(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 March 2022 (17.03.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/055432 A1

(51) International Patent Classification:
G10K 11/178 (2006.01) *G10L 21/0208* (2013.01)
G10K 11/16 (2006.01)

(21) International Application Number:
PCT/SG2021/050549

(22) International Filing Date:
10 September 2021 (10.09.2021)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10202008940T 11 September 2020 (11.09.2020) SG

(71) Applicant: **NANYANG TECHNOLOGICAL UNIVERSITY** [SG/SG]; 50 Nanyang Avenue, Singapore 639798 (SG).

(72) Inventors: **GAN, Woon Seng**; c/o Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798 (SG). **LAM, Bhan**; c/o Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798 (SG). **SHI, Dongyuan**; c/o Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798 (SG). **WEN, Shulin**; c/o Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798 (SG). **BELYI, Valiantsin**; c/o Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798 (SG). **LEE, Yen Leng, Irene**; c/o Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798 (SG).

(74) Agent: **VIERING, JENTSCHURA & PARTNER LLP**; P.O. Box 1088, Rochor Post Office, Rochor Road, Singapore 911833 (SG).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) Title: A SYSTEM AND METHOD FOR ACTIVELY CANCELLING A NOISE SIGNAL ENTERING THROUGH AN APERTURE

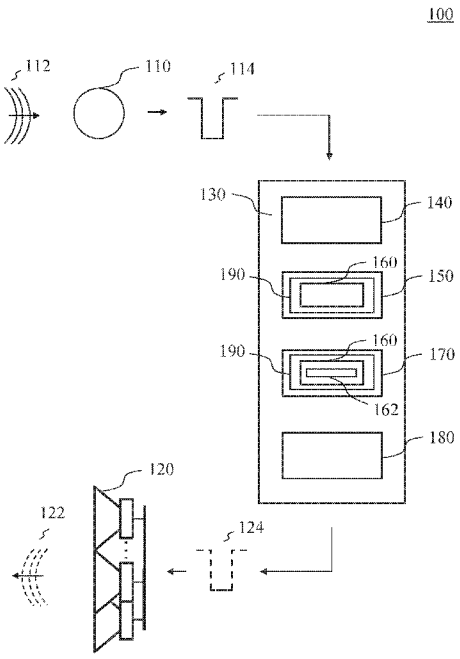


FIG. 1

(57) Abstract: The disclosure concerns a system for actively cancelling an acoustic noise signal entering through an aperture of a room. The system includes a sensor to detect the acoustic noise signal and convert it into an electronic noise signal; a plurality of transducers to generate an acoustic anti-noise signal from an electronic anti-noise signal to cancel the acoustic noise signal; and a controlling circuit operably coupleable to the sensor and the plurality of transducers, which: receives the electronic noise signal, classifies the electronic noise signal by matching a sample of the electronic noise signal to one or more pre-determined cancellation filter candidates, selects a first pre-determined cancellation filter from the one or more pre-determined cancellation filter candidates, based on said classified sample, generates the electronic anti-noise signal by applying the first pre-determined cancellation filter on the electronic noise signal, and transmits the electronic anti-noise signal to the plurality of transducers.

WO 2022/055432 A1

[Continued on next page]

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

A SYSTEM AND METHOD FOR ACTIVELY CANCELLING A NOISE SIGNAL ENTERING THROUGH AN APERTURE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Singapore patent application 10202008940T, filed 11 September 2020 with the Intellectual Property Office of Singapore, the contents of it being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] Various aspects of this disclosure relate to a system for actively cancelling an acoustic noise signal entering a room through an aperture of the room. Various aspects of this disclosure further relate to methods for actively cancelling an acoustic noise signal entering a room through an aperture of the room.

BACKGROUND

[0003] The World Health Organisation (WHO) has recently put forth strong recommendations to reduce urban transportation noise levels, underpinned by a rapidly growing body of evidence associating a myriad of health risks with environmental noise exposure [WHO Regional Office for Europe, *Env. Noise Guidelines for European Region,* **2018**]. In high-rise urban landscapes, traditional noise mitigation approaches such as noise barriers have a limited efficacy in the low-frequency range and are effective only for the lower floors of a high-rise building that are in its shadow zone [Murphy E. et al. *Env. Noise Pollution*, **2014**]. Although noise mitigation at the receivers' end, such as on building façades, is inefficient, it is usually the only form noise control available for land-scarce, high-density urban cities. The sustainability push for naturally ventilated buildings also increases the noise control difficulty as noise propagates easily through any opening in the façade.

[0004] Noise control for naturally-ventilated buildings has been traditionally passive, where physical elements have been employed to obstruct or dampen the acoustic waves as it enters the façade [De Salis M.H.F. et al. *Build. Env.* **2002,** 37, 471-484*;* Tang S.K. *Appl. Sci.* **2017**, 7, 175]. The main limitation of effective passive interventions, such as louvres and plenum windows, appear to be the restriction of airflow. Moreover, passive elements are designed with

the noise control perspective of reducing the total acoustic pressure in the building interior by treating all sounds that enter the façade opening as 'waste' to be reduced. Although the indoor acoustic environment for naturally ventilated buildings is dependent on context, there has been some evidence showing a preference of some external sound sources (e.g. natural sounds, human voices) over others (e.g. heavy traffic), while no indoor sound sources were present [Torresin S. et al. *Build Env.* **2020**, 182, 107152]. With the introduction of international standards on soundscapes [International Organization for Standardization (ISO), *Acoustics Soundscapes Part 1.* **2014**, ISO 12913-1; ISO, *Acoustics Soundscapes Part 2.* **2018**, ISO/TS 12913-2; ISO, *Acoustics Soundscapes Part 3.* **2019**, ISO/TS 12913-3], it is imperative that the indoor acoustic comfort is approached with a perceptual perspective [Torresin, S. et al. *Appl. Sci.* **2019**, 9, 5401].

[0005] Further, one overlooked factor in an indoor environment is the concept of control, which is challenging for naturally ventilated buildings. For instance, opening of windows to lower the temperature increases the influx of exterior noise. Currently, the selective control of external noise sources [Ranjan, R. et al. *Proc. of the INTER-NOISE and NOISE-CON Congress and Conference Proc.* **2016**, 482–492; Shi, D. et al. *IEEE/ACM Trans. Audio, Speech, Lang. Process.* **2020**, 28, 1479–1492; Wen, S. et al. *J. Acoust. Soc. Am.* **2020**, 147, 3490–3501] without obstructing airflow appears to be achievable with an active noise control (ANC) system designed for façade openings [Lam, B. et al. *Sci. Rep.* **2020**, 10, 10021].

[0006] By projecting an opposing sound wave with the same amplitude at the precise time and space of the disturbance to be controlled, ANC has been successfully integrated into automobile cabins [Samarasinghe, P.N. et al. *IEEE Signal Process. Mag.* **2016**, 33, 61–73; Cheer, J. et al. *Mech. Syst. Signal Process.* **2015**, 60–61, 753–769.], aircraft cabins [Elliot, S.J. et al. *J. Sound Vib.* **1990**, 140, 219–238] and headsets [Chang, C.-Y. et al. *IEEE Consum. Electron. Mag.* **2016**, 5, 34–43] to reduce low-frequency noise. The ANC principle has been recently adapted for façade openings to provide significant noise control without obstruction to natural ventilation [Lam, B. et al. *Sci. Rep.* **2020**, 10, 10021; Murao, T. et al. *J. Environ. Eng.* **2012**, 7, 76–91; Murao, T. et al. *Mech. Eng. J.* **2014**, 1, EPS0065–EPS0065; Lam, B. et al. *Build. Environ.* **2018**, 141, 16–27]. However, even though the proposed method where noise sources are distributed across the entire aperture allows for optimal control [Lam, B. et al. *Appl. Acoust.* **2018**, 137, 9–17], the limited size of the loudspeakers in such a layout inherently limits the noise control performance in the low frequency range.

[0007] Thus, it is desired to provide better means to improve ANC performance, in particular, for cancelling noise in the low-frequency range, typically perceived as being undesired, without obstruction to natural ventilation.

SUMMARY

[0008] Various embodiments may relate to systems and methods for ANC performance, without obstruction to natural ventilation. In particular, various embodiments may actively cancel at least part of the noise entering a room through an aperture of the room. Various embodiments may provide instantaneous noise reduction, optimized ANC performance, and may be used for the selective (e.g. user-specific) cancellation of noise in the low-frequency range.

[0009] A first aspect of the disclosure concerns a system for actively cancelling an acoustic noise signal entering a room through an aperture of the room. The system includes a sensor configured to detect the acoustic noise signal and to convert the acoustic noise signal into an electronic noise signal, and a plurality of transducers configured to generate an acoustic anti-noise signal from an electronic anti-noise signal to cancel, at least part of, the acoustic noise signal, when the acoustic anti-noise signal is added to the acoustic noise signal. The system further includes a controlling circuit operably coupleable to the sensor and the plurality of transducers, such that when operably coupled, the controlling circuit: receives the electronic noise signal from the sensor; classifies the electronic noise signal by matching a sample of the electronic noise signal to one or more pre-determined cancellation filter candidates; selects a first pre-determined cancellation filter from the one or more pre-determined cancellation filter candidates, by basing a selection on the classified sample of the electronic noise signal; generates the electronic anti-noise signal by applying the first pre-determined cancellation filter on the electronic noise signal; and transmits the electronic anti-noise signal to the plurality of transducers.

[0010] A second aspect of the disclosure concerns a method for actively cancelling an acoustic noise signal entering a room through an aperture of the room. The method includes providing a sensor to detect the acoustic noise signal and to convert the acoustic noise signal into an electronic noise signal, and transmitting the electronic noise signal from the sensor to a controlling circuit operably coupled to the sensor and to a plurality of transducers. The method further includes classifying using the controlling circuit, the electronic noise signal by matching

a sample of the electronic noise signal to one or more pre-determined cancellation filter candidates; and selecting using the controlling circuit, a first pre-determined cancellation filter from the one or more pre-determined cancellation filter candidates, by basing a selection on the classified sample of the electronic noise signal. The method also includes generating using the controlling circuit, an electronic anti-noise signal by applying the first pre-determined cancellation filter on the electronic noise signal; and transmitting using the controlling circuit, the electronic anti-noise signal to the plurality of transducers, wherein the plurality of transducers generates the acoustic anti-noise signal from the electronic anti-noise signal to cancel, at least part of, the acoustic noise signal, when the acoustic anti-noise signal is added to the acoustic noise signal.

[0011] A third aspect of the disclosure concerns a method for actively cancelling an acoustic noise signal entering a room through an aperture of the room. The method includes: providing a sensor to detect the acoustic noise signal and to convert the acoustic noise signal into an electronic noise signal; and providing a plurality of transducers to generate an acoustic anti-noise signal to cancel at least part of the acoustic noise signal, when the acoustic anti-noise signal is added to the acoustic noise signal, and to convert an electronic anti-noise signal into the acoustic anti-noise signal. The method further includes: transmitting the electronic noise signal to a controlling circuit operably coupled to the sensor and the plurality of transducers; classifying using the controlling circuit, the electronic noise signal by matching a sample of the electronic noise signal to one or more pre-determined cancellation filter candidates; selecting using the controlling circuit, a first pre-determined cancellation filter from the one or more pre-determined cancellation filter candidates, by basing a selection on the classified sample of the electronic noise signal; generating using the controlling circuit, the electronic anti-noise signal by applying the first pre-determined cancellation filter on the electronic noise signal; and transmitting using the controlling circuit, the electronic anti-noise signal to the plurality of transducers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

- FIG. 1 shows an exemplary schematic illustration of a use condition of a system 100 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments;
- FIG. 2A and 2B show exemplary schematic illustrations of a training system 200 and the algorithm 250 implemented by the training system 200, for generating each one of the one or more pre-determined cancellation filter candidates 160, in accordance with various embodiments;
- FIG. 3 shows an exemplary schematic illustration of the method 300 employed by the training system 200, in accordance with various embodiments;
- FIG. 4 shows an exemplary schematic illustration of a use condition and the layout of the system 400 for actively cancelling the acoustic noise signal 112 entering through an aperture 420 of a room 410, in accordance with various embodiments;
- FIGS. 5A to 5G show exemplary schematic illustrations of the physical configurations of the system 100, 400, in relation to the aperture 420 of the room 410, in accordance with various embodiments;
- FIG. 6 shows an exemplary schematic illustration of a use condition of the system 600, in accordance with various embodiments;
- FIG. 7 shows an exemplary schematic illustration of method 700 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments;
- FIGS. 8A and 8B show exemplary schematic illustrations of methods 800A and 800B for activating and deactivating method 700, in accordance with various embodiments;
- FIG. 8C shows an exemplary schematic illustration of method 800C as a flow diagram for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments
- FIG. 9 shows an exemplary schematic illustration of method 900 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments;
- FIG. 10 shows the (A) layout of the 4 secondary sources (e.g. plurality of transducers 120) around a customized wooden frame (e.g. support 520) and 4 error microphones (e.g. reference sensor 440 or training error microphone array 240) placed 30 cm away, and (B) the primary source (e.g. acoustic noise signal 112) and reference microphone

(e.g. sensor 110) on the outside of the fully-opened top-hung window (e.g. aperture 420), in accordance with various embodiments;

- FIG. 11 shows the room dimensions of the: observation microphone layout, primary source (e.g. acoustic noise signal 112), reference microphone (e.g. sensor 110), error microphone placement (e.g. reference sensor 440 or training error microphone array 240), in accordance with various embodiments;
- FIG. 12 shows the: (A) impulse response of the primary paths measured from the reference microphone (e.g. sensor 110) to each of the four error microphones (e.g. reference sensor 440 or training error microphone array 240), and (B) the corresponding frequency responses, in accordance with various embodiments;
- FIG. 13 shows the offline measurements of the secondary paths from the four loudspeakers (e.g. plurality of transducers 120) to error microphones (e.g. reference sensor 440 or training error microphone array 240 (A) 1, (B) 2, (C) 3, and (D) 4, in accordance with various embodiments;
- FIG. 14 shows the frequency responses of the secondary paths from the four loudspeakers (e.g. plurality of transducers 120) to error microphones (e.g. reference sensor 440 or training error microphone array 240 (A) 1, (B) 2, (C) 3, and (D) 4, in accordance with various embodiments;
- FIG. 15 shows the one-third octave band spectra at observation microphone 7 for (A) aircraft, (B) motorbike, (C) traffic, and (D) compressor noise, in accordance with various embodiments;
- FIG. 16 shows the (A) finite element method simulation model of a regular window system with a 45° opened awning window (e.g. aperture 420) and a closed casement with a fixed glass panel, and (B) acoustic transmission loss in dB as a function of frequency for four scenarios: (i) full glazing, (ii) top and bottom ANC sources turned on (q1 & q2), (iii) bottom ANC source turned on (q1), and (iv) top ANC source turned on (q2), in accordance with various embodiments;
- FIG. 17 shows the attenuation in dB at microphone 7 as a function of frequency during ANC ON (window opened) and ANC OFF (window closed) across (A) aircraft, (B) motorbike, (C) traffic and (D) compressor noise types, in accordance with various embodiments; and

- FIG. 18 shows the attenuation in dB as a function of frequency during ANC ON (window opened), and ANC OFF (window closed) for (A) aircraft, (B) motorbike, (C) traffic, and (D) compressor noises types; in accordance with various embodiments.

DETAILED DESCRIPTION

[0013] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the disclosure may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the disclosure. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0014] The disclosure illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms “comprising”, “including,” containing”, etc. shall be read expansively and without limitation. The word "comprise" or variations such as "comprises" or "comprising" will accordingly be understood to imply the inclusion of a stated integer or groups of integers but not the exclusion of any other integer or group of integers. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the disclosure. Thus, it should be understood that although the present disclosure has been specifically described in exemplary embodiments and optional features, modification and variation of the disclosure embodied herein may be resorted to by those skilled in the art.

[0015] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0016] In the context of various embodiments, the articles "a", "an" and "the" as used with regard to a feature or element include a reference to one or more of the features or elements.

[0017] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0018] According to various embodiments, the term "noise signal", as used herein, may refer to any signal in the acoustic domain, relating to sound, and the sense of hearing which is processed by the auditory system of a user. For example, the term noise signal may refer to any audio or acoustic signal, and not to noise specifically. In other words, the noise signal may be indistinguishable from a desired audio signal. Within the context of the disclosure, the term is referred to as a noise signal, since it may represent audio signals that is perceived as being unwanted, unpleasant, or loud to a user. As a further example, the term noise signal may be perceived as any audio signal perceived as causing disturbance or disruption to a user.

[0019] According to various embodiments, the term "acoustic noise signal" and "acoustic anti-noise signal", as used herein, may refer to any analog signal in the acoustic domain. For example, an analog acoustic signal may refer to a continuous signal where the instantaneous voltage of the signal varies continuously with the pressure of the sound waves.

[0020] According to various embodiments, the term "electronic noise signal" and "electronic anti-noise signal" as used herein, may refer to a digitized signal in the digital domain. Within the context of the disclosure, the electronic noise signal represents a converted digital form of the acoustic noise signal. The electronic anti-noise signal may represent a converted digital form of the acoustic anti-noise signal, and vice versa. For example, the electronic noise or anti-noise signals represents the original voltage of the noise or anti-noise signal, respectively, as a sampled sequence of quantitized values. In other words, the electronic noise or anti-noise signal is a representation of the acoustic noise or anti-noise signal, respectively, that has been sampled and quantized, e.g. an abstraction that is discrete in time and amplitude and exists at regular time intervals. The electronic noise or anti-noise signal may be stored, processed or transmitted physically, for example, as a pulse-code modulation (PCM) signal by a circuit.

[0021] According to various embodiments, the term "aperture", as used herein, may refer to a space through which an acoustic noise signal may pass through. For example, an aperture may refer to any opening of a room which admits and allows the acoustic noise signal to enter.

In a preferred embodiment, the aperture of a room may include or may be: windows and/or doors of a room.

[0022] According to various embodiments, the term "room", as used herein, may refer to an area, or a part of a space of a building enclosed by walls, floor and a ceiling. For example, a room may include a partition, e.g. section or division, inside a building that is separated from other parts by walls, floor and a ceiling.

