezoelectric disc sounder 2. The acoustic signals are generated by a vibratory element, in this case a piezoelectric disc 2 having a main element 3 and a feedback element 4. The feedback element 4 is linked to the transistor 5, which drives an oscillator circuit 6 according to a control signal 7 from an encoding processor 8. The encoding processor 8 is in one example that of a smoke alarm device, and it is programmed to drive the interface 1 to provide data concerning the alarm device.

[0020] The feedback component 4 provides a signal which is used as a simple means of maintaining the drive frequency at a desired level.

[0021] The microcontroller (MCU) 8 is in this example an 8-bit processor capable of generating minimum timing pulses in the range of 4μs to 25μs and it provides control signals to the high voltage oscillator circuit 6 having either an inductor-capacitor type oscillator or a dedicated IC for generating high voltage pulses from a lower voltage input, necessary to drive the sounder at high audio output.

[0022] As shown in Fig. 1(b) the feedback component 4 is linked to a transistor switch 5, which is activated/deactivated via the control signal 7 from the MCU 8, and when the transistor 5 is active it allows the higher voltage from the oscillator to drive the main element 3 of the piezo disc 2. This in turn generates a small feedback signal which is used to control the voltage (or current) to the oscillator 6. In this way, the feedback helps maintain the oscillator frequency so that the disc 2 is driven at its designed frequency (natural frequency) for optimum output. This fixed feedback circuit is very advantageous for alarm devices, which must maintain high sound output even under changing ambient conditions which could potentially alter the piezo resonance frequency. The feedback ensures that it is always driven at its optimum for the given conditions.

[0023] The microcontroller MCU 8 is programmed to provide a higher data rate and a lower audio level than is known.

[0024] The acoustic interface 1 is part of a smoke alarm device in this example, the microcontroller being part of the alarm device, and is preferably the main controller. However, the interface may be part of a different device such as a domestic appliance.

[0025] As is described in more detail below the piezo disc vibratory element 3 has a natural frequency and the control signals provided by the microcontroller MCU 8 are pulses with pulse widths which are significantly smaller than the period corresponding to the piezoelectric disc's natural frequency. In this case the natural frequency is 3kHz, and in general it is preferred that the piezo disc has a natural frequency in the range of 2 kHz to 4 kHz.

[0026] The microcontroller 8 is programmed to generate a test output record including various items of data such as the device's serial number, the battery level, a contamination level if it is an optical alarm, an event log, and an installation date. This information is encoded by control of the high voltage oscillator linked to the piezoelectric disc horn, which is an item required by the alarm device anyway for generating an audible alarm output.

[0027] The data is decoded by any electronic device having a microphone and a processing capability, such as a PDA, a laptop computer, or a smartphone. If the device has a camera, then it could both capture the acoustic signal and take an image of the alarm device to provide a more comprehensive record. In one example, a mobile phone downloads over a mobile network an application to do this processing.

[0028] In one example of use, in order to do an audit, it is only necessary for the technician to press a test button (not shown) upon which the microprocessor 8 generates a control signal encoding the audit data. The resulting sound generated by the horn is captured by the user device. It may be decoded locally by the device, and the decoded data may be uploaded to a remote host. Alternatively, a representation of the acoustic signal may be uploaded to a central host for decoding and further processing and storage. Whenever the test button is pressed the horn will send out a coded signal with test response information. This could be done immediately, or 5 seconds after the horn has reached full volume. The data which is conveyed may include any one or more of: preamble bits, a device identification number, a device status flag, battery status, contamination status, alarm events, faulty smoke sensor, installation date, location, whether the device is in standby, hush, or alarm modes.

[0029] The testing device has an acoustic pick-up and a decoding processor which provides an output for display of the received data on a display and/or transmission it to a remote host server. It may provide an instruction for an action such as battery replacement, device replacement, or device, cleaning.

[0030] Having a unique serial number greatly helps with the tracking of smoke alarm devices - the devices can be sent back to the manufacturer for analysis and the subsequent report will clearly identify the unit and allow the maintenance company to relate it to the apartment from which it was removed. For example, if the unit was heavily contaminated or damaged, and it was clear that this was caused by a tenant, then the tenant (or landlord) could be billed for the replacement costs of fitting a new unit.

[0031] As noted above, on the three-wire piezo disc 2, two of the wires are for power while the third is for the feedback. When the main element of the piezo disc is energized with an electrical oscillation, it causes the disc to deform and mechanically oscillate. This mechanical oscillation of the disc 2 generates an electrical signal from the piezo material. A portion of this signal is generated from the feedback element of the disc and is used as part of the feedback circuit which amplifies this signal and uses it to drive the main element of the disc. The microcontroller 8 ensures that the disc 2 is always driven at its optimum frequency for optimum sound and data output.

[0032] A digital control signal is fed to the base of the transistor to turn the oscillation ON/OFF. A sufficiently long ON duration will cause the disc to oscillate at full power at its natural frequency, usually around 3kHz. The microcontroller 8is configured to drive the disc to avoid the prior art problem of the oscillation taking a significant time to build up to maximum resonance and subsequently, a significant ring-down time. In particular, it modulates the control signal with pulses significantly shorter in time than the disc's natural period (1/natural frequency), and hence the circuit-disc resonance behavior can be interrupted, and this reduces the audio output at the fundamental.