[0023] According to various embodiments, the term "sensor", as used herein, may refer to a device which detects, e.g. measures, a physical property of the acoustic noise signal. For example, the sensor may be an audio or acoustic, e.g. sound, sensor that detects sound waves through its intensity or pressure, and may include or may be: active or passive decibel meters. In a further example, the sensor may include the required architecture, e.g. analog-to-digital converter (ADC), to convert an acoustic noise signal into an electronic noise signal. In yet a further example, the sensor may include amplifiers, e.g. microphones, to amplify the acoustic or electronic noise signal.

[0024] According to various embodiments, the term "transducer", as used herein, may refer to a device which converts an electronic signal into an acoustic signal, e.g. a digital signal into an analog signal. For example, the transducer may include the required hardware, e.g. amplifier, circuits to receive an electronic signal and convert an electronic signal into an acoustic signal. Within the context of the disclosure, the transducer may receive an electronic anti-noise signal and convert it into an acoustic anti-noise signal, in response to the detected acoustic noise signal.

[0025] According to various embodiments, a circuit may include analog circuits or components, digital circuits or components, or hybrid circuits or components. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit" in accordance with an alternative embodiment. A digital circuit may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, firmware, or any combination thereof. Thus, in various embodiments, a "controlling circuit" may be a digital circuit, e.g. a hard-wired logic circuit or a programmable logic circuit such as a programmable processor, e.g. a microprocessor (e.g. a Complex Instruction Set Computer (CISC) processor or a Reduced Instruction Set Computer (RISC) processor). A "controlling circuit" may also

include a processor executing software, e.g. any kind of computer program, e.g. a computer program using a virtual machine code such as e.g. Java.

[0026] FIG. 1 shows an exemplary schematic illustration of a use condition of a system 100 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments.

[0027] The system 100 includes a sensor 110 configured to detect the acoustic noise signal 112, and to convert the acoustic noise signal 112 into an electronic noise signal 114. For example, the sensor 110, which may be an acoustic sensor, detects any acoustic noise signal 112, that enters through the aperture of the room. As a further example, the sensor 110 may amplify and/or buffer the detected acoustic noise signal 112. The sensor 110 further converts the acoustic noise signal 112 into the electronic noise signal 114, and may include for example, the necessary hardware such as ADCs to convert the acoustic noise signal 112 in the analog domain, to the electronic noise signal 114 in the digital domain.

[0028] According to various embodiments, the electronic noise signal 114 may be stored in the sensor 110, for example, in a memory in the sensor 110, before being transmitted to a controlling circuit 130. In another example, the electronic noise signal 114 may immediately, e.g. upon acquisition, be transmitted to a controlling circuit 130. For instance, the electronic noise signal 114 may be transmitted to the controlling circuit 130 in accordance with a pre-defined communication protocol, which may include wireless communications. The sensor 110 and the controlling circuit 130 may thus be equipped with the required hardware and/or software protocols to transmit and receive 140 the electronic noise signal 114. Examples of the pre-defined communication protocol include: Wi-Fi, Bluetooth, ZigBee, SigFox, LPWan, LoRaWan, GPRS, 3G, 4G, LTE, and 5G communication systems. To illustrate, the sensor 110 may include a wireless communicator configured to transmit the electronic noise signal 114 to the controlling circuit 130 via wireless communications. Alternatively, it may also be envisioned that the sensor 110 may be configured to transmit the electronic noise signal via wired communications, e.g. electrical cables.

[0029] The system 100 further includes a controlling circuit 130 which is operably coupled to the sensor 110 and to a plurality of transducer 120, such that the controlling circuit 130 when in operation is in communication with the sensor 110 and the plurality of transducers 120. According to various embodiments, the controlling circuit 130 is configured to: (i) receive 140 the electronic noise signal 114 from the sensor 110, for example, the electrical noise signal 114

of the respective acoustic noise signal 112 detected by the sensor 110; (ii) classify 150 the electronic noise signal 114 by matching a sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160, for example, by implementing a software protocol, to match the sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160; (iii) selects 170 a first pre-determined cancellation filter 162 from the one or more pre-determined cancellation filter candidates 160, wherein the selection 170 is based on the classified sample 150 of the electronic noise signal 114. For example, said selection 170 may be implemented using another software protocol to select 170 the first pre-determined cancellation filter 162 from the one or more pre-determined cancellation filter candidates 160; (iv) generate 180 an electronic anti-noise signal 124 by applying the first pre-determined cancellation filter 162 on the electronic noise signal 114; and (iv) transmit the electronic anti-noise signal 124 to the plurality of transducers 120.

[0030] According to various embodiments, the system 100 includes a prior training stage to generate each one of the one or more pre-determined cancellation filter candidate 160. Methods and means to obtain each one of the one or more pre-determined cancellation filter candidate 160 will be explained below, with reference to FIGS. 2A and 2B.

[0031] The controlling circuit 130 of system 100 is configured to (i) receive 140 the electronic noise signal 114. For example, the controlling circuit 130 may be configured to receive 140 electronic noise signals 114 within the aforementioned specified frequency range. Various communication protocols to enable the controlling circuit 130 to receive the electronic noise signal 114 from the sensor 110 have also been described above, e.g. via wireless or wired communications. In some embodiments, the received electronic noise signal 114 may be stored, e.g. in a memory of the controlling circuit 130, before being classified 150 by the controlling circuit 130. In another example, the electronic noise signal 114 may classified 150 immediately, e.g. upon acquisition, by the controlling circuit 130.

[0032] The controlling circuit 130 of system 100 is further configured to (ii) classify 140 the electronic noise signal 114 by extracting a sample of the electronic noise signal 114. For example, the controlling circuit 130 may process, e.g. analyze, the electronic noise signal 114 and extract a part of the electronic noise signal 114. In another example, the controlling circuit 130 processes the electronic noise signal 114 and reproduces a part of the electronic noise signal 114 to create a sample of the respective electronic noise signal 114. The controlling

circuit 130 is further configured to match the sample of the electronic noise signal 114 to one or more pre-determined filter candidates 160.

[0033] According to various embodiments, matching the sample of the electronic noise signal 114 to the one or more pre-determined cancellation filter candidates 160 may include determining at least one characteristic from the sample of the electronic noise signal 114. For example, the controlling circuit 130 may process the sample of the electronic noise signal 114 to determine the at least one characteristic of the sample of the electronic noise signal 114. The at least one characteristic may include or be: an amplitude, frequency and/or phase of the sample of the electronic noise signal 114, in accordance with various embodiments. For example, an amplitude of the sample of the electronic of the noise signal 114 may refer to the discrete levels of the signal, e.g. pulse train signal. In another example, a phase of the sample of the electronic noise signal 114 may refer to the position at a point in time of the sample of the electronic noise signal 114. In yet another example, the frequency of the sample of the electronic noise signal 114 may refer to the number of cycles within a unit of time, e.g. cycles / second or Hz. Means to determine the amplitude, phase and/or frequency of the sample of the electronic noise signal 114 will be known to those skilled in the art.

[0034] According to various embodiments, matching the sample of the electronic noise signal 114 to the one or more pre-determined cancellation filter candidates 160 may further include, determining if the at least one characteristic from the sample of the electronic noise signal 114 has a same characteristic to at least one corresponding characteristic of an exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. In other words, the controlling circuit 130 may be configured to compare the characteristic, e.g. amplitude, phase and/or frequency, of the sample of the electronic noise signal 114 to that of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates. For example, the controlling circuit 130 further determines, from said comparison, if the characteristic, e.g. amplitude, phase and/or frequency, of the sample of the electronic noise signal 114, is equal, e.g. identical, to that of the corresponding characteristic of the exemplary electronic signal stored in each one of the one or more pre-determined filter candidates 160. As a further example, the controlling circuit 130 may determines if, the amplitude of the sample of the electronic noise signal 114 is equal to that of the amplitude of the exemplary electronic signal stored in each one of the one or more pre-determined filter candidates 160. In another example, the controlling circuit 130 further

determines, from said comparison, if the characteristic, e.g. amplitude, phase and/or frequency, of the sample of the electronic noise signal 114, falls within a pre-defined range of the corresponding characteristic of the exemplary electronic signal stored in each one of the one or more pre-determined filter candidates 160. For instance, the pre-defined range may include specified limits of the characteristic (which may be user-defined), and the controlling circuit 130 may determine if the characteristic of the sample of the electronic noise signal 114 falls within, the pre-defined range of the exemplary electronic signal stored in each one of the one or more pre-determined filter candidates 160. By way of illustration, the controlling circuit 130 may determine if, the frequency of the sample of the electronic noise signal 114 is within the pre-defined range of frequencies of the exemplary electronic signal stored in each one of the one or more pre-determined filter candidates 160. In some embodiments, the controlling circuit 130 may be configured to further determine if more than one characteristic, e.g. amplitude and frequency, of the sample of the electronic noise signal 114 is equal to, or falls within the pre-defined range, of the more than one corresponding characteristic of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160.

[0035] The controlling circuit 130 of the system 100 is configured to (iii) select 170 a first pre-determined cancellation filter 162 from the one or more cancellation filter candidates 160, wherein said selection 170 is based on the classified sample of the electronic noise signal 114. For example, the controlling circuit 130 selects 170 the first pre-determined cancellation filter 162, when the at least one characteristic of the sample of the electronic noise signal 114 has the same characteristic, e.g. amplitude, phase and/or frequency, as the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. As a further example, the first pre-determined cancellation filter 162 is selected 170 when the characteristic, e.g. amplitude, phase and/or frequency, is equal to, or falls within the pre-defined range, of the corresponding characteristic of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. Thus, selection 170 of a cancellation filter, e.g. the first pre-determined cancellation filter 162, is dependent on the classified 150 electronic noise signal 114, which may be determined by matching of the sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160. That is to say, the selected cancellation filter, e.g. the first

pre-determined cancellation filter 162, has the same characteristic, e.g. amplitude, phase, and/or frequency, to that of the electronic noise signal 114.

[0036] The controlling circuit 130 is further configured to (iv) generate 180 an electronic anti-noise signal 124 by applying the first pre-determined cancellation filter 162 on the electronic noise signal 114. For example, the controlling circuit 130 may include the required programs and instructions to generate the electronic anti-noise signal 124. The electronic anti-noise signal 124 may include or be an opposing electronic signal to that of the electronic noise signal 114. For example, the electronic anti-noise signal 124 may be the same as the electronic noise signal 114, having an opposite phase at a precise time and space.

[0037] According to various embodiments, the term "applying", as used herein, may be used in the context of signal processing, and may refer to the application or implementation of a digital filter on the sampled, discrete-time signal, e.g. the electronic noise signal.

[0038] According to various embodiments, the term "anti-noise", as used herein, may refer to a signal in the digital and/or analog domain, that is produced to cancel, e.g. reduce, at least part of the incoming noise signal. For example, the acoustic anti-noise signal may be an opposing sound wave with the same amplitude at the precise time and space of the incoming acoustic noise signal, such that the acoustic anti-noise signal at least, cancels or reduces the amplitude of the incoming acoustic noise signal. Within the context of the disclosure, the acoustic anti-noise signal is configured to cancel at least part of the acoustic noise signal such that the user no longer perceives the disturbance, e.g. acoustic noise signal, or it is at a level that may be acceptable to the user.

[0039] The controlling circuit 130 is further configured to be operably coupleable to a plurality of transducers 120, such that when operably coupled, the controlling circuit 130 is in communication with the plurality of transducers 120. The controlling circuit 130 thus, (v) transmits the electronic noise signal 124 to a plurality of transducers 120. For example, the electronic anti-noise signal 124 may be stored in the controlling circuit 130, e.g. in a memory in the controlling circuit 130 before being transmitted to the plurality of transducers 120. In another example, the electronic anti-noise signal 124 may immediately, e.g. upon acquisition, be transmitted to a controlling circuit 130. Means for the transmission of the electronic anti-noise signal 124 to the plurality of transducers 120 may include wireless or wired communications, as explained above, and the controlling circuit 130 and the plurality of

transducers 120 may thus be equipped with the required architecture to transmit and receive, respectively, the electronic anti-noise signal 124.

[0040] The plurality of transducers 120 are configured to generate the acoustic anti-noise signal 122 from the electronic anti-noise signal 124 received from the controlling circuit 130. For example, the plurality of transducers 120 may include a digital-to-analog (DAC) converter to convert the electronic anti-noise signal 124 in the digital domain, into the acoustic anti-noise signal 122 in the analog domain. In a further example, the plurality of transducers 120 may include amplifiers to amplify the acoustic anti-noise signal 122. According to various embodiments, the acoustic anti-noise signal 122 may include or be: an acoustic wave with the same or similar amplitude but with an inverted phase, i.e. anti-phase, relative to the acoustic noise signal 112. For example, the amplitude of the acoustic anti-noise signal 122 may be proportional to the amplitude of the original acoustic noise signal 112.

[0041] The ANC system 100, in accordance with various embodiments of the disclosure, generates the acoustic anti-noise signal 122, to cancel, at least part of, the acoustic noise signal 112, when the acoustic anti-noise signal 122 is added to the acoustic noise signal 112, for example, via wave superimposition and destructive interference. Specifically, when the acoustic anti-noise 122 and noise 112 signals superimpose, they interfere with each other to form a resultant acoustic signal which may have a lower amplitude, such that the superimposition of said signals effectively cancels, at least part of, the acoustic noise signal 112. That is to say, the addition of the acoustic anti-noise signal 122 to the acoustic noise signal 112 results in destructive interference, which effectively reduces the volume of the perceivable noise to the user. In preferred embodiments, the acoustic anti-noise signal 122 effectively cancels the acoustic noise signal 112, such that the acoustic noise signal 112 is no longer perceived as noise to the user. As a result, noise disturbance or disruption to the user is no longer present or at least, significantly reduced.

[0042] According to various embodiments, the one or more pre-determined cancellation filter candidates 160 may be stored within a library of pre-determined cancellation filters 190. For example, the library of pre-determined cancellation filters 190 may be assembled by the one or more pre-determined cancellation filter candidates 160 which may be obtained from the prior training stage, as will be explained below.

[0043] According to various embodiments, the library of pre-determined cancellation filters 190 may be stored in the controlling circuit 130, for example, a memory in the controlling

circuit 130. In another example, the library of pre-determined cancellation filters 190 may be stored on a server of a cloud network. In such embodiments, the classification 150 of the electronic noise signal 114, and selection 170 of the first pre-determined cancellation filter 162 from the one or more pre-determined cancellation filter candidates 160 within the library of pre-determined cancellation filters 190 may be performed on the server. Accordingly, the controlling circuit 130 may be configured to communicate with the server via wired or wireless communications, and may be equipped with the required architecture to support such communication, as explained above. In some embodiments, the library of pre-determined cancellation filters 190 may be stored in another microprocessor external to the controlling circuit 130. The controlling circuit 130 may thus be configured to communicate with another microprocessor via wired or wireless communications, and may be equipped with the required architecture to support such communication, as explained above.

[0044] Advantageously, the system 100 for actively cancelling at least part of an acoustic noise signal 112, via the application of a selected pre-determined cancellation filter among the one or more pre-determined cancellation filters 160 on the electronic noise signal 114, provides content-aware, i.e. tailored to noise type, and instantaneous noise reduction or cancellation.

[0045] FIGS. 2A and 2B show exemplary schematic illustrations of a training system 200 and the algorithm 250 implemented by the training system 200, for generating each one of the one or more pre-determined cancellation filter candidates 160, in accordance with various embodiments. FIG. 2A shows a schematic illustration of a training system 200 of the prior training stage for generating each one of the one or more pre-determined cancellation filter candidates 160. The prior training stage may be based on an adaptive filtering process as known to those skilled in the art. In preferred embodiments, the training system 200 of the prior training stage may be based on a multichannel, feedforward, filtered *x*-least, mean square (FXLMS) algorithm on a feedforward ANC structure. The training system 200 may be used to determine an optimized, pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for each one of the one or more pre-determined cancellation filter candidates 160, which is used to generate the electronic anti-noise signal 124.

[0046] The training system 200 may include a training reference microphone array 210 configured to detect a training acoustic noise signal 212, which may include or may be primary noise types which is desired by a user to be cancelled. For example, the training noise signal 212 may include low-frequency noise, specifically, low-frequency urban environmental noise

typically perceived as unwanted by the user. As a further example, the training noise signal 212 may be selected from the group of: aircraft fly-by, motorbike pass-by, traffic noise, or compressor noise. The training acoustic noise signal 212 may be converted into a training electronic noise signal 214, for example, by an ADC. As a further example, the training electronic noise signal 214 may be filtered by an estimation of the secondary path $\hat{S}(z)$. The filtered training electronic noise signal 214 may then be applied to a least-mean-square block 230 (LMS) employing the FXLMS algorithm, and to training cancellation filters 260. The FXLMS algorithm employed by the LMS block 230 may then calculate and update a training coefficient for each one of the training cancellation filters 260, to generate a training electronic anti-noise signal 224.

[0047] The training electronic anti-noise signal 224 may be generated by applying the training coefficient on a reference signal $\boldsymbol{x}(n)$, which may be the training electronic noise signal 214. The training electronic anti-noise signal 224 may be transmitted to a training transducer array 220 which generates a training acoustic anti-noise signal 222, for example, via a DAC converter. The training acoustic anti-noise signal 222 may be added to the training acoustic noise signal 212 to cancel, at least part of the training acoustic noise signal 212, which may generate a resultant training acoustic signal 242 via destructive interference, in a similar manner to that as explained with reference to system 100. In other words, the resultant training acoustic signal 242 may be a sound wave resulting from the superposition of the training acoustic noise 212 and anti-noise 222 signals.

[0048] The training system 200 further includes the training error microphone array 240 configured to detect the resultant training acoustic signal 242, and convert it into a resultant training electronic signal 244, which is fed-back to the LMS block 230. The training system 200 aims to reduce the sum-of-the-squared pressure at the training error microphone array 240, and the training process may thus be re-iterated until a steady-state is achieved, whereby noise is minimized to a desired level (which may be determined by the user). In other words, the LMS block 230 optimizes and updates the training coefficient of the training cancellation filters 260, based on the sum-of-squared pressure level at a training error microphone array 240, and re-iterates the process until the sum-of-squared pressure level at the training error microphone array 240 is minimized. The optimized training coefficient may then be stored as a pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for each one of the one or more pre-determined cancellation filter candidates 160, which is employed in system 100 to generate the electronic

anti-noise signal 124. In sum, the training system 200 utilizes the multichannel, feedforward FXLMS algorithm 250 to update the training coefficients in the training cancellation filter 260 until it converges to a steady-state, to obtain the optimized pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for each one of the one or more pre-determined cancellation filter candidates 160.

[0049] FIG. 2B shows an exemplary schematic illustration of the multichannel, feedforward FXLMS algorithm 250, adopted by training system 200. Referring to training system 200 and algorithm 250, the training reference microphone array 210 may include a single reference microphone ($J = 1$) to detect an impinging noise, e.g. the training acoustic noise signal 212, and convert it into the training electronic noise signal 214. The training electronic noise signal 214 may be provided to for example, four training cancellation filters 260 ($K = 4$), to drive the training transducer array 220, which includes four transducers ($K = 4$) to minimize the sum-of-the-squared pressures at the training error microphone array 240, which includes four error microphones ($M = 4$). The m-th error microphone signal $e_m(n)$ can thus be expressed as:

$$e_m(n) = d_m(n) - \sum_{k=1}^{K} s_{mk}(n) * \left[\boldsymbol{w}_k^{\mathrm{T}}(n)\boldsymbol{x}(n)\right], \tag{1}$$

where $d_m(n) = p_m(n) * x(n)$ is the disturbance to be cancelled at the m-th error microphone of the training error microphone array 240, and $s_{mk}(n)$ is the real secondary path transfer function from the k-th transducer of the training transducer array 220, to the m-th error microphone of the training error microphone array 240. $\boldsymbol{w}_k(n) = [w_{k,0}(n) \quad w_{k,1}(n) \quad \cdots \quad w_{k,L-1}(n)]^{\mathrm{T}}$ is the training coefficient vector of the training cancellation filters 260, which may have an order L, and $\boldsymbol{x}(n) = [x(n) \quad x(n-1) \quad \cdots \quad x(n-L+1)]^{\mathrm{T}}$, e.g. training electronic noise signal 214, is the reference signal vector of $\mathbf{W}(z)$.

[0050] The k-th equation of the FXLMS algorithm is thus given by:

$$w_k(n+1) = \boldsymbol{w}_k(n) + \mu \sum_{m=1}^{M} \boldsymbol{x}'_{km}(n) e_m(n), \tag{1}$$

where μ is the step size, and $\boldsymbol{x}'_{km}(n) = \hat{s}_{mk}(n) * \boldsymbol{x}(n)$ is the filtered reference signal, e.g. filtered training electronic noise signal 214, from the measured secondary path estimates

$\hat{s}_{mk}(n)$. Hence, the k-th secondary source output of the training transducer array 220, is given by:

$$\boldsymbol{y}_k(n) = \boldsymbol{w}_k^{\mathrm{T}}(n) * \boldsymbol{x}(n). \quad (3)$$

[0051] The fixed-filter approach was adopted by training system 200 for repeatability in the measurement of attenuation and to mimic practical realization of system 100 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410. During the training stage, each primary noise type, e.g. the training acoustic noise signal 212, was played on loop to allow the FXLMS algorithm to converge to a steady state, after which the optimized coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ was stored, as the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ in each one of the one or more pre-determined cancellation filters candidates 160 for implementation in system 100. In other words, the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ stored in each one of the one or more pre-determined cancellation filter candidates 160, for generating the electronic anti-noise signal 124 based on the electronic noise signal 112, is an optimized coefficient obtained from training system 200.

[0052] In accordance with various embodiments, the library of pre-determined cancellation filters 190 including the pre-determined, e.g. optimized, coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for each one of the one or more pre-determined cancellation filter candidates 160 may be deployed in system 100 for actively cancelling the acoustic noise signal 112. However, unlike the training system 200 where the FXLMS approach is employed, the selection of a pre-determined cancellation filter is based on the classified 150 sample of the electronic noise signal 114. In other words, adaptive filtering and the FXLMS algorithm may not be performed by system 100 for actively cancelling at least, part of the acoustic noise signal 112.

[0053] According to various embodiments, the training system 200 and the system 100 for actively cancelling the acoustic noise signal 112, may be operably coupled such that they are in communication with each other. For example, the training system 200 and system 100 may communicate via wired or wireless communications and may include the required architecture to support such communication means. In accordance with various embodiments, additional pre-determined cancellation filter candidates may be added to the library of pre-determined cancellation filters 190. In a further example, the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for

each one of the one or more pre-determined cancellation filter candidates 160 may be updated with a further optimized pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$.

[0054] According to various embodiments, the generation 180 of the electronic anti-noise signal 124 may include convolving, e.g. linear convolution, the reference signal $\boldsymbol{x}(n)$ with the pre-determined coefficient $\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$of the first pre-determined cancellation filter 162. The pre-determined coefficient $\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$ may include or be the optimized coefficient obtained using adaptive filtering and the FXLMS algorithm during the prior training stage 200. The reference signal $\boldsymbol{x}(n)$, may include or be a constant stream of digitized audio signal that is picked up by the sensor 110. For example, the reference signal $\boldsymbol{x}(n)$, may be the electronic noise signal 114 detected by the sensor 110. Thus, generating the electronic anti-noise signal 124 of the k-th transducer of the plurality of transducers 120, may be given by:

$$\boldsymbol{y}_k(n) = \boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n) * \boldsymbol{x}(n). \tag{4}$$

where $\boldsymbol{w}_{k,fixed}(n)$ is the pre-determined coefficient vector of the k-th pre-determined cancellation filter. For example, generating the electronic anti-noise signal 124 using the first pre-determined cancellation filter 162 is given by, $\boldsymbol{y}_1(n) = \boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n) * \boldsymbol{x}(n)$. Said convolution may be implemented using a finite impulse response filter, which is known to those skilled in the art. Alternatively, it is envisioned that generating the electronic anti-noise signal 124 may be implemented in an infinite impulse response filter.

[0055] FIG. 3 shows a schematic illustration of the method 300 employed by the training system 200, by way of example and in accordance with various embodiments. Method 300 may include a noise database 310 for generating 320 a desired noise signal. New primary noise types, e.g. training acoustic noise signal 212, may be added to the noise database 310. Further, the updated noise database 310 may be transmitted to the controlling circuit 130, and may be used in to classify 140 the electronic noise signal 114 in system 100 for actively cancelling at least part of the acoustic noise signal 112. At step 320, the noise database 310 may thus be used to generate the training acoustic noise signal 212. At step 330, method 300 may include detecting the training acoustic noise signal 212 at the training microphone array 210 and converting it into the training electronic noise signal 214. Step 340 may include generating the training electronic anti-noise signal 224 by applying a training cancellation filter 260 on the training electronic noise signal 214. Step 340 further includes, transmitting the training electronic anti-noise signal 224 to the training transducer array 220, where said signal is

converted into the training acoustic anti-noise signal 222. Step 340 may further include adding the training acoustic noise 212 and anti-noise 222 signals to generate the resultant training acoustic signal 242. Step 350 may thus include, monitoring the resultant training acoustic signal 242 at the training error microphone array 240, and to convert it into the resultant training electronic signal 244, which is fed-back to the LMS block 230. Step 360 may include detecting, if the training system 200 is at steady-state, and may further include re-iterating 362, steps 340 and 350 until steady-state is achieved, where noise is minimized to a desired level. Once steady-state is achieved, step 370 may include storing the optimized coefficient as the pre-determined coefficient $\boldsymbol{w}_{k,fixed}(n)$ of the one or more pre-determined cancellation filter candidates 160 for implementation in system 100. Step 380 may thus include preparing and assembling the library of pre-determined cancellation filters 190, including the pre-determined coefficient $\boldsymbol{w}_{k,fixed}(n)$ for each one of the one or more pre-determined cancellation filter candidates 160, which may be transmitted 382 and stored in the controlling circuit 130, or transmitted for storage in a server. The library of pre-determined cancellation filters 190 is then employed in system 100 to generate the electronic anti-noise signal 124.

[0056] FIG. 4 shows an exemplary schematic illustration of a use condition and the layout of the system 400 for actively cancelling the acoustic noise signal 112 entering through an aperture 420 of a room 410, in accordance with various embodiments. The ANC system 400 may be deployed in a room 410 which includes an aperture 420. For example, the aperture 420 may include or be the window or door of the room 410. The system 400 is based on system 100 and repeated descriptions are omitted for brevity. In system 400 for actively cancelling the acoustic noise signal 112, the sensor 110 may be located at a position proximal to the aperture 420 of the room 410 as will be explained with reference to FIGS. 5A to 5F. For example, the sensor 110 may be located on an outer moveable frame 530, e.g. window panel, attached to the aperture 420 of the room. As a further example, the sensor 110 may be located exterior to the aperture 420 of the room 410, for instance, on the façade of the building. The system 400 further includes the plurality of transducers 120, which may be placed at the aperture 420 of the room 410, as will be explained with reference to FIGS. 5A to 5F. For example, the plurality of transducers 120 may be placed at the stool or the casing of the window. The controlling circuit 130 configured to generate the electronic anti-noise signal 124 may be located in the room 410. For example, the controlling circuit 130 may be placed adjacent to the plurality of

transducers 120, at the stool or the casing of the window. As a further example, the controlling circuit 130 may be placed inside the room 410.

[0057] A reference position 430, which is spaced apart from the aperture 420 of the room 410, may be designated. For example, the reference position 430 may be spaced 0.2 m, 0.5 m, 1 m, or 2 m apart from the aperture 420 of the room 410. As mentioned above, the addition of the acoustic noise 112 and anti-noise 122 signals generates the resultant acoustic signal 432, which may be detected by the reference sensor 440 placed at the reference position 430 of the room 410. Said reference sensor 440 may be configured to convert the resultant acoustic signal 432 into a resultant electronic signal 434, and may further be configured to determine a sum-of-squared acoustic pressure at the reference position 430 from the resultant electronic signal 434.

[0058] In accordance with various embodiments, since system 400 includes the library of pre-determined cancellation filters 190, where each one of the one or more pre-determined cancellation filter candidates 160 within the library 190 includes the pre-determined, e.g. optimized, coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$, for generating the electronic anti-noise signal 124, the acoustic anti-noise signal 122 may effectively cancel, at least part of, the acoustic noise signal 112. As a result, the sum-of-the-squared acoustic pressure level of the resultant acoustic signal 432 (i.e. based on the addition of the acoustic noise 112 and anti-noise 122 signals) at the reference position 430 may be minimized.

[0059] FIGS. 5A to 5G show exemplary schematic illustrations of the physical configurations of the system 100, 400, in relation to the aperture 420 of the room 410, in accordance with various embodiments.

[0060] FIG. 5A shows a cross-sectional view 500A of the physical configuration of the system 100, 400. As shown in FIG. 5A, a stationary frame 510 may include a stationary frame 510 attached to the aperture 420 of the room 410. For example, the stationary frame 510 may be fixed, or permanently attached to the aperture 420 of the room 410. As a further example, the stationary frame 510 may include or be, a window frame or door frame which is affixed to the aperture 420 of the room 410. The stationary frame 510 may be configured to receive a support 520. In other words, the support 520 and the stationary frame 510 are separate and the support 520 may thus be removably disposable in relation to the stationary frame 510. The plurality of transducers 120 may be mounted on the support 520. For example, the plurality of transducers 120 may be fixed on the boundary, e.g. edge of the support 520, and may not be

distributed across the support 520. The support 520, including the plurality of transducers 120, may then be attached to the stationary frame 510. That is to say, the plurality of transducers 120, which is mounted on the support 520 may be fitted to the stationary frame 510 of any aperture 420, and is removeable to the aperture 420. In some embodiments, the controlling circuit 130 may also be mounted on the support 520, for instance, adjacent to the plurality of transducers 120. Alternatively, the controlling circuit 130 may be positioned in the room 410.

[0061] According to various embodiments, plurality of transducers 120 may be mounted on at least one edge of the support 520. For example, the plurality of transducers 120 may be mounted on at least one edge of the boundary or border, of the support 520. In preferred embodiments, the plurality of transducers 120 may be mounted on the entire circumference, e.g. all edges of the support 520, as may be seen in the examples of FIGS. 5A to 5G.

[0062] FIGS. 5B to 5D show the 3D perspective view 500B, side view 500C, and inner view 500D of the physical configuration of system 100, 400, respectively, which may be mounted on an awning, i.e. top-hung window. Referring to FIGS. 5B to 5D, in addition to the stationary frame 510 and support 520 including the plurality of transducers 120, the system 100, 400 may further include an outer moveable frame 530 coupled to the stationary frame 510. The outer moveable frame 530 may include a pane 540 set within the outer moveable frame 530. For example, the pane 540 may include or be a glass window pane or a wooden pane of a door. As a further example, the outer moveable frame 530 may include or be the hinged portion of the window or door.

[0063] According to various embodiments, the sensor 110 may be affixed to the outer moveable frame 530 which is coupled to the stationary frame 510. For example, as shown in configuration 500B, the sensor 110 be placed on the outer moveable frame 530, facing the acoustic noise signal 112. As a further example, as shown in configuration 500C, the sensor 110' may also be placed on the façade 550 of the building, for instance, on any permanent protrusion extending from the building.

[0064] Advantageously, since the support 520, including the plurality of transducers 120, is removably disposable in relation to the stationary frame 510, the system 100, 400 may therefore be easily fitted, e.g. installed and removed, on a stationary frame 510 which is fixed to the aperture 420. Further, the plurality of transducers 120 which are mounted on the boundary of the support 520 may provide minimal visual and physical obstructions. As a result, an

undesired acoustic noise signal 112 may be instantaneously cancelled, with minimal visual and physical obstruction, for example, to natural ventilation.

[0065] According to various embodiments, the system 100, 400 may further include a motion sensor 560, as shown in the example of FIG. 5D. The motion sensor 560 may be placed on the outer moveable frame 530, the support 520, and/or the stationary frame 510, and may include or be a contact sensor, e.g. window or door contact sensor. The motion sensor 560 may be configured to detect a movement of the outer moveable frame 530 in relation to the stationary frame 510. In addition, the motion sensor 560 may determine information about an arrangement of the stationary frame 510 and the outer moveable frame 530. The arrangement of the stationary frame 510 and the outer moveable frame 530 may adopt a closed arrangement, where the outer moveable frame 530 is in contact with the stationary frame 510. For example, the outer moveable frame 530 may block the aperture 420 (via the pane 540) in the closed arrangement, and thus block the ventilation flow passing through the aperture 420. In the closed arrangement, the pane 540 may also act as a passive noise barrier to reduce an acoustic noise signal 112 that may enter in the closed arrangement. The arrangement of the stationary frame 510 and the outer moveable frame 530 may also adopt an open arrangement, where the outer moveable frame 530 is partially separated from the stationary frame 510. For example, the outer moveable frame 530 may be spaced apart from the stationary frame 510, such that the aperture 420 may not be blocked and may permit natural ventilation through the aperture 420.

[0066] FIGS. 5E to 5G show examples of the placement of the support 520 on the stationary frame 510 attached to the aperture 420 of a room 410, in accordance with various embodiments. In the example shown in FIG. 5E, the plurality of transducers 120 may be mounted on the support 520 and fixed to the stationary frame 510 of, for example, a sliding window. In the example shown in FIG. 5F, the support 520 may be fixed to the stationary frame 510 of, for example, a casement window. In the example shown in FIG. 5G, the support 520 may be fixed to the stationary frame 510 of multiple window types, for example, a window including awning and casement windows, illustrating the versatility of the system 100, 400. In the examples shown in FIGS. 5E to 5G, the sensor 110, 110' and motion sensor 560 may be placed as described above in relation to FIGS. 5A to 5D, and repeated description will be omitted.

[0067] FIG. 6 shows an exemplary schematic illustration of a use condition of the system 600, according to various embodiments. The system 600 may be based on the system 100, 400 described in relation to FIGS. 1 to 5G, and repeated descriptions will be omitted for brevity.

System 600 may include a user interface 610 operably coupled to the controlling circuit 130 and may communicate with the controlling circuit 130 to receive a user's input. The user interface 610 and controlling circuit 130 be coupled via wired or wireless means, and may include the necessary architecture to support said communication protocols. For example, the user interface 610 may be a portable interface and may include hand-held devices such as smartphones, laptops, tablets, or consoles. Alternatively, the user interface 610 may be a display panel attached to the controlling circuit 130. In accordance with various embodiments, the user interface may receive an input of a user's selection of a pre-determined cancellation filter, for example, the second pre-determined cancellation filter 164, selected from the one or more pre-determined cancellation filter candidates 160. The second pre-determined cancellation filter 164 may differ from a previously selected pre-determined cancellation filter, e.g. the first pre-determined cancellation filter 164. For example, the user may select a pre-determined cancellation filter to cancel undesired construction noise, instead of a previously selected pre-determined cancellation filter which cancels undesired aircraft noise. In accordance with various embodiments, the controlling circuit 130 may receive the input from the user interface 610 and in response, may deactivate the first pre-determined cancellation filter 162 and activate the second pre-determined cancellation filter 164. For example, the controlling circuit 130 may terminate the application of the first pre-determined cancellation filter 162 and apply the second pre-determined cancellation filter 164, regardless of the acoustic noise signal 112 detected by sensor 110. In other words, the user's selection of the second pre-determined cancellation filter 164 may override the previously selected first pre-determined cancellation filter 162.