[0033] By controlling the pulse width and frequency of the control signal, additional frequencies can be generated with a sufficient relative intensity to the fundamental that they become useful for data transmission and allow a more efficient encoding scheme such as Frequency Shift Keying (FSK). This control scheme provides that data is transmitted at lower audio output level because the disc never fully achieves resonance. Also, it generates and controls additional frequencies allowing the use of more efficient encoding schemes, such as Binary-FSK. Driving the disc off-resonance decreases the ring-down time and consequently increases the maximum data rate. The invention has the benefit of not requiring change to the physical hardware, so the same circuit used for high sound output during alarming can also be used for data transmission that is both faster and quieter than previous methods. We have found that the data rate is about 5-10 times faster than prior approaches.

[0034] Frequency Shift-Keying ("FSK") encodes data in the frequency of the control signal. A minimum of two controllable frequencies is required. One frequency is used to represent the binary '0's, while the other is used for '1's. This is more efficient than single frequency encoding, which relies on time delays or transitions to determine whether the bit is a '1' or '0'. Manchester encoding for example is only 50% efficient because its data rate is only half the clock rate since it must generate transitions from low-to-high or high-to-low, in order to be decoded successfully. FSK does not have this issue and can be much faster. Many modern wireless systems, such as Wi-Fi™, use some version of FSK.

[0035] As shown in Fig. 2 the control pulses are significantly shorter than the period of the disc's natural frequency, in order to prevent (or reduce) resonance at the fundamental. The processor 8 is programmed to provide the control signals 7 so that the control signal frequency f_d does not approach f_N, or so that the control signal pulse width t_p does not approach $1/f_N$. Hence, the fundamental frequency will not dominate the response and other useful frequencies are produced. In general, it is preferred that f_d is greater than f_N by a value in the range of 40% to 250%. Also, it is preferred that the control signal pulse width t_p is much less than the disc's natural frequency period $1/f_N$, and in general it is preferred that it is less than 8% of $1/f_N$.

[0036] In one example the control signals used for generating binary 'O's are at 6.8kHz and binary '1's are at 5.5kHz, from the 3kHz natural frequency piezo disc 2, as shown in Fig. 3. In the first example, for a binary "1", the pulse width is 16μs and the gap is 165μs giving a repetition rate of 181μs. The pulse width of 16μs is much less than the $1/f_N$ duration of 333μs. In another example, for binary "0", the repetition rate is 147μs and the pulse width is the same (16 μs).

[0037] The frequency difference between a 0 and a 1 is in this example 1.3kHz. It is preferred that the difference be at least 1kHz.

[0038] The processor 8 control signal 7 drive scheme avoids a situation such as shown in Fig. 4 in which a high dB level is reached at the disc's fundamental. Referring to Fig. 4, when the control signal pulse widths are greater than $1/f_N$ the output audio signal is dominated by a high amplitude 3kHz signal, and its 3rd harmonic.

[0039] On the other hand, referring to Fig. 5, with f_d = 6.8kHz and the pulse width of the control signal $t_p \ll 1/f_N$ the output audio signal shows a dominant peak at a disc vibration (sound) frequency of 6.8kHz, which is approximately 5dB larger than the disc's natural vibration frequency of 3kHz. Compared to the output shown in Fig. 4, the fundamental intensity has decreased by over 30dB, and is thus significantly quieter while also generating a more controllable frequency.

[0040] Fig. 6 demonstrates the audio output for a binary-FSK signal generated by the above procedure. In this example, data was transmitted by alternately driving at frequencies of 5.5kHz and 6.8kHz, representing binary 1s and 0s respectively. The decoder listens for audio signals at 5.5kHz and 6.8kHz to recognize 1s and 0s.

[0041] For improved decoding, the difference between a binary 1 or 0 must be as clear as possible. In the above scheme, since only one drive frequency can be used at a time, it is important that the chosen FSK output frequencies can be produced independently with little cross-talk. For example, when a 6.8kHz output is generated, the output at 5.5kHz should be as low as possible. Therefore, an important parameter for decoding performance is the relative ON-OFF amplitude difference between the chosen FSK frequencies.

[0042] In reference to Fig.5, where only 6.8kHz is active (a binary 0 is being sent), it can be seen that the amplitude at 6.8kHz is significantly larger than that at 5.5kHz - a relative difference of 29dB. This is sufficiently high that the decoder should not mistake a 1 for a 0 or vice versa, even in the presence of background noise. This demonstrates that the control scheme above allows frequencies to be driven independently with a large signal-to-noise ratio, making FSK data-encoding practical, even though the disc and feedback circuit are primarily designed for 3kHz output.

[0043] In general, it is preferred that:

The control signal frequency difference between encoding 0 and 1 is at least 1kHz.

The pulse width t_p is less than 8% of the disc natural frequency period.

The drive frequency is greater than the disc's natural vibration frequency by at least 40%.

[0044] In summary, the acoustic interface uses Binary FSK modulation, one frequency for binary 1, and another frequency for the 0. Turning it on and off rapidly at frequencies greater than the disc's natural frequency by at least 40% has the effect of dampening the feedback of the primary resonance (in one example, 3kHz), preventing the disc from resonating at the natural frequency. It is repeatedly interrupted and is used to generate other frequencies of sufficient amplitude that they become useful. Because it is not driven at resonance, disc vibration dampens down a lot faster, so higher data rate is possible. The microcontroller can generate and control multiple control signal frequencies. When it generates say 6.8kHz for binary 0, that 6.8kHz is not unintentionally generated for a binary 1 at 5.5kHz. While there are unwanted frequencies, that is not a problem because the difference between a 1 and a 0 is sufficient to make them easily distinguishable. We have found that the acoustic interface is at least 5 times faster and significantly quieter than if the drive signals have a frequency close to the disc's natural frequency. The control is via the duty cycle and frequency of the pulses used to turn on/off the piezo.