[0068] System 600 may further include the embodiment, wherein the controlling circuit 130 is further configured to receive information about the arrangement of the stationary frame 510 in relation to the outer moveable frame 530, from the motion sensor 560. In system 600, the controlling circuit 130 may be operably coupled to the motion sensor 560 and may communicate with the motion sensor 560. The motion sensor 560 and the controlling circuit 130 may be connected via wired or wireless means, and may include the necessary architecture to support such communication protocols. The controlling circuit 130 may be configured to receive the information about the arrangement from the motion sensor 560. For example, the controlling circuit 130 may receive information as to whether the arrangement of the stationary frame 510 in relation to the outer moveable frame 530 is in the closed, or in the open

arrangement. In another example, the motion sensor 560 may detect the movement of the outer moveable frame 530 in relation to the stationary frame 510. In accordance with various embodiments, the controlling circuit 130 may activate the system 600 when the motion sensor 560 determines that the arrangement is in the open arrangement. For example, the system 600 may be activated to actively cancel a detected acoustic noise signal 112 when said acoustic noise signal 112 passes through the aperture 420 of the room 410 in the open arrangement. As a further example, when the aperture 420 is the window or door of the room 410, the system 600 may be activated when it receives information that the window or door is open. In accordance with various embodiments, the controlling circuit 130 may be configured to deactivate the system 600 when the motion sensor 560 determines that the arrangement is the closed arrangement. For example, the system 600 may not operate to actively cancel the detected acoustic noise signal 112, in particular, since the outer moveable frame 530 including pane 540, may act as a passive noise barrier to reduce the perceived noise level to a volume that may be acceptable by the user. As a further example, when the aperture 420 is a window or a door of the room 410, the system 600 may be deactivated when it receives information that the window or door is closed. Nevertheless, it is envisioned that the system 600 may be activated when the motion sensor 560 determines that the arrangement is the closed arrangement. For example, to cancel the acoustic noise signal 112 which leaks through the pane 540. In some other embodiments, the system 600 may be activated when the motion sensor 560 detects a movement of the outer moveable frame 530 in relation to the stationary frame 510, for example, when the window is being opened by the user.

[0069] According to various embodiments, the controlling circuit 130 may deactivate the system 100, 400, 600, when at least one characteristic from the sample of the electronic noise signal 114 is different from the at least one corresponding characteristic of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. For example, the system 100, 400, 600 may be deactivated when it is determined that the phase, frequency and/or amplitude of the sample of the electronic noise signal 114 does not have the same characteristic to a corresponding characteristic of the exemplary electronic noise signal stored within each one of the one or more pre-determined cancellation filter candidates 160. In other words, the system 100, 400, 600 may be deactivated when the sample of the electronic noise signal 114 may not be matched to the one or more pre-

determined cancellation filter candidates 160, and hence may not be classified 150 by the controlling circuit 130.

[0070] According to various embodiments, the controlling circuit 130 may be further configured to determine a deviation of the at least one characteristic from the sample of the electronic noise signal 114 to a corresponding pre-determined threshold value. For example, the controlling circuit 130 may be configured to subtract a value of the characteristic, e.g. value of the amplitude, phase and/or frequency, from a corresponding pre-determined threshold value. The controlling circuit 130 may then activate the system 100, 400, 600 when the deviation of the at least one characteristic from the sample of the electronic noise signal is greater than the corresponding pre-determined threshold value. For example, the controlling circuit 130 may activate the system 100, 400, 600 when the deviation, e.g. subtracted value determined in the preceding step, is greater than the corresponding pre-determined threshold value. For example, the system 100, 400, 600 may be activated to cancel the detected acoustic noise signal 112 when the deviation, e.g. value of frequency, is greater than that of the pre-determined threshold value. In other words, the system 100, 400, 600 may operate when it is determined that the subtracted amplitude, phase and/or frequency is greater than the pre-determined threshold value determined by the user.

[0071] According to various embodiments, the controlling circuit 130 may be configured to generate the electronic anti-noise signal 124, when the electronic noise signal 114 is in a range of 20 Hz to 850 Hz. In preferred embodiments, the electronic anti-noise signal 124 may be generated when the electronic noise signal 114 is within the range of 100 Hz to 700 Hz. For example, the controlling circuit 130 may determine the at least one characteristic as being the frequency of a sample of the electronic noise signal 114, and may activate the system 100, 400, 600 when it detects that the frequency of the sample of the electronic noise signal 114 is within said range. As a further example, the one or more pre-determined cancellation filter candidates 160 within the library of pre-determined cancellation filters 190 may be optimized, e.g. during the prior training stage, such that the pre-determined coefficient $\boldsymbol{w}_{k,fixed}(n)$ for each one of the one or more pre-determined cancellation filter candidates 160, cancels acoustic noise signals 112 within the indicated range. In other words, the system 100, 400, 600, may be configured to actively cancel acoustic noise signals 112 in in the frequency range of 20 Hz to 850 Hz, or preferably, 100 Hz to 700 Hz, and does not cancel acoustic noise signals 112 outside of said frequency range.

[0072] Advantageously, the system 100, 400, 600 in accordance with various embodiments of the disclosure may be optimized for low-frequency urban environmental noise, which may be typically perceived as being undesired or unwanted by a user. Further, the ANC system 100, 400, 600 may be easily fitted to any aperture, e.g. openable façade element to provide minimal visual and physical obstruction, e.g. to natural ventilation. The ANC system 100, 400, 600 may also function independently, and provide user-specific, content-aware, instant noise cancellation through the application of a selected pre-determined cancellation filter, for low-frequency urban environmental noise.

[0073] FIG. 7 shows an exemplary schematic illustration of method 700 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments. Method 700 includes, at step 710, providing a sensor 110 to detect the acoustic noise signal 112 and to convert the acoustic noise signal 112 into an electronic noise signal 114. For example, the sensor 110 may include or be an acoustic sensor that detects the acoustic noise signal 112 entering through the aperture 420. The sensor 110 may further include, for example, an ADC to convert the acoustic noise signal 112 into the electronic noise signal 114. Method 700 also includes, at step 720, transmitting the electronic noise signal 114 from the sensor 110 to a controlling circuit 130 operably coupled to the sensor 110 and to a plurality of transducers 120. For example, the sensor 110, plurality of transducers 120 and the controlling circuit 130 may be coupled through wireless or wired means, and may include the necessary architecture to support such communication protocols. Method 700 also includes, at step 730, classifying using the controlling circuit 130, the electronic noise signal 114 by matching a sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160. For example, the controlling circuit 130 extracts a sample of the electronic noise signal 114, and determines at least one characteristic which may be selected from the group of: frequency, phase and/or amplitude. Step 730 may further include, determining if the at least one characteristic from the sample of the electronic noise signal 114 has a same characteristic to at least one corresponding characteristic of an exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. For example, the controlling circuit 130 may determine if the phase, amplitude and/or frequency of the sample is equal to, or falls within a specific range of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160.

[0074] Based on the classified sample of the electronic noise signal, method 700 also includes, at step 740, selecting using the controlling circuit 130, a first pre-determined cancellation filter 162 from the one or more pre-determined cancellation filter candidates 160. For example, the exemplary electronic signal stored in the first pre-determined cancellation filter 162, may have at least one same characteristic of a phase, amplitude and/or frequency, to a corresponding at least one same characteristic of the sample of the electronic noise signal 114.

[0075] Method 700 also includes, at step 750, generating using the controlling circuit 130, an electronic anti-noise signal 124 by applying the first pre-determined cancellation filter 162 on the electronic noise signal 114. In accordance with various embodiments, each one of the one or more pre-determined cancellation filter candidates may include a pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for generating the electronic anti-noise signal 124. For example, the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ may be obtained from a prior training stage as explained above with reference to training system 200 in FIGS. 2A and 2B. As a further example, the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ may be the optimized coefficient for cancelling a training acoustic noise signal 212, and may be obtained by adaptive filtering and employing the FXLMS algorithm. According to various embodiments, generating the electronic anti-noise signal 124 using the controlling circuit 130, at step 750, may include convolving a reference signal $\boldsymbol{x}(n)$ with the pre-determined coefficient $\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$ of the first pre-determined cancellation filter 162. For example, the electronic anti-noise signal 124 may be generated by convolving the pre-determined coefficient $\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$ of the first pre-determined cancellation filter 162 with the reference signal $\boldsymbol{x}(n)$, which may be the electronic noise signal 114, and given by, $\boldsymbol{y}_1(n) = \boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n) * \boldsymbol{x}(n)$.

[0076] The convolution of the signals may be implemented in a finite impulse response filter, in accordance with the various embodiments of the disclosure. Alternatively, the convolution of the signals may be implemented in an infinite impulse response filter. As such, the generated electronic anti-noise signal 124 based on the optimized pre-determined coefficient $\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$ of the first pre-determined cancellation filter 162 may be designed to effectively cancel at least part of, the acoustic noise signal 112.

[0077] Method 700 includes, at step 760, transmitting using the controlling circuit 130, the electronic anti-noise signal 124 to the plurality of transducers 120. For example, the electronic

anti-noise signal 124 may be transmitted via wired or wireless communications since the plurality of transducers 120 are operably coupled, e.g. in communication, to the controlling circuit 130. Step 760 further includes generating the acoustic anti-noise signal 122 from the electronic anti-noise signal 124, by the plurality of transducers 120. For example, the plurality of transducers 120 may include a DAC to generate the acoustic anti-noise signal 122. According to various embodiments, the acoustic anti-noise signal 112 cancels at least part of, the acoustic noise signal 112, when the acoustic anti-noise signal 122 is added to the acoustic noise signal 112. For example, the addition of the acoustic noise 112 and anti-noise 122 signals results in destructive interference to cancel at least part of the acoustic noise signal 112. As a further example, acoustic anti-noise signal 122 may have the same amplitude and frequency but a phase opposite to that of the acoustic noise signal 112. In preferred embodiments, the acoustic anti-noise signal 122 effectively cancels, via destructive interference, the acoustic noise signal 112, such that the user no longer perceives the unwanted or undesired acoustic noise signal 112.

[0078] In accordance with various embodiments, the addition of the acoustic anti-noise 122 and noise 112 signals at step 760 may minimize the sum-of-squared acoustic pressure level at a reference position 430 in the room 410. The reference position 430 may be spaced apart from the aperture 420 of the room 410. For example, a reference sensor 440, e.g. acoustic sensor, may be placed at the reference position 430 to detect the acoustic pressure level, and to calculate the sum-of-squared acoustic pressure level at the reference position 430. In accordance with the various embodiments of the disclosure, the cancellation of the acoustic noise signal 112 by the acoustic anti-noise signal 122 minimizes the sum-of-squared acoustic pressure level at the reference position 430.

[0079] According to various embodiments, the one or more pre-determined cancellation filter candidates 160 may be stored within a library of pre-determined cancellation filters 190. For example, the library of pre-determined cancellation filter 190 may be assembled during the prior training stage as explained with reference to FIGS. 2A and 2B. According to various embodiments, the library of pre-determined cancellation filters 190 may be stored in one or more of: a server (e.g. cloud network of the server), or within a memory of the controlling circuit 130. For example, the library of pre-determined cancellation filters 190 may be stored in a server external to the controlling circuit 130, e.g. another microprocessor. Alternatively, in another example, the library of pre-determined cancellation filters 190 may be stored in a

physical memory storage within the controlling circuit 130. The library of pre-determined cancellation filters 190 may be updated via wired or wireless communications, in accordance with various embodiments. For example, the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ for the one or more pre-determined cancellation filter candidates 160 may be replaced with an updated optimized pre-determined coefficient. As a further example, additional pre-determined cancellation filter candidates 160 may be added to the library of pre-determined cancellation filters 190.

[0080] Method 700 may further include, at step 770, attaching a stationary frame 510 which is coupled to an outer moveable frame 530, to the aperture 420 of the room 410, as illustrated with reference to examples 500A to 500G of FIGS. 5A to 5G. For example, the stationary frame 510 may include a casing around or surrounding the border of the aperture 420, and the outer moveable frame 530 may enclose a pane 540. As a further example, the stationary frame 510 may be a window frame or a door frame, and the outer moveable frame 530 may include the moveable frame enclosing the windowpane or a door frame enclosing the door, e.g. hinged portion of window or door frame.

[0081] Step 770 may further include, providing a support 520, configured to be attached to the stationary frame 510. For example, the support 520 may have similar dimensions to that of the stationary frame 510, and may be fixed to the stationary frame 510. In other words, the support 520 may be removably disposable in relation to the stationary frame 510. The plurality of transducers 120 may be mounted on the support 520, for example on at least one edge of the support 520. In preferred embodiments, the plurality of transducers 120 may be mounted on all edges of the support 520, for example, on the entire circumference of the support 520.

[0082] Step 770 may also include, affixing the sensor 110 on the outer moveable frame 530 coupled to the stationary frame 510. For example, the sensor 110 may be fixed on the outer moveable frame 530 such that it faces the noise source, e.g. acoustic noise signal 112. In another example, the sensor 110 may be placed on the exterior of the building, for instance, on the building façade near the aperture 420 of the room 410.

[0083] According to various embodiments, method 700 may further include, at step 780, terminating said method 700, using the controlling circuit 130, when the at least one characteristic from the sample of the electronic noise signal is different from the at least one corresponding characteristic of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. For example, the method 700

may be terminated when either of the frequency, phase and/or amplitude of the sample of the electronic noise signal 114 does not have the same characteristic, e.g. equal to, or fall within the specified range, of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates 160. To put it in another way, the method 700 may be terminated when the sample of the electronic noise signal 114 does not match one or more of the pre-determined cancellation filter candidates 160.

[0084] According to various embodiments, method 700 may further include, at step 790, determining using the controlling circuit 130, a deviation of the at least one characteristic, e.g. amplitude, phase, and/or frequency, from the sample of the electronic noise signal to a corresponding pre-determined threshold value. For example, the controlling circuit 130 may calculate the deviation of, for instance, the frequency of the sample of the electronic noise signal 114 to that of a frequency of the pre-determined threshold value. Method 700 may be initialized, using the controlling circuit 130, when the deviation of the at least one characteristic from the sample of the electronic noise signal is greater than the corresponding pre-determined threshold value. To put it in another way, the method 700 may be initialized when the frequency of the sample of the electronic noise signal 114 is greater than a pre-determined threshold value.

[0085] FIG. 8A shows an exemplary schematic illustration of method 800A for receiving a user-selected pre-determined cancellation filter and activating said filter, in accordance with various embodiments. Method 800A may be in addition to method 700 as described above. Method 800A may include, at step 810, providing a user interface 610 operably coupled to the controlling circuit 130. For example, the user interface 610 may be in communication with the controlling circuit 130 via wired or wireless means, and may include the necessary architecture required to support such means. The user interface 610 may be portable and include hand-held devices. Alternatively, the user interface 610 may be a display panel of the controlling circuit 130. Step 812 may include, receiving using the controlling circuit 130, an input from the user interface 610, wherein the input may include a user's selection of a second pre-determined cancellation filter 164 from the one or more pre-determined cancellation filter candidates 160. The second pre-determined cancellation filter 164 may differ to that of the first pre-determined cancellation filter 162. For example, the second pre-determined cancellation filter 164 according to the user's selection may include a filter designed to cancel acoustic noise signals 112 of a different frequency, amplitude and/or phase. In other words, the second pre-

determined cancellation filter 164 may cancel a different noise type from that of the first pre-determined cancellation filter 162.

[0086] Method 800A may further include, at step 814 and in response to the user's selection at step 812, terminating the application of the first pre-determined cancellation filter 162 on the electronic noise signal 114, and applying the second pre-determined cancellation filter on the electronic noise signal 114. For example, the controlling circuit 130 may terminate the operation of the first pre-determined cancellation filter 162 and activate the second pre-determined cancellation filter 164, regardless of the acoustic noise signal 112 detected by sensor 110. In other words, the user's selection of the second pre-determined cancellation filter 164 may override the previously selected first pre-determined cancellation filter 162.

[0087] FIG. 8B shows an exemplary schematic illustration of method 800B for receiving an information about the arrangement of the stationary frame 510 and outer moveable frame 530, in accordance with various embodiments. Method 800B may be in addition to method 700 and 800A as explained above. Method 800B may include, at step 820, providing a motion sensor 560 to detect a movement of the outer moveable frame 530 in relation to the stationary frame 510. For example, the motion sensor 560 may be placed on the outer moveable frame 530 and/or the stationary frame 510 to detect information about an arrangement of the stationary frame 510 and the outer moveable frame 530. At step 822, method 800B further includes, determining, using the motion sensor 560, information about the arrangement which may include a closed arrangement or an open arrangement. For example, in the closed arrangement, the outer moveable frame 530 may be in contact with the stationary frame 510, and in the open arrangement, the outer moveable frame 530 may be partially separated from the stationary frame 510. In other words, in the closed arrangement, at least part of the acoustic noise signal 112 may not pass through the aperture 420 and enter the room 410, and in the open arrangement, the acoustic noise signal 112 may enter the room 410 through the aperture 420. As a further example, when the aperture 420 is a window, the closed arrangement may refer to a closed window, and the open arrangement, a partially open, or open window. In another example, the motion sensor 560 may detect a movement of the outer moveable frame 530 in relation to the stationary frame 510.

[0088] Method 800B may further include at step 824, receiving using the controlling circuit 130, the information about the arrangement, e.g. closed or open arrangement, from the motion sensor 560. In some embodiments, step 824 may also include receiving information about the

movement of the outer moveable frame 530 in relation to the stationary frame 510. Method 800B may also include at step 826, initializing the method 700, 800A, 800B, using the controlling circuit 130, when it is determined that the arrangement is the open arrangement. In addition, step 826 may also initialize the method 700, 800A, 800B, in response to the movement of the outer moveable frame 530 in relation to the stationary frame 510. If it is determined (at step 822) that the arrangement is the closed arrangement, step 828 may include, terminating the method 700, 800A, 800B, using the controlling circuit 130. For example, a detected acoustic noise signal 112 which is detected by sensor 110, may not be cancelled by the methods and system in accordance with the various embodiments of the disclosure. For instance, when the outer moveable frame 530 which is in contact with the stationary frame 510 in the closed arrangement, the pane 540 may act as a passive noise barrier to prevent at least, part of the acoustic noise signal 112 from entering the room 410.

[0089] FIG. 8C shows an exemplary schematic illustration of method 800C as a flow diagram for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments. Method 800C may be based on methods 700, 800A and 800B and repeated description are omitted.