[0045] In various examples the drive processor providing the control signals is a dedicated IC of the host device, while in other examples it is an LC oscillator circuit. In general, it is preferred that there be a 3-wire arrangement with feedback from the vibrating element such as a piezo.

[0046] In one example the frequencies are 5.5kHz for binary 1, and 9kHz for binary 0. In another example it is 5.5khz and 6.8kHz respectively. In the 9kHz signal example, this may for example be generated by driving at 4.5kHz and taking advantage of the second harmonic output produced at 9kHz, and the listening device decoding processor may listen out for 9kHz or 4.5kHz.

[0047] Other higher frequency harmonics can also be used, such as 11kHz from a 5.5kHz drive signal, or 13.5kHz from the 3rd harmonic caused by a drive signal at 4.5kHz. In general, it is preferred to drive the piezo with a control signal in the range of 4kHz to7kHz.

[0048] If the drive signals are at say 4.5kHz, this produces disc vibration harmonics at 9kHz and 13.5kHz, both of which can be used to decode the signals. There are particularly good results from decoding at 9kHz because the signal is larger, however the listening device can successfully decode at 13.5kHz also.

[0049] As shown in Fig. 7, audio frequency noise dB level usually decreases as frequency increases. In this example the noise is as high as -60dB for frequencies in the region of 10Hz to low hundreds Hz. In the context of data transmission, common sources of audio frequency noise, such as speech, music and road traffic usually have higher amplitudes at the lower end of the audible range (<5kHz). Beyond this, the amplitude of ambient noise tends to decrease towards zero. Therefore, to maximise signal-to-noise ratio (SNR), a higher audio frequency carrier wave should ideally be used.

[0050] Also, since the data transmissions are advantageously decoded by a smartphone, the characteristics of the smartphone microphone system are important to the overall operation of the data transfer. Most modern phones have active noise-cancellation algorithms and use multiple microphones to reduce noise. In some cases, the data transmission can be regarded as noise by the phone, and it therefore actively attempts to eliminate this perceived "noise" signal. This can severely interfere with decoding the data and leads to errors. An additional problem is that different makes and models of phones behave differently in terms of noise cancelling and therefore there is no single range of preferred frequencies that will work for audio data transmission on all phones. Having the ability to decode with different frequencies when required is an advantage.

[0051] As set out above it is advantageous if resonance is avoided. For successful transmission, another important factor is the amplitude of the output. A higher duty cycle gives more power to the transmission but requires a higher pulse width during the ON phase, which can lead to the resonance condition we try to avoid. There is therefore a balance between audio output level and maximum frequency before resonance occurs in the 3-wire piezo circuit.

[0052] We find that the useful limit for upper drive frequency is about 7kHz for a 3kHz disc. Beyond this, the timing constraints becomes more difficult, and the output amplitude drops to unacceptable levels.

[0053] To achieve output frequencies beyond 7kHz and take advantage of the lower background noise at higher frequencies, in some examples the processor is configured to utilise the harmonics which are naturally produced by the disc when driven. For example, as shown in Fig. 8, when driven at 5.5kHz, a harmonic at 11kHz is created.

[0054] Fig. 9 shows the sound output when driven at 4.5kHz, with disc vibration (sound) intensity peaks at 5.5kHz and 9kHz. It also shows a relatively strong 3rd harmonic at 13.5kHz. As can be seen, the 9kHz output signal is actually larger than the signal at the driven frequency of 4.5kHz. This is because 9kHz is a multiple of the disc's natural frequency. The disc will therefore be relatively efficient at oscillating at 9kHz even though it is electronically driven at 4.5kHz.

[0055] The data transmitted is thus present in the 4.5kHz signal and the 9kHz signal and the 13.5 kHz signal. This provides three sources from which decoding can take place to recover the data. This is very beneficial in the context of noise-cancelling smart-phone systems, where one range of frequencies may be more prone to cancellation on a particular phone. Successful decoding of the transmitted data is more likely when decoding on more than a single frequency. For example, if a particular phone has a weak response at 4.5kHz, the decoded signal may have errors, but decoding at 9kHz or 13.5kHz can resolve the errors.

[0056] Components of embodiments can be employed in other embodiments in a manner as would be understood by a person of ordinary skill in the art. The invention is not limited to the embodiments described but may be varied in construction and detail. While the acoustic interface has been described as being for a smoke alarm device, it may be for any other appliance for which status information is to be communicated acoustically to be picked up and decoded by a processor such as a smartphone.

Claims

1. An acoustic interface (1) for a device such as an alarm device, the acoustic interface comprising a vibratory element (2), and a drive circuit (8, 5) with a processor (8) for delivering drive electrical control signals (7) to the element to cause it to vibrate and generate a sound signal with encoded binary data, wherein the vibrating element (2) has a natural frequency

   characterized in that,

   the control signals are frequency encoded with pulses having pulse widths (t_p) which are shorter than the vibrating element natural frequency period ($1/f_N$) and a frequency which is greater than said natural frequency.

2. An acoustic interface as claimed in claim 1, wherein the processor (8) is configured to provide the control signals via a feedback transistor (5) and a voltage oscillator (6).

3. An acoustic interface as claimed in claim 2, wherein the vibratory element (2) comprises at least three electrical contacts of which two are for power and a third is for feedback to the feedback transistor (5), in which mechanical oscillation of the vibratory element generates an electrical feedback signal used to amplify this control signal (7).

4. An acoustic interface as claimed in any preceding claim, wherein the processor (8) is configured to generate the control signals according to a Frequency Shift Keying scheme.

5. An acoustic interface as claimed in claim 4, wherein the processor is configured to generate the control signals according to a Binary Frequency Shift Keying scheme, in which one frequency is used to represent a binary '0' and a different frequency is used to represent a '1'.

6. An acoustic interface as claimed in claim 5, wherein the processor is configured to generate the control signals with a frequency difference between binary 0 and 1 representations of at least 1kHz.

7. An acoustic interface as claimed in any preceding claim, wherein the processor is configured to generate the control signals having a pulse width t_p less than 8% of said natural frequency period.

8. An acoustic interface as claimed in any preceding claim, wherein the processor is configured to generate the control signals having a frequency which is greater than said natural frequency by at least 40%.

9. An acoustic interface as claimed in any preceding claim, wherein the processor is configured to generate the control signals having a frequency which causes at least one additional vibratory element harmonic of double or treble the drive control signal frequency for encoding a binary value a said at least one harmonic.

10. An alarm device comprising a condition sensor, a controller, an alarm sound emitter with a vibrating element, and an acoustic interface of any preceding claim, in which the controller is configured to encode alarm status data in the acoustic output of the interface.

11. An alarm device as claimed in claim 10, wherein the acoustic interface vibrating element is also the alarm sound emitter.

12. An alarm device as claimed in either of claims 9 or 10, wherein the alarm device is a fire alarm device, and the condition sensor is a heat or smoke detector.

13. A system comprising an acoustic interface of any of claims 1 to 9 or an alarm device of any of claims 10 to 12, and a decoding device having an acoustic pick-up and a decoding processor configured to decode acoustic signals and provide a user data output.

14. A system as claimed in claim 13, wherein the encoding processor is configured to provide the control signals to generate a strong second harmonic, and the decoding processor is configured to decode at double or treble the drive control frequency.

15. A system as claimed in claim 14, wherein the second harmonic decoding is used for only one of a binary 0 or 1 decoding.

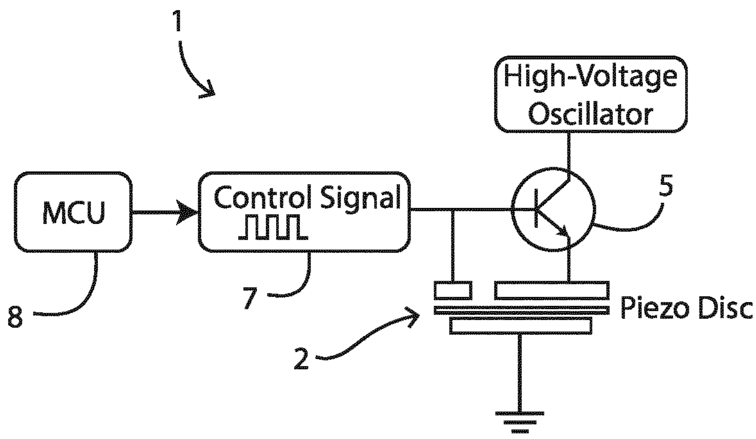

1
High-Voltage Oscillator
MCU
Control Signal
5
8
7
Piezo Disc
2

Fig.1(a)

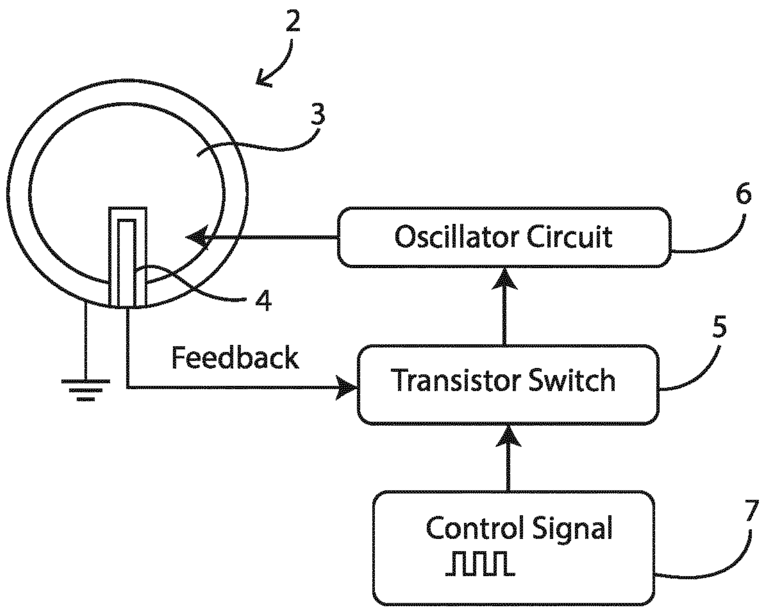

2
3
6
Oscillator Circuit
4
5
Feedback
Transistor Switch
Control Signal
7

Fig.1(b)