[0090] Method 800C may include at step 710, providing the sensor 110 to detect the acoustic noise signal 112 and converting it into an electronic noise signal 113. Step 720 includes, transmitting the electronic noise signal 114 to the controlling circuit 130 operably coupled to the sensor 110 and to the plurality of transducers 120.

[0091] After step 720 of transmitting the electronic noise signal 114 to the controlling circuit 130, method 800C may proceed to step 822 which includes, determining, using the motion sensor 560, information about the whether the arrangement of the stationary frame 510 and the outer moveable frame 530 is in a closed arrangement or an open arrangement. If it is determined that the arrangement of the stationary frame 510 and the outer moveable frame 530 is in a closed arrangement, the method 800C may be terminated 830 at step 828. Conversely, if is determined that the arrangement of the stationary frame 510 and the outer moveable frame 530 is in an open arrangement, the method 800C may continue at step 826, and may proceed to step 730 which includes, classifying using the controlling circuit 130, the electronic noise signal 114 by matching a sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160.

[0092] After step 730 of classifying the electronic noise signal 114, method 800C may proceed to step 840 which includes, determining using the controlling circuit 130, if a selected pre-determined cancellation filter may be selected from the one or more pre-determined cancellation filter candidates 160. If it is determined that no selection may be made, for example, because the at least one characteristic of the sample of the electronic noise signal 114 does not have a same characteristic, e.g. match, to at least one corresponding characteristic of the exemplary electronic signal 114 stored within each one of the one or more pre-determined cancellation filter candidates 160, the process of method 800C may be terminated 830 at step 842. Else, method 800C may continue at step 844, and proceed to subsequent step 740 which includes, selecting using the controlling circuit 130, the first pre-determined cancellation filter 162 from the one or more pre-determined cancellation filter candidates 160, by basing the selection on the classified sample of the electronic noise signal 114. As mentioned above, the selection of a pre-determined cancellation filter is based on the library of pre-determined cancellation filters 190 including each one of the one or more pre-determined cancellation filters 160 which may be obtained based on a prior training stage, in particular, with reference to training system 200 and the FXLMS algorithm 250 of FIGS. 2A and 2B.

[0093] Method 800C may also include, at step 810, providing the user interface 610 operably coupled to the controlling circuit 130, and at step 820, receiving an input from the user interface 610, wherein the input comprises the user's selection of a second pre-determined cancellation filter 164 from the one or more pre-determined cancellation filter candidates 160, and wherein the second pre-determined cancellation filter 164 differs from the first pre-determined cancellation filter 162. Based on the user's selection, method 800C may then proceed to step 814 which includes, terminating the application of the first pre-determined cancellation filter 162 on the electronic noise signal 114, and applying the second pre-determined cancellation filter on the electronic noise signal 112, thereby overriding the pre-selected first pre-determined cancellation filter 162.

[0094] Method 800C may then proceed to step 750 which includes, generating using the controlling circuit 130, the electronic anti-noise signal 124 by applying the first pre-determined cancellation filter 162, or alternatively the second pre-determined cancellation filter 164 (based on step 814) on the electronic noise signal 114.

[0095] Method 800C may also include, upon termination of the method 800C at step 830, proceeding to step 850, which includes proceeding back to step 710 of detecting the acoustic

noise signal 112 and converting the acoustic noise signal 112 into the electronic noise signal 114 by the sensor 110. In other words, once it is determined that method 800C has been terminated, method 800C may be re-started, in accordance with various embodiments.

[0096] Method 800C may also include, step 860, wherein method 800C continues to detect incoming the acoustic noise signal 112 and proceeds in accordance with the various steps of method 800C. That is to say, method 800C may continue to detect the acoustic noise signal 112, and to update the selected pre-determined cancellation filter to cancel the incoming acoustic noise signal 112. For example, method 800C may detect construction noise and apply the respective pre-determined cancellation filter for the construction noise type. Upon detecting aircraft fly-by, for instance, method 800C may apply the respective pre-determined cancellation filter for the aircraft fly-by noise type. In a further example, method 800C may apply more than one pre-determined cancellation filter, for instance, the respective pre-determined cancellation filters for the construction and aircraft fly-by noise types. In other words, the application of a selected pre-determined cancellation filter is based on the most recent, e.g. updated noise type, and/or on all detected noise types. In accordance with various embodiments, the application of the selected pre-determined cancellation filters may be in real-time such that the user perceives a reduced acoustic noise signal 112, or does not perceive any acoustic noise signal 112, even though the noise type may have been changed.

[0097] According to various embodiments, the controlling circuit 130 of method 700, 800A, 800B, 800C may generate the electronic anti-noise signal 124, when it is determined that the electronic noise signal 114 is within the range of 20 Hz to 850 Hz, specifically, in the range of 100 Hz to 700 Hz. For example, the method 700, 800A, 800B, 800C may be initialized when it is determined that the frequency of the electronic noise signal 114 is within said range. Accordingly, the method 700, 800A, 800B, 800C according to the various embodiments of the disclosure, may actively cancel acoustic noise signals 112 in in the frequency range of 20 Hz to 850 Hz, and may not cancel acoustic noise signals 112 outside said frequency range.

[0098] FIG. 9 shows an exemplary schematic illustration of method 900 for actively cancelling an acoustic noise signal 112 entering a room 410 through an aperture 420 of the room 410, in accordance with various embodiments. At step 910, method 900 includes providing a sensor 110 to detect the acoustic noise signal 112 and to convert the acoustic noise signal 112, for example, through an ADC, into an electronic noise signal 114. At step 920, method 900 includes providing a plurality of transducers 120 to generate an acoustic anti-noise

signal 122 to cancel at least part of the acoustic noise signal 112, when the acoustic anti-noise signal 122 is added to the acoustic noise signal 112. Step 920 also includes converting the electronic anti-noise signal 124 into the acoustic anti-noise signal 122, for example via a DAC. Step 930 includes, transmitting the electronic noise signal 112 to a controlling circuit 130 operably coupled to the sensor 110 and the plurality of transducers 120, for example, via wired or wireless means. Step 940 includes, classifying using the controlling circuit 130, the electronic noise signal 112 by matching a sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160. Step 950 includes, selecting using the controlling circuit 130, a first pre-determined cancellation filter 162 from the one or more pre-determined cancellation filter candidates 160, by basing a selection on the classified sample of the electronic noise signal 114. Step 960 includes, generating using the controlling circuit 130, the electronic anti-noise signal 124 by applying the first pre-determined cancellation filter 162 on the electronic noise signal 114. Method 900 also includes, at step 970, transmitting using the controlling circuit 130, the electronic anti-noise signal 124 to the plurality of transducers 120, for example via wired or wireless means.

[0099] In accordance with various embodiments of the disclosure, individual sub-steps for matching the sample of the electronic noise signal 114 to one or more pre-determined cancellation filter candidates 160 at step 940, selecting the first pre-determined filter 162 at step 950, and generating the electronic anti-noise signal 124 at step 960, have been explained above and repeated descriptions are omitted.

[00100] In accordance with the various embodiments, the controlling circuit 130 may include a microprocessor. In some embodiments, the controlling circuit 130 may be included in a microprocessor. For example, the microprocessor may be a computer or a server in a cloud network.

[00101] According to various embodiments, method 700, 800A, 800B, 800C and 900 may be performed by a computing program including instructions to cause a computing system to execute the steps of method 700, 800A, 800B, 800C and 900. For example, a computer program may include instructions to execute the steps of method 700, 800A, 800B, 800C and 900, to actively cancel an acoustic noise signal 112 entering a room 410 through an aperture of the room 410.

[00102] According to various embodiments, a computer program may include instructions to cause the system 100, 400, 600 to execute the steps of methods 700, 800A, 800B, 800C and

900, to actively cancel an acoustic noise signal 112 entering a room 410 through an aperture of the room 410.

[00103] Advantageously, the system 100, 400, 600 and methods 700, 800A, 800B, 800C, 900, in accordance with various embodiments of the disclosure may provide a system 100, 400, 600 where a desired noise type for instance, low-frequency urban environmental noise types, may be cancelled in a standalone system. Further, a user may override the system and select a desired noise types to be cancelled. Said system 100, 400, 600 and methods 700, 800A, 800B, 800C, 900, described herein also provides content-aware, instantaneous noise cancellation, since the pre-determined coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ stored within each one of the one or more pre-determined cancellation filter candidates 160 have been optimized in the prior training stage. Further, the system 100, 400, 600 and methods 700, 800A, 800B, 800C, 900, according to the present disclosure results in an ANC system that may be easily fitted to any aperture (via mounting on a support 520 and placement of transducers 120 on the boundary of the support 520), and provides minimal visual and physical obstruction. The system 100, 400, 600 is in particular, suitable for naturally ventilated high-rise buildings since it does not block natural ventilation, while reducing noise signals entering through the aperture(s) of the building.

EXAMPLES

[00104] The system 100, 400, 600 and methods 700, 800A, 800B, 800C, 900, herein disclosed are further illustrated in the following examples, which are provided by way of illustration and are not intended to be limiting the scope of the present disclosure.

[00105] In the Examples, to improve the low-frequency active control performance, the plurality of transducers 120 (also referred to as control loudspeakers) were affixed to a full-sized but smaller top-hung ventilation window (also referred to as aperture 420). Active control of recorded urban noise (also referred to as the acoustic noise signal 112) was evaluated in a full-scale room of a mockup residential apartment. For comparison, the active control performance of said system 100, 400, 600, is benchmarked to the passive insulation provided by fully closing the window.

Materials and Methods

Experimental Setup

[00106] The ANC system 100, 400, 600 was installed on a single 60 cm by 40 cm top-hung window on a full-sized apartment window, as shown in FIGS. 10A and 10B. A single reference microphone (PylePro PLM3, Pyle Audio Inc, USA; e.g. sensor 110), senses the primary noise (e.g. acoustic noise signal 112), from a single loudspeaker (8341A, Genelec Oy, Finland) located in an adjoining 270 cm by 340 cm by 260 cm chamber outside the window, as depicted in FIG. 10B. The reference signal (e.g. acoustic noise signal 112) is fed into the controller (NI 8135, National Instruments, USA; e.g. controlling circuit 130), which drives four control loudspeakers (T3-2190S, TB Speaker Co. Ltd., Taiwan; e.g. plurality of transducers 120) to actively minimize the sum-of-the-squared pressures at four error microphones (PylePro PLM3l; e.g. training error microphone array 240 or reference sensor 440).

[00107] An array of six observation microphones (GRAS 40PH, GRAS Sound & Vibration A/S, Denmark) were distributed across the entire 287.5 cm by 525 cm by 260 cm room to evaluate the global control performance in the entire room as denoted by the observation microphones numbered from 1 to 6 in FIG. 11. These 6 observation microphones were arranged based on recommendations in ISO 16283-3:2016 [EN ISO 16283-3, *Acoustics Part 3: Façade sound insulation,* **2016**, ISO]. The 7th observation microphone (GRAS 40PH) was mounted in the center of the error microphone array (e.g. training error microphone array 240 or reference

sensor 440), which is 30 cm from the window aperture 420, to evaluate the performance at the error microphone positions (e.g. training error microphone array 240 or reference sensor 440).

[00108] As the chamber where the primary source (e.g. acoustic noise signal 112) was located was designed as a reverberation chamber, both the doors were left opened to release some of the acoustic modes. The doors in the receiving room were kept closed during the experiment.

[00109] The active control formulation was in accordance with the training system 200 explained with reference to FIGS. 2A and 2B. Briefly, a multichannel feedforward FXLMS algorithm was adopted, as explained with reference to FIG. 2B. The parameters used in the execution of the FXLMS algorithm is summarized in Table 1. The filter order of the training cancellation filters 260 for determining the one or more pre-determined cancellation filters 160, and sampling rate were maximized to fully utilize the available resources on the real-time platform of the ANC system 100, 400, 600. The control filter (e.g. training cancellation filters 260 for determining the one or more pre-determined cancellation filters 160) length was also maximized to account for the non-ideal acoustic condition to be described in the following section.

Reference microphones (e.g. sensor 110)	$J = 1$
Control sources (e.g. plurality of transducers 120)	$K = 4$
Control filters (e.g. training cancellation filters 260 for determining the one or more pre-determined cancellation filters 160)	$K = 4$
Error microphones (e.g. training error microphone array 240 or reference sensor 440)	$M = 4$
Sampling rate	16000 Hz
Control filter (e.g. training cancellation filters 260 for determining the one or more pre-determined cancellation filters 160) length, $L + 1$	640
Secondary path length	256
Step size (μ)	$1\text{x}10^{-11}$

Table 1: Active control parameters

System Characteristics

[00110] The impulse response of the primary paths measured from the reference microphone (e.g. sensor 110) at the periphery of the opened top-hung window panel (see FIG. 10B) to each of the four error microphones (e.g. training error microphone array 240 or reference sensor 440) is shown in FIG. 12A. The reverberations in the adjacent chamber, where the primary noise (e.g. acoustic noise signal 112) is placed, is reflected in the jitter of the impulse responses. There is also a prominent mode at around 300 Hz as portrayed in the frequency response of the primary paths, as shown in FIG. 12B. This is despite keeping the doors open to release the modes and employing unidirectional microphones for both the reference (e.g. sensor 110) and error microphones (e.g. training error microphone array 240 or reference sensor 340).

[00111] The same jitter is also observed in the secondary paths. Secondary paths were measured from each of the speakers to each error microphone to obtain a total of 16 transfer functions, i.e. s_{mk}, as shown in FIG. 13 (i.e. transfer function s_{11}, s_{12}, s_{13}, s_{14} in FIG. 13A, transfer function s_{21}, s_{22}, s_{23}, s_{24} in FIG. 13B, transfer function s_{31}, s_{32}, s_{33}, s_{34} in FIG. 13C, and transfer function s_{41}, s_{42}, s_{43}, s_{44} in FIG. 13D for each error microphone). It seems that only the secondary paths at error microphone 3 (e.g. training error microphone array 240 or reference sensor 440) was adversely affected by the acoustic mode at 300 Hz, as shown in FIG. 14C. FIGS. 14A, 14B and 14D indicate that the secondary paths at error microphones 1, 2 and 4, respectively (e.g. training error microphone array 240 or reference sensor 440), were not adversely affected by the acoustic mode at 300 Hz. Despite the jitter and acoustic mode observed, preliminary tests indicated that the acoustic condition was satisfactory for the control filters (e.g. training cancellation filters 260 for determining the one or more pre-determined cancellation filters 160) to converge.

Primary noise types

[00112] A total of four representative primary noise samples (e.g. acoustic noise signal 112) were employed in the evaluation of the ANC system 100, 400, 600. These noise samples are a representation of common urban noises in Singapore with dominant low-frequency content. All but the compressor noise was recorded on a window panel (e.g. aperture 420) with a surface microphone (GRAS 147AX, GRAS Sound & Vibration A/S, Denmark). The compressor noise was recorded next to an industrial air conditioning compressor on the roof of the University building with a handheld recorder (Zoom H6, Zoom Corporation, Japan). Both the aircraft fly-by, and the traffic noises were recorded in residential districts, whereas the motorbike passby

noise was recorded in an industrial district. The duration of each of passby noise sample reflects the entire buildup, whereas the duration was selected to be longer than 6 s for stationary noises according to ISO 16283-3. The dominant frequencies of the aircraft flyby noise seem to occur between 200 Hz to 400 Hz one-third octave bands, as shown in FIG. 15A. There are prominent tonal components in the motorbike and compressor noise as illustrated in FIGS. 15B and 15D, respectively. The energy appears to be evenly distributed between 160 Hz to 630 Hz one-third octave bands in traffic noise, as shown in FIG. 15C.

Noise Types	Aircraft	Motorbike	Traffic	Compressor
Duration, s	47.2	16.41	13.19	10
Frequency range, Hz	100 to 700	100 to 700	100 to 700	100 to 700
Recording location	Residential	Industrial	Residential	University
Description	Jet aircraft fly-by	Motorbike pass-by	Non-peak traffic from expressway	Adjacent to source

Table 2: Characteristics of the primary noise samples, which may be the acoustic noise signal 112

Evaluation criteria

[00113] The space and time average sound pressure level (SPL) in the room is defined as the energy-average sound pressure level, L_{EA}, and in the receiving room (e.g. room 410) given by:

$$L_{EA} = 10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} 10^{L_{Aeq,i}/10}\right), \quad (5)$$

where $L_{Aeq,i}$ is the A-weighted equivalent SPL at the ith observation microphone position (i.e. $n = 6$) in the room (e.g. room 410) [EN ISO 16283-3, *Acoustics Part 3: Façade sound insulation,* **2016**, ISO]. The energy-average attenuation due to the ANC system 100, 400, 600 with the windows (e.g. aperture 420) fully opened is written as:

$$\alpha_{active,EA} = L_{EA,Off} - L_{EA,On}, \quad (6)$$

where $L_{EA,Off}$ and $L_{EA,On}$ are the energy-average SPLs with the ANC system turned off and on, respectively, both while the windows (e.g. aperture 420) were fully opened. It follows that the passive attenuation is given by:

$$\alpha_{passive,EA} = L_{EA,Off} - L_{EA,Closed}, \quad (7)$$

where $L_{EA,Closed}$ is the energy-average SPL with the ANC system turned off and with the windows (e.g. aperture 420) fully closed.

[00114] Similarly, the active and passive attenuation at the 7th observation microphone near the error microphones (e.g. training microphone array 240 or reference sensor 440) can be written as:

$$\alpha_{active,Error} = L_{Aeq,7,Off} - L_{Aeq,7,On}, \quad (8)$$

and

$$\alpha_{passive,Error} = L_{Aeq,7,Off} - L_{Aeq,7,Closed}, \quad (9)$$

respectively.

[00115] It is important to note that, since all four primary noise types (e.g. acoustic noise signal 112) were temporally different, the duration for the equivalent sound pressure level, L_{Aeq}, calculation was track-dependent, i.e. 47.2 s for aircraft noise and 10 s for compressor noise. This ensures that the attenuation is measured across the entire sound event, especially for transient noise sources such as aircraft fly-by and motorbike pass-by noises.