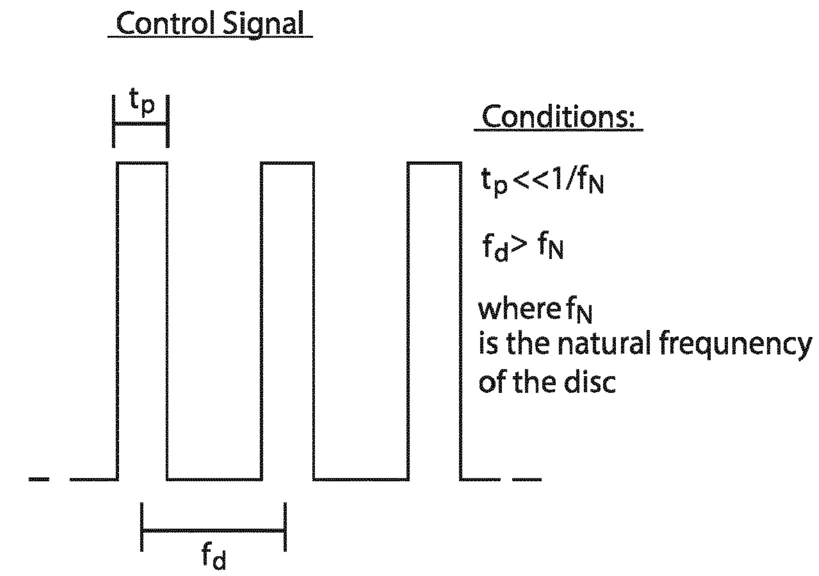
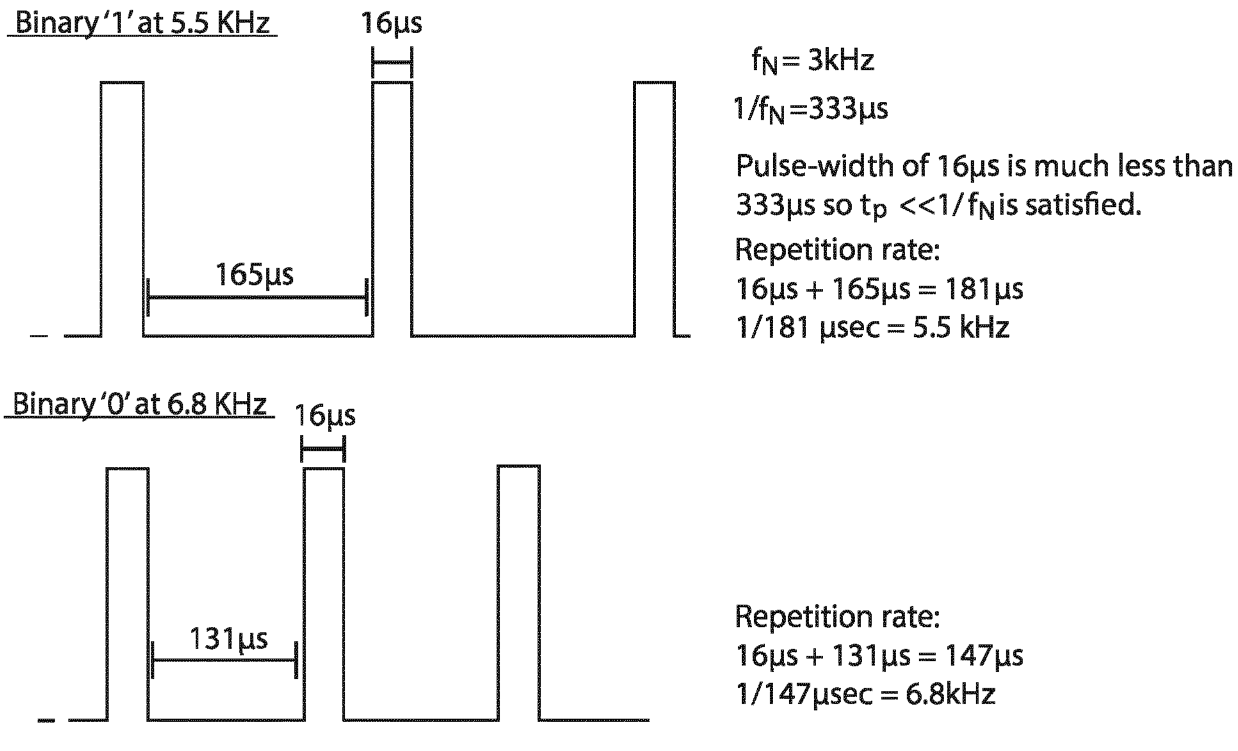
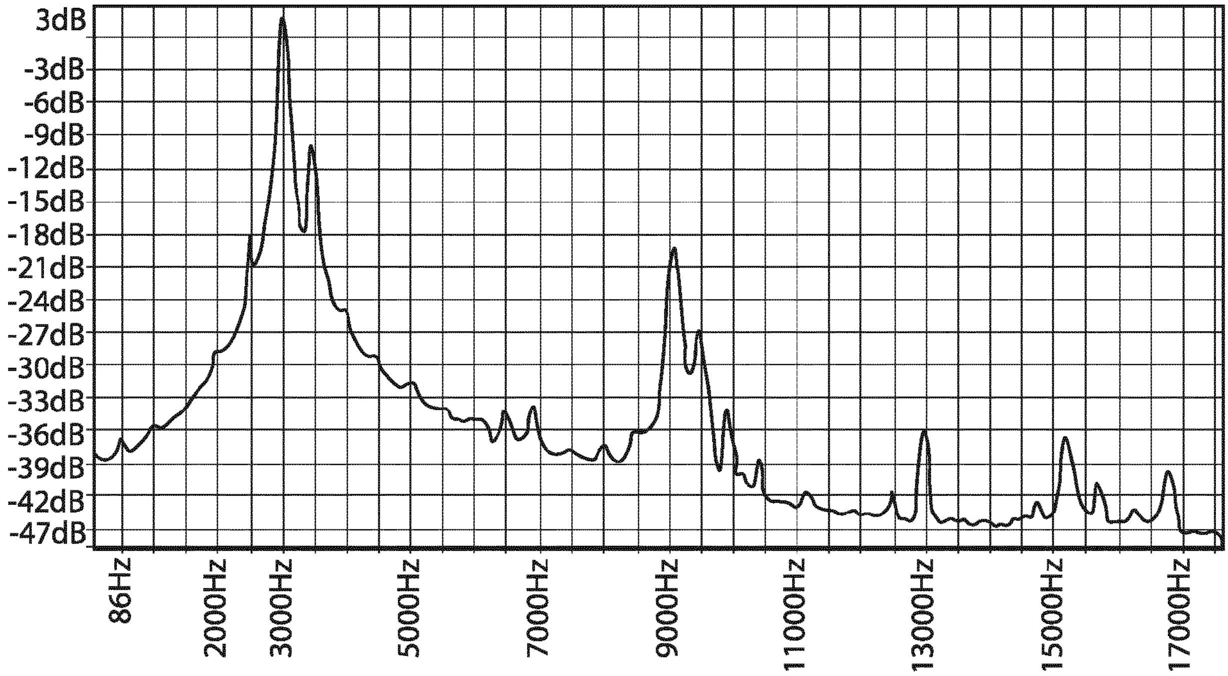