Finite element method (FEM) simulations

[00116] In addition, the ANC system 100, 400, 600 in accordance with the various embodiments of the disclosure is also physically (i.e. limits of physics) optimized to cancel noise types (e.g. acoustic noise signal 112), in the low-frequency region, since such noise types (e.g. acoustic noise signal 112) correspond to most environmental noise (e.g. traffic, train, aircraft, construction). The layout of the ANC system 100, 400, 600, is also supported by numerical FEM simulations conducted with realistic conditions to demonstrate the feasibility and physical limits of the said system, as shown in FIG. 16A, which includes a top-hung awning window panel that is open (e.g. aperture 420) at a 45 ° angle. The supporting casement window and fixed windows (e.g. denoted as the stationary frame 510) may be closed. Under ideal conditions, the various noise types (e.g. acoustic noise signal 112) may not enter through the closed windows. The control loudspeakers (e.g. plurality of transducers 120) may be placed at either the: (i) bottom of the awning window panel (q1), (ii) top of the awning window panel (q2); or (iii) top and bottom of the awning window panel (q1 & q2). The transmission loss due to the ANC system 100, 400, 600 was compared to that of a fully-closed window (full glazing), i.e. passive noise attenuation.

[00117] As may be seen from FIG. 16B, the transmission loss as a result of the ANC system (e.g. system 100, 400, 600), where the control loudspeakers were placed at the top and bottom of the awning window panel (q1 & q2), exceeds that of a fully-closed window (full glazing) without the ANC system 100, 400, 600, at frequencies below 800 Hz.

[00118] According to the FEM simulations, the cut-off frequency of the ANC system 100, 400, 600 of the present disclosure may be given by:

$$f_c = c_{air}/d \tag{10}$$

where f_c is the cut-off frequency in Hz, c_{air} is the speed of sound in air in m/s, and d is the smallest, e.g. shortest dimension of the aperture 420 in m. In accordance with various embodiments of the disclosure, the theoretical cut-off frequency of the ANC system 100, 400, 600 would be based on one wavelength of the shortest opening (approximately 0.4 m), and therefore, is about 850 Hz.

Results

[00119] For repeatability in the measurement of attenuation and to mimic practical realization of such an ANC system 100, 400, 600 on domestic windows (e.g. aperture 420), the fixed-filter approach was adopted. Each primary noise type (e.g. acoustic noise signal 112) was played on loop to allow the FXLMS algorithm to converge to a steady state, after which the control filter coefficients (e.g. pre-determined coefficients) were stored. The control signals (e.g. electronic anti-noise signal 124) were generated by convolving the reference signal $\boldsymbol{x}(n)$ (e.g. electronic noise signal 114) with the stored fixed-coefficient $\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$ finite impulse response filters, given by Eqn. 5, i.e. $\boldsymbol{y}_k(n) = \boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n) * \boldsymbol{x}(n)$, where $\boldsymbol{w}_{k,fixed}(n)$ is the k-th fixed-coefficient control filter (e.g. pre-determined coefficient of the one or more pre-determined cancellation filter candidates 160). Hence, the active control attenuation performance of the fixed-filter (e.g. one or more pre-determined cancellation filters 160) implementation measures the instantaneous steady-state attenuation across the entire duration of the primary noise.

Passive and active attenuation performance

[00120] As the ANC system 100, 400, 600 is designed to minimize the sum-of-the-squared sound pressure levels at the error microphone positions (e.g. training microphone array 240 or reference sensor 440), the active control performance of the four primary noise types (see Table

2) is first evaluated at observation microphone 7 placed near the error microphones (e.g. training microphone array 240 or reference sensor 440). The active and passive attenuation at observation microphone 7, $\alpha_{active,Error}$ and $\alpha_{passive,Error}$, respectively, is summarized in Table 3. Across the four primary noise types, active attenuation was somewhat consistent (8 dB to 12 dB), whereas the passive attenuation was about 10 dB with the exception of compressor noise. Passive attenuation of compressor noise was only 6.5 dB, which was about half that of the active attenuation at 12.4 dB.

Mode of operation		Attenuation of primary noise types (dB)			
		Aircraft	Motorbike	Traffic	Compressor
ANC ON (window opened)	$\alpha_{active,Error}$	9.5	8.97	7.99	12.36
	$\alpha_{active,EA}$	5.76	4.84	4.56	10.51
ANC OFF (window closed)	$\alpha_{passive,Error}$	9.98	10.09	10.77	6.47
	$\alpha_{passive,EA}$	5.66	6.57	6.45	4.85

Table 3: Sound pressure level attenuation in dB of observation microphone 7 near the error microphones and the energy-average across six microphones (microphones 1 to 6) across the four noise types with ANC turned on (window opened) and ANC turned off (window closed).

[00121] To evaluate the global control effectiveness of the ANC system 100, 400, 600, the active and passive attenuation calculated with the energy-average SPL of observation microphones 1 to 6 (see FIG. 11) were also presented in Table 3. The active and passive attenuation (i.e. $\alpha_{active,EA}$ and $\alpha_{passive,EA}$) was almost 4 dB lower than at the error microphone position (e.g. reference sensor 440 or training error microphone array 240), except for the compressor noise. However, the trend across the noise types is similar to that in the attenuation at the error microphone position (e.g. reference sensor 440 or training error microphone array 240). Overall, the ANC system 100, 400, 600, on a fully opened top hung window (e.g. aperture 420) offered similar attenuation to the passive insulation provided by fully closing the window. More importantly, active attenuation outperformed passive attenuation significantly for compressor noise.

Attenuation performance as a function of frequency

[00122] To understand the frequency dependency of the attenuation performance for both the ANC system 100, 400, 600 and the passive insulation of the fully-shut window, the attenuation level at observation microphone 7 is plotted as a function of frequency, as shown in FIG. 17. In the low frequencies, the active control performance exceeds that of the passive insulation up to about 250 Hz across all noise types. Attenuation of the aircraft noise between active and passive control is similar across the entire frequency band, with the ANC system 100, 400, 600 providing better reduction in the lower frequencies, as shown in FIG. 17A.

[00123] There is a significant roll-off in ANC attenuation at 300 Hz for the motorbike noise, as shown in FIG. 17B. This dip in ANC performance at 300 Hz is observed for all four noise types (e.g. acoustic noise signal 112), which could be due to the 300 Hz mode observed in the primary and secondary paths. As shown in FIG. 17C, active control outperformed passive insulation to about 250 Hz, and attenuation of the traffic noise between active and passive control is similar across the remaining frequency band, e.g. above 300 Hz. In the case of the compressor noise, active control significantly outperformed passive insulation to about 250 Hz with a match in performance between 350 Hz to 500 Hz, which explains the results in *Table 3*. Moreover, passive control was negligible up to about 150 Hz, as shown in FIG. 17D. In general, passive control outperforms the active control system above about 500 Hz, which is reflected in all the primary noise types (e.g. acoustic noise signal 112).

[00124] Energy-average attenuation performance (i.e. observation microphones 1 to 6) were in line with that near the error microphone position (i.e. observation microphone 7; e.g. training microphone array 240 or reference sensor 440), whereby active control approximately matched that of the passive control up to about 250 Hz, as shown in FIGS. 18A to 18D for aircraft noise, motorbike noise, traffic noise and compressor noise respectively.

Discussion and Conclusion

[00125] An active control system 100, 400, 600, and method 700, 900, to control low-frequency urban noise (e.g. acoustic noise signal 112) whilst maintaining natural ventilation in a building was devised. Four loudspeakers (e.g. plurality of transducers 120) were affixed to a frame (e.g. support 520) surrounding a top-hung ventilation window (e.g. aperture 420) in a full-sized mock-up apartment room (e.g. room 410). The active control system 100, 400, 600, with a fully-opened window (e.g. aperture 420) achieved similar noise reduction to a fully-glazed window for aircraft noise, whereas active attenuation for traffic and motorbike noise

was not too far off from passive insulation. In an extreme example, active attenuation of low-frequency compressor noise significantly outperformed that of a fully-glazed window. This highlights a potential scenario for low-frequency noise (e.g. acoustic noise signal 112) control through apertures (e.g. aperture 420) beyond the domestic setting.

[00126] However, it is important to note that the upper frequency limit of active control is dependent on the distance between the control loudspeakers (e.g. plurality of transducers 120) [Lam, B. et al. *Appl. Acoust.* **2018**, 137, 9–17; Elliott, S.J. et al. *J. Sound Vib.* **2018**, 419, 405–419], and appears to be related to the smallest dimension of the opening as reported in [Wang, S. et a;. *J. Acoust. Soc. Am.* **2018**, 143, 3345–3351]. In the top-hung window (e.g. aperture 420) shown, the theoretical limit would be based on one wavelength of the shortest opening (~0.4 m), which is about 850 Hz. Besides the frequency limit, the directivity of the control loudspeaker (e.g. plurality of transducers 120) becomes critical as the frequency increases, which would have implications on the placement of the loudspeakers (e.g. plurality of transducers 120) and would be worthwhile of further investigation. Moreover, only a single top-hung window (e.g. aperture 420) was affixed with the ANC system 100, 400, 600, potentially allowing low-frequency noise to leak into the interior through other, albeit closed, window panels. Expansion of the system to all available top-hung windows in the window system could be investigated next.

[00127] Despite the limitations, the attenuation results obtained from a single top-hung window (e.g. aperture 420) is promising, especially for noise types (e.g. acoustic noise signal 112) with dominant low-frequency content, such as jet aircraft and compressor noise. Although placement of control sources at the edge of the window frame was previously found to be non-optimal [Lam, B. et al. *Appl. Acoust.* **2018**, 137, 9–17], the tradeoff to obtain improved low-frequency performance and reduced visual obstruction could be worthwhile.

[00128] This ANC window system 100, 400, 600 can also be a solution to the urban planners' dilemma of balancing the proximity and orientation of residential buildings to urban transport infrastructure. Optimisation of the orientation of naturally ventilated buildings for wind flow, solar heat gain and air temperatures [Poh, H.J. et al. *Proc. 4th Int. Conf. on Countermeasures to Urban Heat Island*; **2016**] would not be bogged down by the consideration of noise propagation. Moreover, the ANC system 100, 400, 600 mounted on a window (e.g. aperture 420) also provides an avenue for indoor soundscaping of naturally ventilated buildings, whereby unwanted noise can be removed using selective algorithms [Wen, S. et al. *J. Acoust.*

Soc. Am. **2020**, 147, 3490–3501; Shi, D. et a; *IEEE/ACM Trans. Audio, Speech, Lang. Process.* in press] and wanted sounds can be introduced or amplified via the same loudspeakers (e.g. plurality of transducers 120) that deliver the anti-noise. This element of controllability with an ANC system aligns well with the concept of "adaptive acoustic comfort" suggested by Torresin et al.. [Torresin, S. et al. *Appl. Sci.* **2019**, 9, 5401], which could be worth further investigation.

[00129] While the disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. A system (100, 400, 600) for actively cancelling an acoustic noise signal (112) entering a room (410) through an aperture (420) of the room (410), the system (100, 400, 600) comprising:

- a sensor (110) configured to detect the acoustic noise signal (112) and to convert the acoustic noise signal (112) into an electronic noise signal (114);

- a plurality of transducers (120) configured to generate an acoustic anti-noise signal (122) from an electronic anti-noise signal (124) to cancel, at least part of, the acoustic noise signal (112), when the acoustic anti-noise signal (122) is added to the acoustic noise signal (112); and

- a controlling circuit (130) operably coupleable to the sensor (110) and the plurality of transducers (120), such that when operably coupled, the controlling circuit (130):

- receives (140) the electronic noise signal (114) from the sensor (110),

- classifies (150) the electronic noise signal (114) by matching a sample of the electronic noise signal (114) to one or more pre-determined cancellation filter candidates (160),

- selects (160) a first pre-determined cancellation filter (162) from the one or more pre-determined cancellation filter candidates (160), by basing a selection on the classified sample of the electronic noise signal (114),

- generates (170) the electronic anti-noise signal (124) by applying the first pre-determined cancellation filter (162) on the electronic noise signal (114), and

- transmits (180) the electronic anti-noise signal (114) to the plurality of transducers (120).

2. The system (100, 400, 600) of claim 1, wherein matching the sample of the electronic noise signal (114) to the one or more pre-determined cancellation filter candidates (160) comprises:

- determining, at least one characteristic from the sample of the electronic noise signal (114),

- determining, if the at least one characteristic from the sample of the electronic noise signal (114) has a same characteristic to at least one corresponding characteristic of an

exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates (160).

3. The system (100, 400, 600) of claim 2, wherein the at least one characteristic from the sample of the electronic noise signal (114) comprises an amplitude, a phase, and/or a frequency.

4. The system (100, 400, 600) of any one of claims 2 to 3, wherein the controlling circuit (130) is further configured to deactivate the system (100, 400, 600) when the at least one characteristic from the sample of the electronic noise signal (114) is different from the at least one corresponding characteristic of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates (160).

5. The system (100, 400, 600) of any one of claims 2 to 4, wherein the controlling circuit (130) is further configured to:

- determine a deviation of the at least one characteristic from the sample of the electronic noise signal (114) to a corresponding pre-determined threshold value, and
- activate the system when the deviation of the at least one characteristic from the sample of the electronic noise signal (114) is greater than the corresponding pre-determined threshold value.

6. The system (100, 400, 600) of any one of claims 1 to 5, wherein each of the one or more pre-determined cancellation filter candidates (160) comprises a pre-determined coefficient ($\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$) for generating the electronic anti-noise signal (124).

7. The system (100, 400, 600) of any one of claims 1 to 5, wherein generating the electronic anti-noise signal (124) comprises convolving a reference signal $\boldsymbol{x}(n)$ with a pre-determined coefficient ($\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$) of the first pre-determined cancellation filter (162) implemented using a finite impulse response filter.

8. The system (100, 400, 600) of any one of claims 1 to 7, wherein the one or more pre-determined cancellation filter candidates (160) are stored within a library of pre-determined cancellation filters (190), and

wherein the library of pre-determined cancellation filters (190) is stored in one or more of: a server; a memory of the controlling circuit (130).

9. The system (100, 400, 600) of any one of claims 1 to 8, wherein the acoustic anti-noise signal (122) cancels, at least part of, the acoustic noise signal (112) entering the aperture (420) of the room (410) by minimizing a sum-of-the-squared acoustic pressure level at a reference position (430) in the room, wherein the reference position (430) is spaced apart from the aperture (420) of the room (410).

10. The system (100, 400, 600) of any one of claims 1 to 9, wherein the controlling circuit (130) is configured to generate the electronic anti-noise signal (124), when the electronic noise signal (114) is in a range of 20 Hz to 850 Hz, preferably between 100 Hz to 700 Hz.

11. The system (100, 400, 600) of any one of claims 1 to 10, further comprising a user interface (610) operably coupled to the controlling circuit (130), wherein the controlling circuit (130) is further configured to:

- receive an input from the user interface (610), wherein the input comprises a user's selection of a second pre-determined cancellation filter (164) from the one or more pre-determined cancellation filter candidates (160), and wherein the second pre-determined cancellation filter (164) differs from the first pre-determined cancellation filter (162), and
- deactivate the first pre-determined cancellation filter (162) and activate the second pre-determined cancellation filter (164) in response to the received input.

12. The system (100, 400, 600) of any one of claims 1 to 11, further comprising a stationary frame (510) attached to the aperture (420) of the room (410), and

wherein the plurality of transducers (120) configured to generate the acoustic anti-noise signal (122) are mounted on a support (520) which is removably disposable in relation to the stationary frame (510).

13. The system (100, 400, 600) of claim 12, wherein the plurality of transducers (120) configured to generate the acoustic anti-noise signal (122) are mounted on at least one edge of the support (520).

14. The system (100, 400, 600) of any one of claims 12 to 13, wherein the sensor (110) is affixed to an outer moveable frame (530) coupled to the stationary frame (510).

15. The system (100, 400, 600) of any one of claim 14, further comprising a motion sensor (560) configured to detect a movement of the outer moveable frame (530) in relation to the stationary frame (510), and to determine information about an arrangement of the stationary frame (510) and the outer moveable frame (530), wherein the arrangement comprises a closed arrangement or an open arrangement,

wherein in the closed arrangement, the outer moveable frame (530) is in contact with the stationary frame (510),

wherein in the open arrangement, the outer moveable frame (530) is partially separated from the stationary frame (510), and

wherein the controlling circuit (130) is further configured to:

- receive the information about the arrangement from the motion sensor (560),

- activate the system (100, 400, 600) when the motion sensor (560) determines that the arrangement is the open arrangement, and

- deactivate the system (100, 400, 600) when the motion sensor (560) determines that the arrangement is the closed arrangement.

16. A method (700, 800A, 800B, 800C) for actively cancelling an acoustic noise signal (112) entering a room (410) through an aperture (420) of the room (410), comprising:

- providing (710) a sensor (110) to detect the acoustic noise signal (112) and to convert the acoustic noise signal (112) into an electronic noise signal (114);

- transmitting (720) the electronic noise signal (114) from the sensor (110) to a controlling circuit (130) operably coupled to the sensor (110) and to a plurality of transducers (120);

- classifying (730) using the controlling circuit (130), the electronic noise signal (124) by matching a sample of the electronic noise signal (114) to one or more pre-determined cancellation filter candidates (160);

- selecting (740) using the controlling circuit (130), a first pre-determined cancellation filter (162) from the one or more pre-determined cancellation filter candidates (160), by basing a selection on the classified sample of the electronic noise signal (114),

- generating (750) using the controlling circuit (130), an electronic anti-noise signal (124) by applying the first pre-determined cancellation filter (162) on the electronic noise signal (114),

- transmitting (760) using the controlling circuit (130), the electronic anti-noise signal (124) to the plurality of transducers (120),

wherein the plurality of transducers (120) generates the acoustic anti-noise signal (122) from the electronic anti-noise signal (124) to cancel, at least part of, the acoustic noise signal (112), when the acoustic anti-noise signal (122) is added to the acoustic noise signal (112).

17. The method (700, 800A, 800B, 800C) of claim 16, wherein matching the sample of the electronic noise signal (114) to the one or more pre-determined cancellation filter candidates (160) comprises:

- determining at least one characteristic from the sample of the electronic noise signal (114),

- determining if the at least one characteristic from the sample of the electronic noise signal (114) has a same characteristic to at least one corresponding characteristic of an exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates (160).

18. The method (700, 800A, 800B, 800C) of claim 17, wherein the at least one characteristic from the sample of the electronic noise signal (114) comprises an amplitude, a phase, and/or a frequency.

19. The method (700, 800A, 800B, 800C) of any one of claims 17 to 18, further comprising:

- terminating (780, 842), using the controlling circuit (130), the method (700, 800A, 800B, 800C) when the at least one characteristic from the sample of the electronic noise signal (114) is different from the at least one corresponding characteristic of the exemplary electronic signal stored within each one of the one or more pre-determined cancellation filter candidates (160).

20. The method (700, 800A, 800B, 800C) of any one of claims 17 to 19, further comprising:

- determining (790), using the controlling circuit (130), a deviation of the at least one characteristic from the sample of the electronic noise signal (114) to a corresponding pre-determined threshold value, and

- initializing an operation of the method (700, 800A, 800B, 800C), using the controlling circuit (130), when the deviation of the at least one characteristic from the sample of the electronic noise signal (114) is greater than the corresponding pre-determined threshold value.

21. The method (700, 800A, 800B, 800C) of any one of claims 16 to 20, wherein each of the one or more pre-determined cancellation filter candidates (160) comprises a pre-determined coefficient ($\boldsymbol{w}_{k,fixed}^{\mathrm{T}}(n)$) for generating the electronic anti-noise signal (124).

22. The method (700, 800A, 800B, 800C) of any one of claims 16 to 20, wherein generating the electronic anti-noise signal (124) using the controlling circuit (130) comprises convolving a reference signal ($\boldsymbol{x}(n)$) with a pre-determined coefficient ($\boldsymbol{w}_{1,fixed}^{\mathrm{T}}(n)$) of the first pre-determined cancellation filter (162), implemented using a finite impulse response filter.

23. The method (700, 800A, 800B, 800C) of any one of claim 16 to 22, wherein the one or more pre-determined cancellation filter candidates (160) are stored within a library of pre-determined cancellation filters (190), and

wherein the library of pre-determined cancellation filters (190) is stored in one or more of: a server, within a memory of the controlling circuit (130).

24. The method (700, 800A, 800B, 800C) of any one of claims 16 to 23, wherein the acoustic anti-noise signal (122) cancels, at least part of, the acoustic noise signal (112) entering the aperture (420) of the room (410) by minimizing a sum-of-the-squared acoustic pressure level at a reference position (430) in the room (410), wherein the reference position (430) is spaced apart from the aperture (420) of the room (410).

25. The method (700, 800A, 800B, 800C) of any one of claims 16 to 24, wherein the controlling circuit (130) generates the electronic anti-noise signal (124), when the electronic noise signal (114) is in a range of 20 Hz to 850 Hz, preferably between 100 Hz to 700 Hz.

26. The method (700, 800A, 800B, 800C) of any one of claims 16 to 25, further comprising:

- receiving (812) an input from a user interface (610) operably coupled to the controlling circuit (130), wherein the input comprises a user's selection of a second pre-determined cancellation filter (164) from the one or more pre-determined cancellation filter candidates (160), and wherein the second pre-determined cancellation filter (164) differs from the first pre-determined cancellation filter (162), and

- the controlling circuit (130) in response to the received input, terminating (814) the application of the first pre-determined cancellation filter (162) on the electronic noise signal (114), and applying the second pre-determined cancellation filter (164) on the electronic noise signal (114).

27. The method (700, 800A, 800B, 800C) of any one of claims 16 to 26, further comprising a stationary frame (510) attached to the aperture (420) of the room (410), and

wherein the plurality of transducers (120) are mounted on a support (520) which is removably disposable in relation to the stationary frame (510).

28. The method (700, 800A, 800B, 800C) of claim 27, wherein the plurality of transducers (120) are mounted on at least one edge of the support (520).

29. The method (700, 800A, 800B, 800C) of any one of claims 27 to 28, wherein the sensor (110) is affixed to an outer moveable frame (530) coupled to the stationary frame (510).

30. The method (700, 800A, 800B, 800C) of any one of claims 27 to 29, further comprising:

- providing (820) a motion sensor (560) to detect a movement of the outer moveable frame (530) in relation to the stationary frame (510),

- determining (822), using the motion sensor (560), information about an arrangement of the stationary frame (510) and the outer moveable frame (530), wherein the arrangement comprises a closed arrangement or an open arrangement,

wherein in the closed arrangement, the outer moveable frame (530) is in contact with the stationary frame (510), and in the open arrangement, the outer moveable frame (530) is partially separated from the stationary frame (510),

- receiving using the controlling circuit (130), the information about the arrangement from the motion sensor (560),

- initializing (826) the method (700, 800A, 800B, 800C), using the controlling circuit (130), when it is determined that the arrangement is the open arrangement, and

- terminating (828) the method (700, 800A, 800B, 800C), using the controlling circuit (130), when it is determined that the arrangement is the closed arrangement.

31. A method (900) for actively cancelling an acoustic noise signal (112) entering a room (410) through an aperture (420) of the room (410), the method (900) comprising:

- providing (910) a sensor (110) to detect the acoustic noise signal (112) and to convert the acoustic noise signal (112) into an electronic noise signal (114);

- providing (920) a plurality of transducers (120) to generate an acoustic anti-noise signal (122) to cancel at least part of the acoustic noise signal (112), when the acoustic anti-noise signal (122) is added to the acoustic noise signal (112), and to convert an electronic anti-noise signal (124) into the acoustic anti-noise signal (122);

- transmitting (930) the electronic noise signal (114) to a controlling circuit (130) operably coupled to the sensor (110) and the plurality of transducers (120);

- classifying (940) using the controlling circuit (130), the electronic noise signal (114) by matching a sample of the electronic noise signal (114) to one or more pre-determined cancellation filter candidates (160);

- selecting (950) using the controlling circuit (130), a first pre-determined cancellation filter (162) from the one or more pre-determined cancellation filter candidates (160), by basing a selection on the classified sample of the electronic noise signal (114),

- generating (960) using the controlling circuit (130), the electronic anti-noise signal (124) by applying the first pre-determined cancellation filter (162) on the electronic noise signal (114),

- transmitting (970) using the controlling circuit (130), the electronic anti-noise signal (124) to the plurality of transducers (120).

32. The method (900) of claim 31, wherein the controlling circuit (130) comprises a microprocessor or is included in a microprocessor.

33. A computer program comprising instructions to cause a computing system to execute the steps of the method (700, 800A, 800B, 800C, 900) of any one of claims 16 to 32.

34. A computer program comprising instructions to cause the system (100, 400, 600) of any one of claims 1 to 15 to execute the steps of the method (700, 800A, 800B, 800C, 900) of any one of claims 16 to 32.

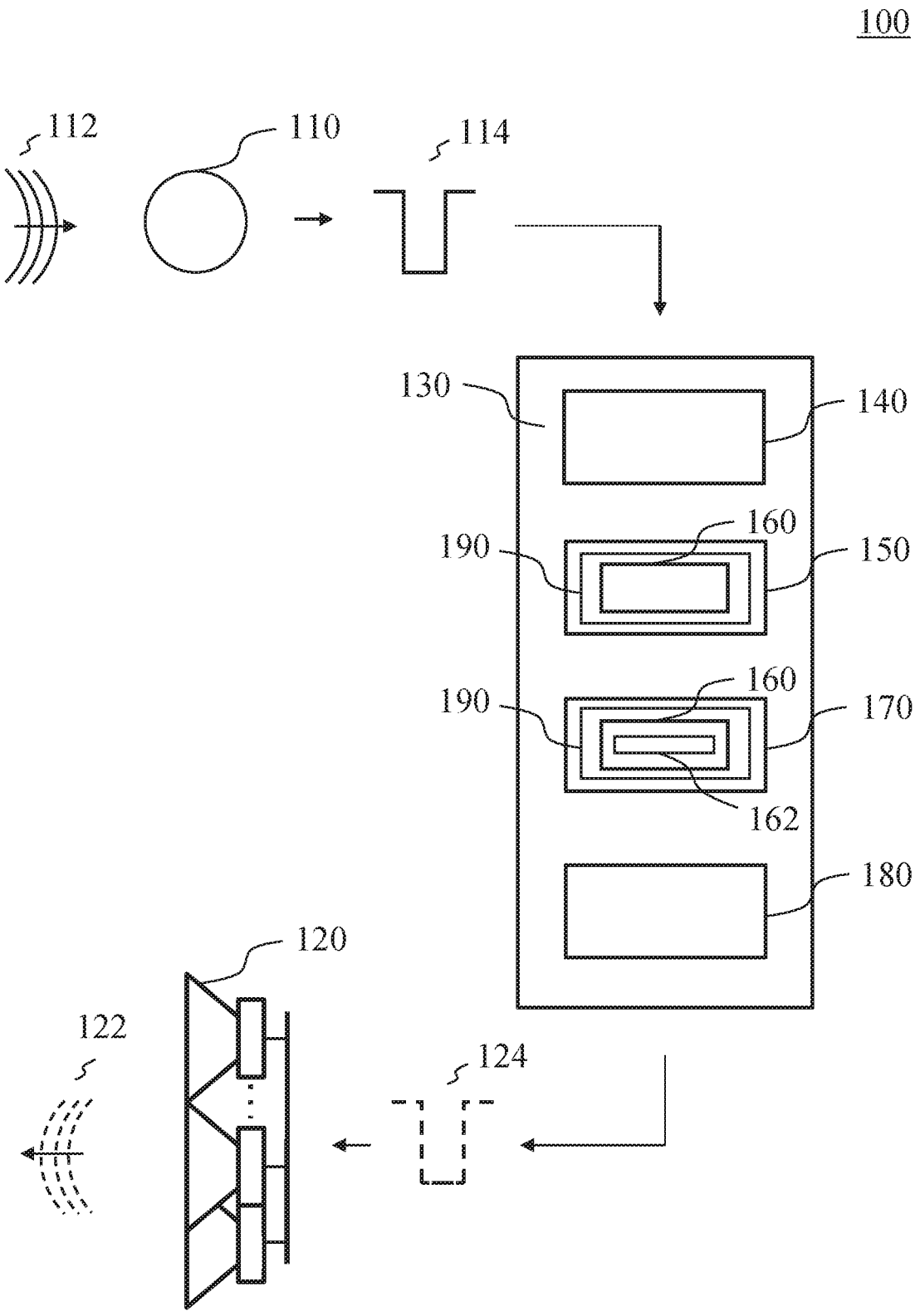

100
112
110
114
130
140
160
190
150
160
190
170
162
180
120
122
124

FIG. 1

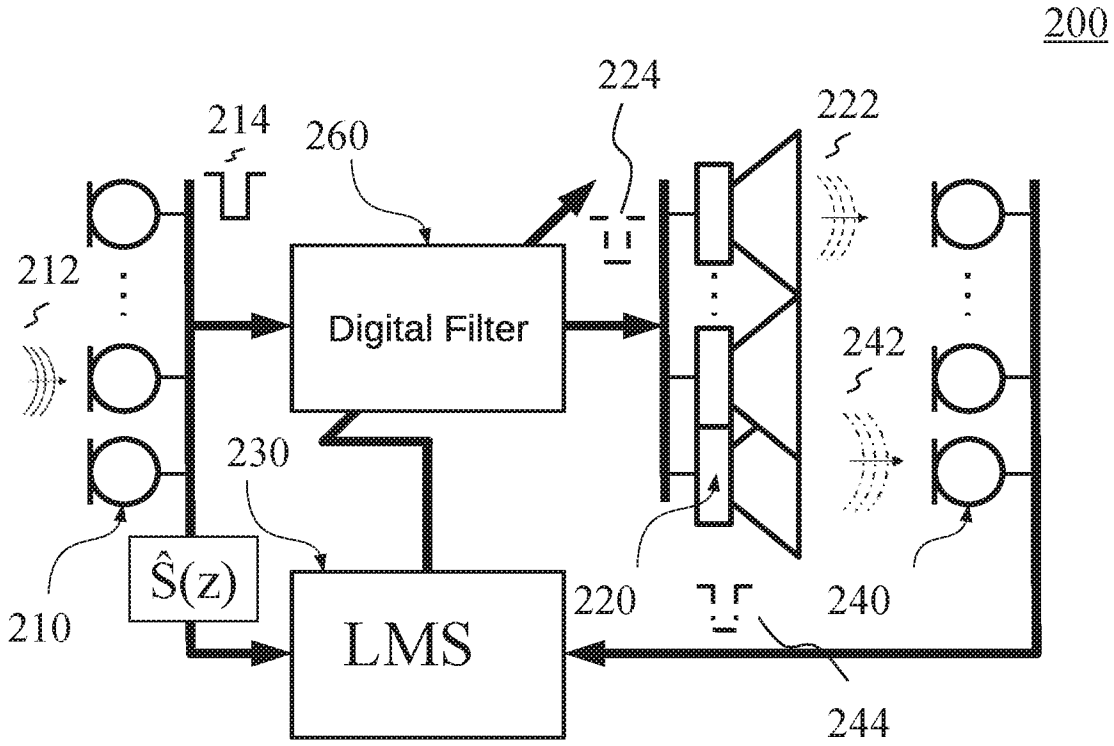

200
224
214
260
222
212
Digital Filter
242
230
Ŝ(z)
210
220
240
LMS
244

FIG. 2A

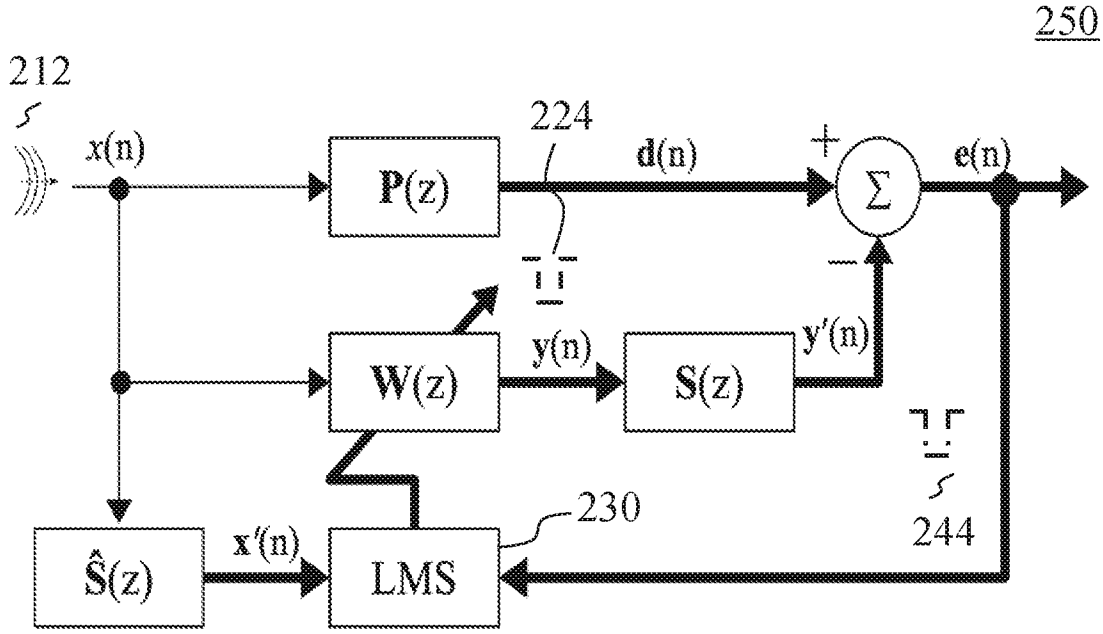

250
212
224
x(n)
P(z)
d(n)
+
Σ
e(n)
W(z)
y(n)
S(z)
y'(n)
244
230
Ŝ(z)
x'(n)
LMS

FIG. 2B

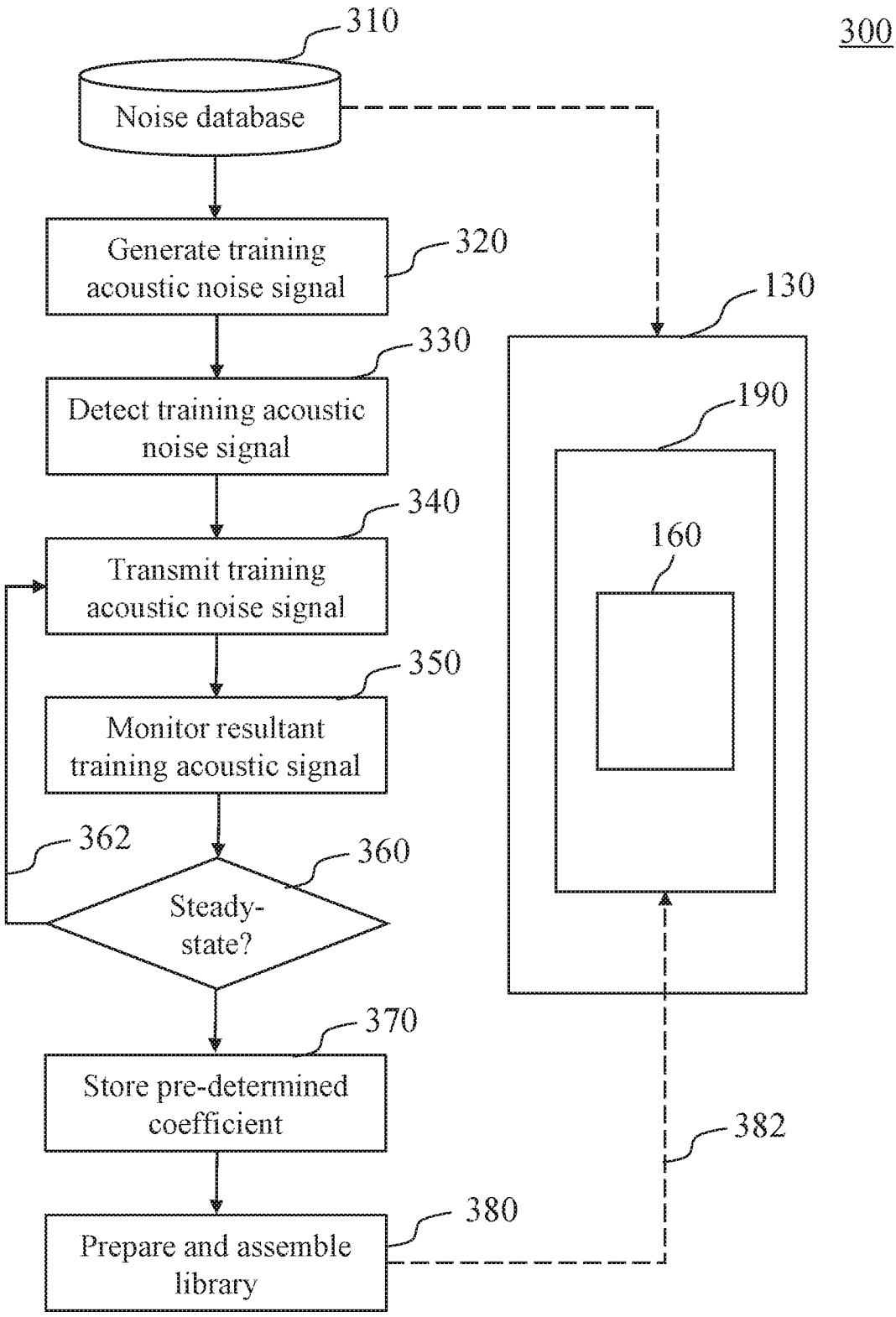

300
310
Noise database
Generate training acoustic noise signal
320
130
330
Detect training acoustic noise signal
190
340
160
Transmit training acoustic noise signal
350
Monitor resultant training acoustic signal
362
360
Steady-state?
370
Store pre-determined coefficient
382
380
Prepare and assemble library