Fig.2



Example of control signals used for generating binary '0's at 6.8kHz and binary '1's at 5.5kHz, from a 3kHz piezo disc.

Fig.3


3dB
-3dB
-6dB
-9dB
-12dB
-15dB
-18dB
-21dB
-24dB
-27dB
-30dB
-33dB
-36dB
-39dB
-42dB
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11000Hz
13000Hz
15000Hz
17000Hz

Fig.4

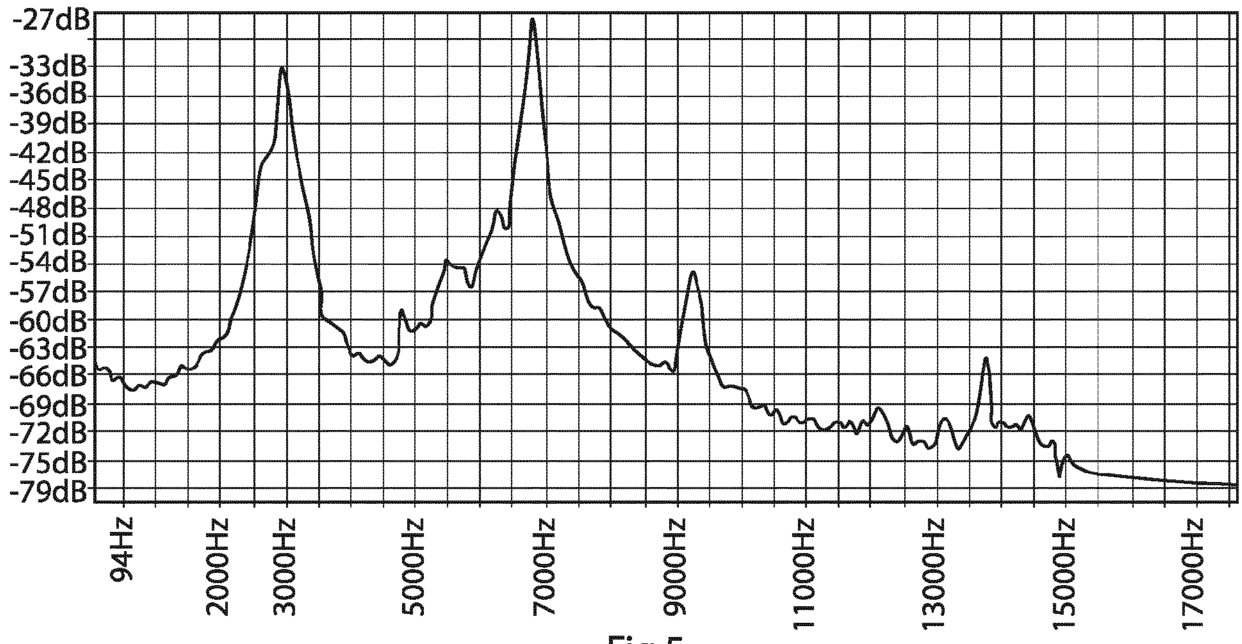
-27dB
-33dB
-36dB
-39dB
-42dB
-45dB
-48dB
-51dB
-54dB
-57dB
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-79dB
94Hz
2000Hz
3000Hz
5000Hz
7000Hz
9000Hz
11000Hz
13000Hz
15000Hz
17000Hz

Fig.5

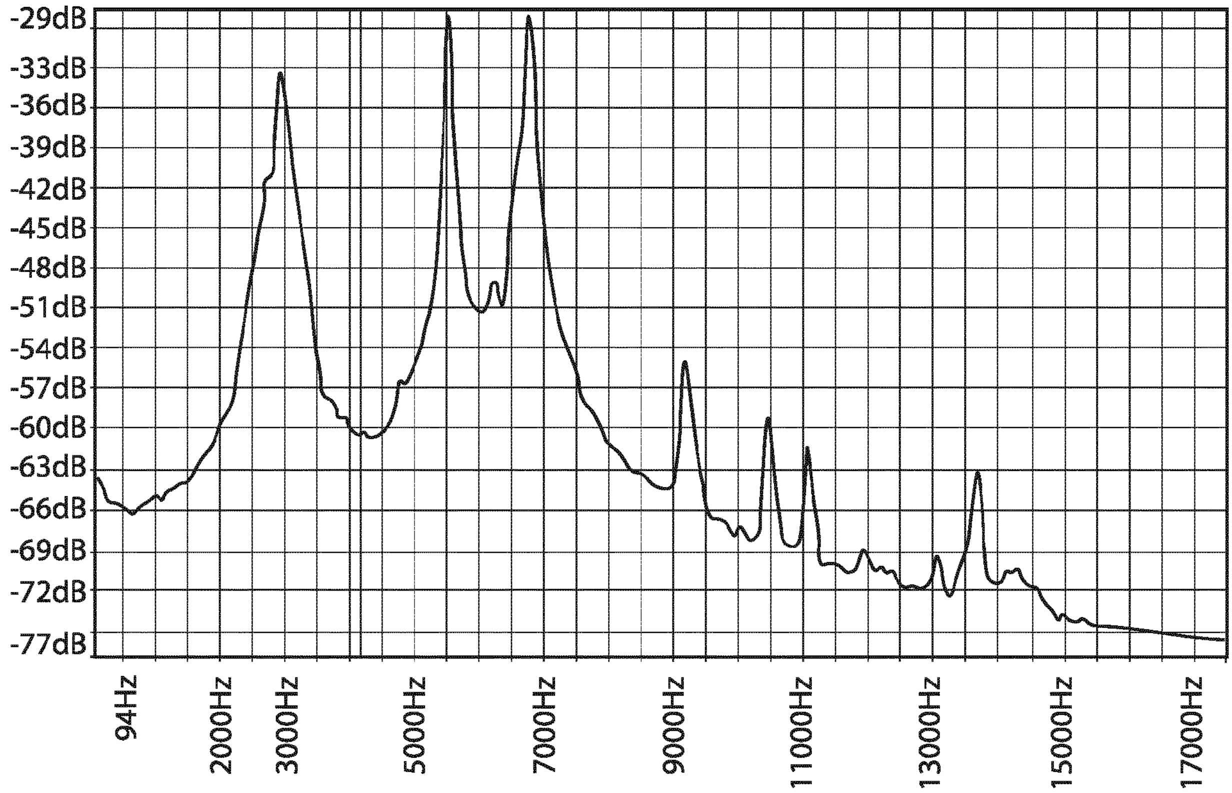
-29dB
-33dB
-36dB
-39dB
-42dB
-45dB
-48dB
-51dB
-54dB
-57dB
-60dB
-63dB
-66dB
-69dB
-72dB
-77dB
94Hz
2000Hz
3000Hz
5000Hz
7000Hz
9000Hz
11000Hz
13000Hz
15000Hz
17000Hz

Fig.6

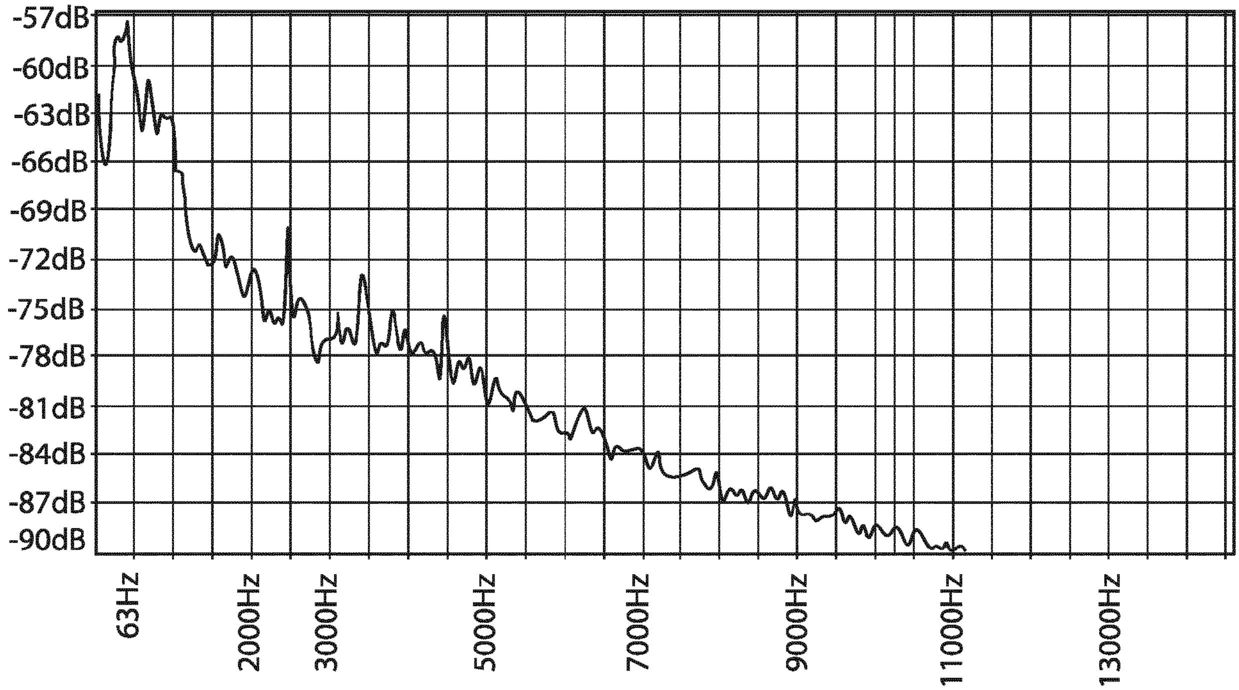
-57dB
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-87dB
-90dB
63Hz
2000Hz
3000Hz
5000Hz
7000Hz
9000Hz
11000Hz
13000Hz

Fig.7

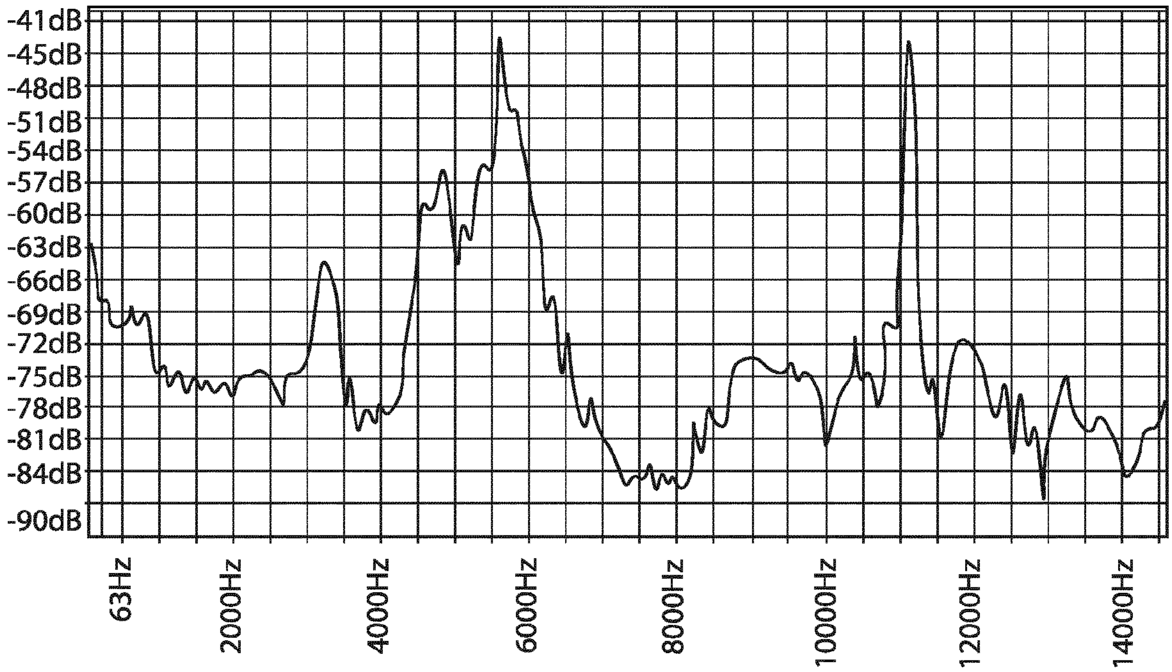
-41dB
-45dB
-48dB
-51dB
-54dB
-57dB
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-90dB
63Hz
2000Hz
4000Hz
6000Hz
8000Hz
10000Hz
12000Hz
14000Hz

Fig.8

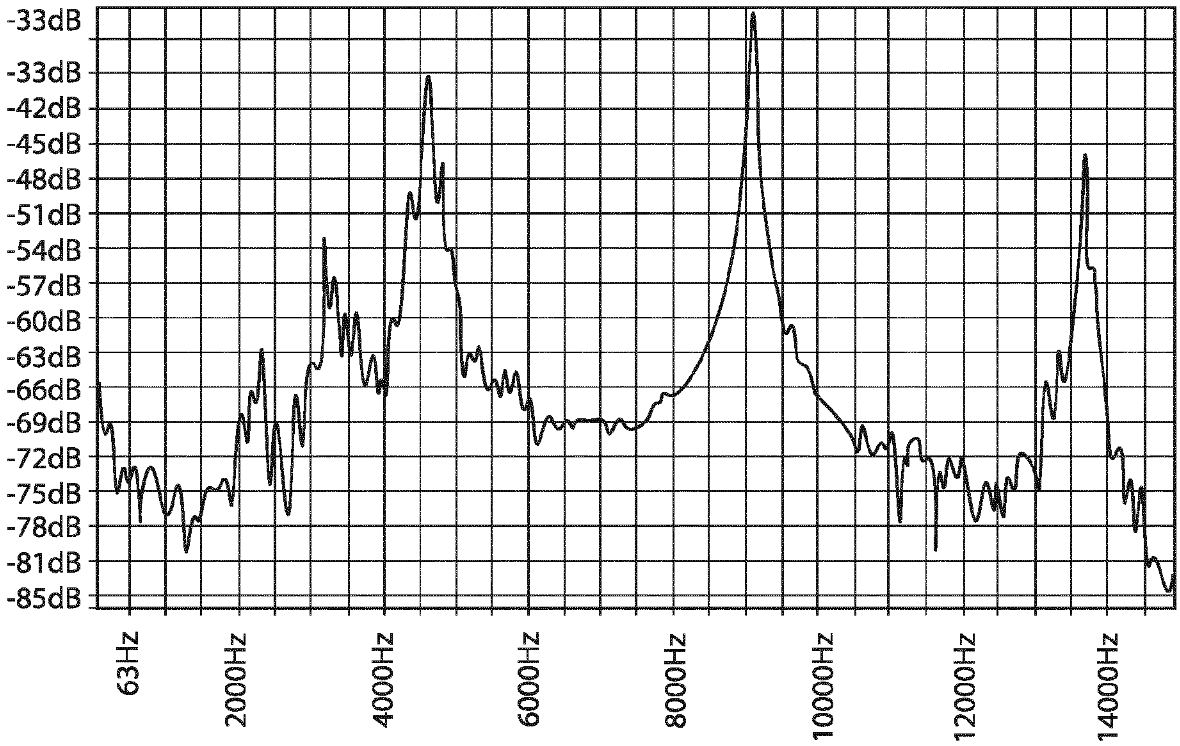
-33dB
-33dB
-42dB
-45dB
-48dB
-51dB
-54dB
-57dB
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-85dB
63Hz
2000Hz
4000Hz
6000Hz
8000Hz
10000Hz
12000Hz
14000Hz

Fig.9

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EUROPEAN SEARCH REPORT

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