FIG. 3

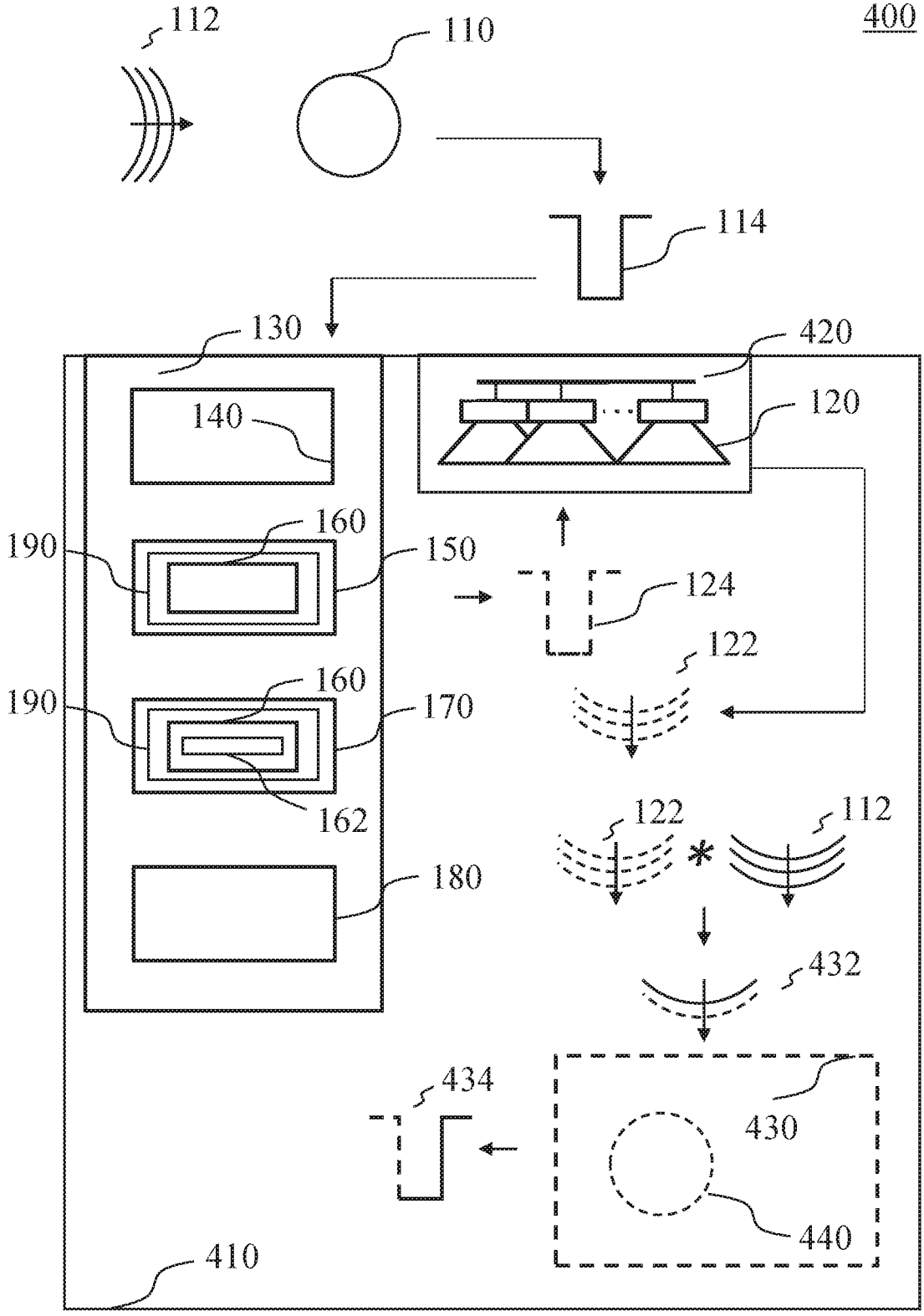

112
110
400
114
130
420
140
120
160
190
150
124
122
160
190
170
162
122
112
180
432
434
430
440
410

FIG. 4

500A

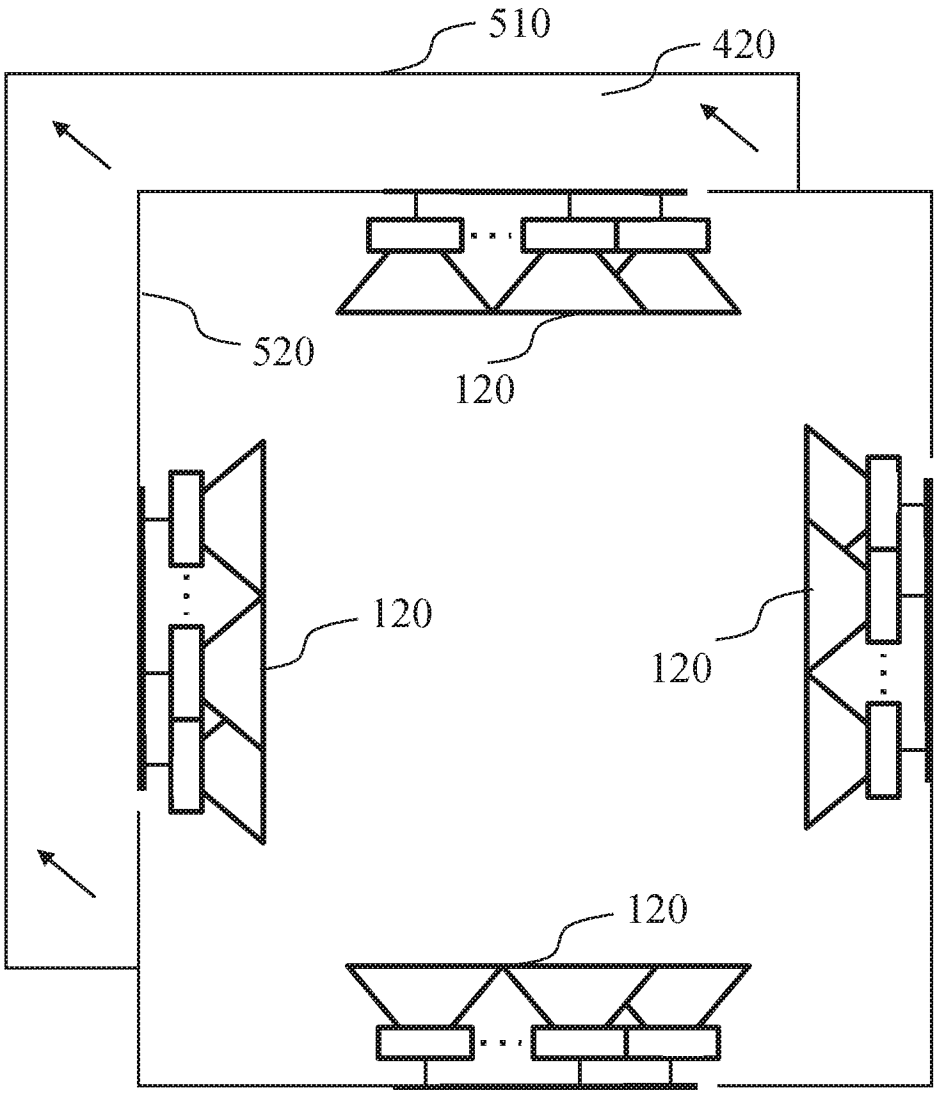


FIG. 5A

500B

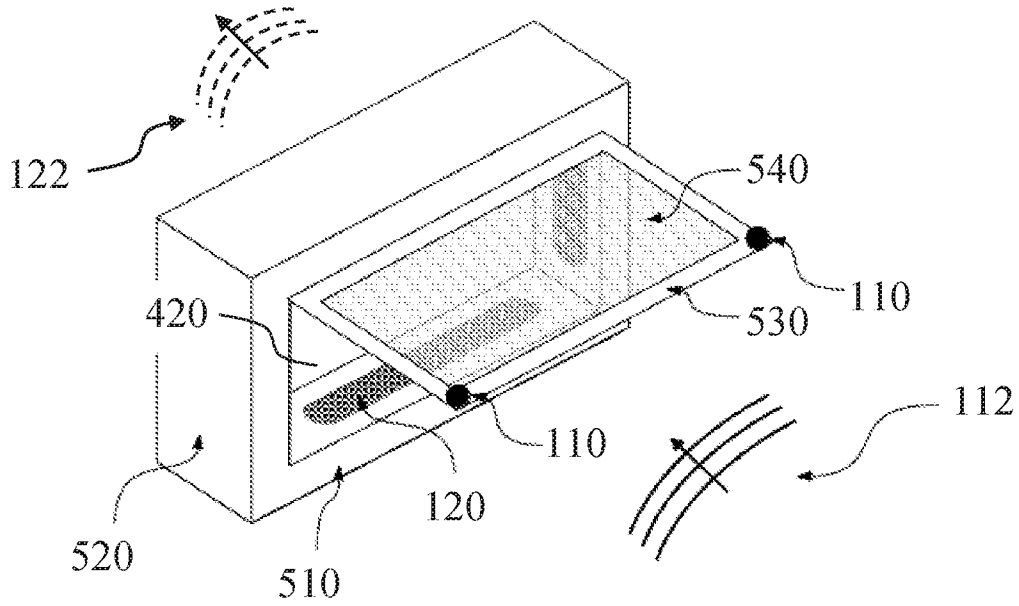


FIG. 5B

500C

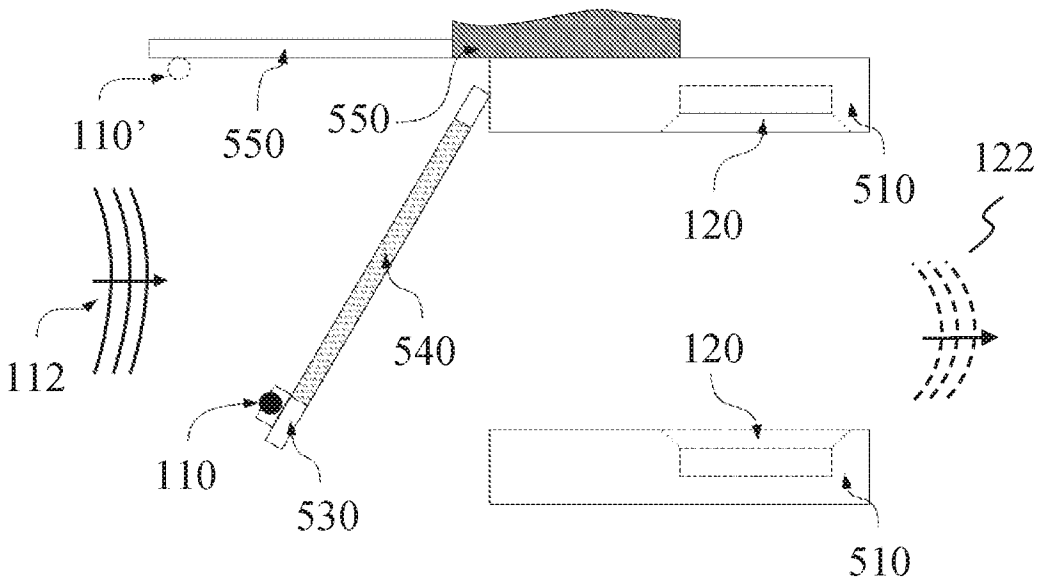


FIG. 5C

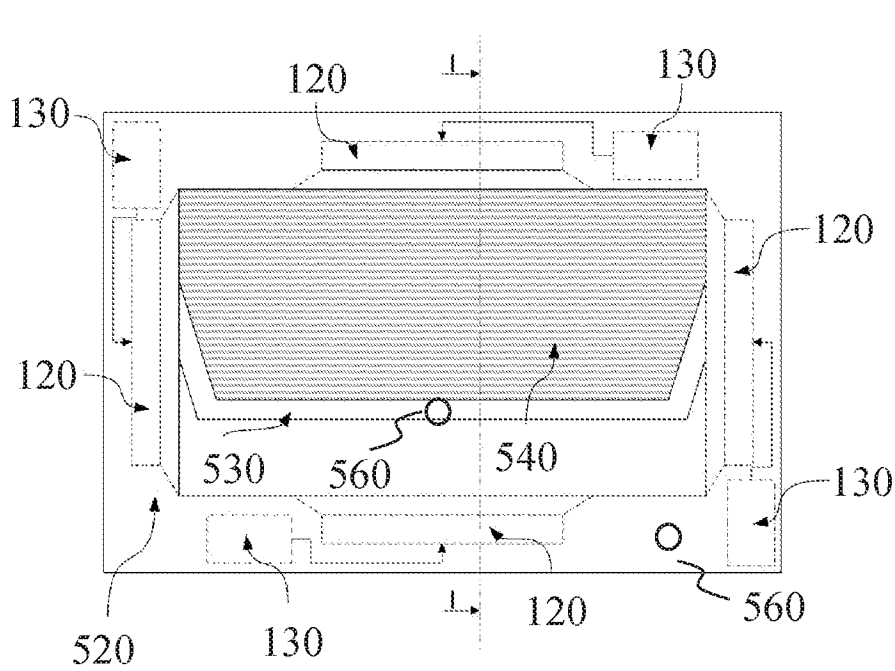

500D
120
130
130
120
120
530
560
540
130
520
130
120
560

FIG. 5D

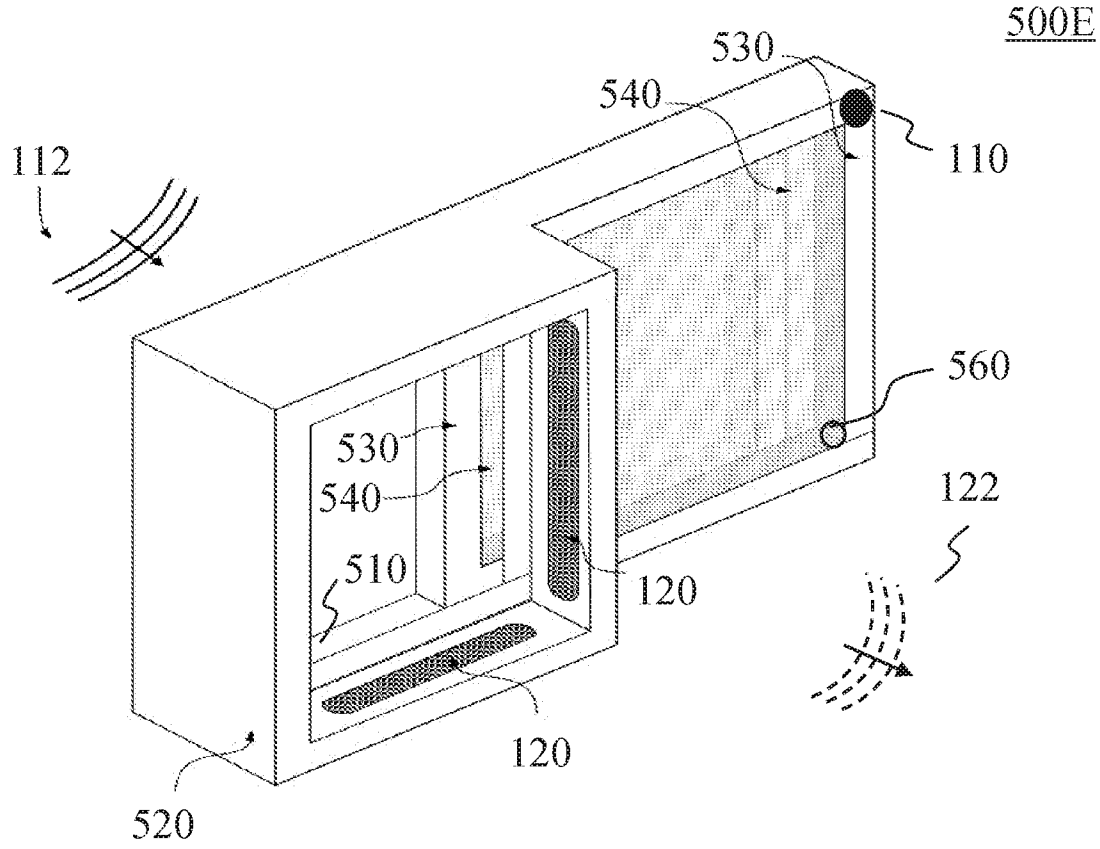

500E
530
540
110
112
560
530
540
122
510
120
120
520

FIG. 5E

500F

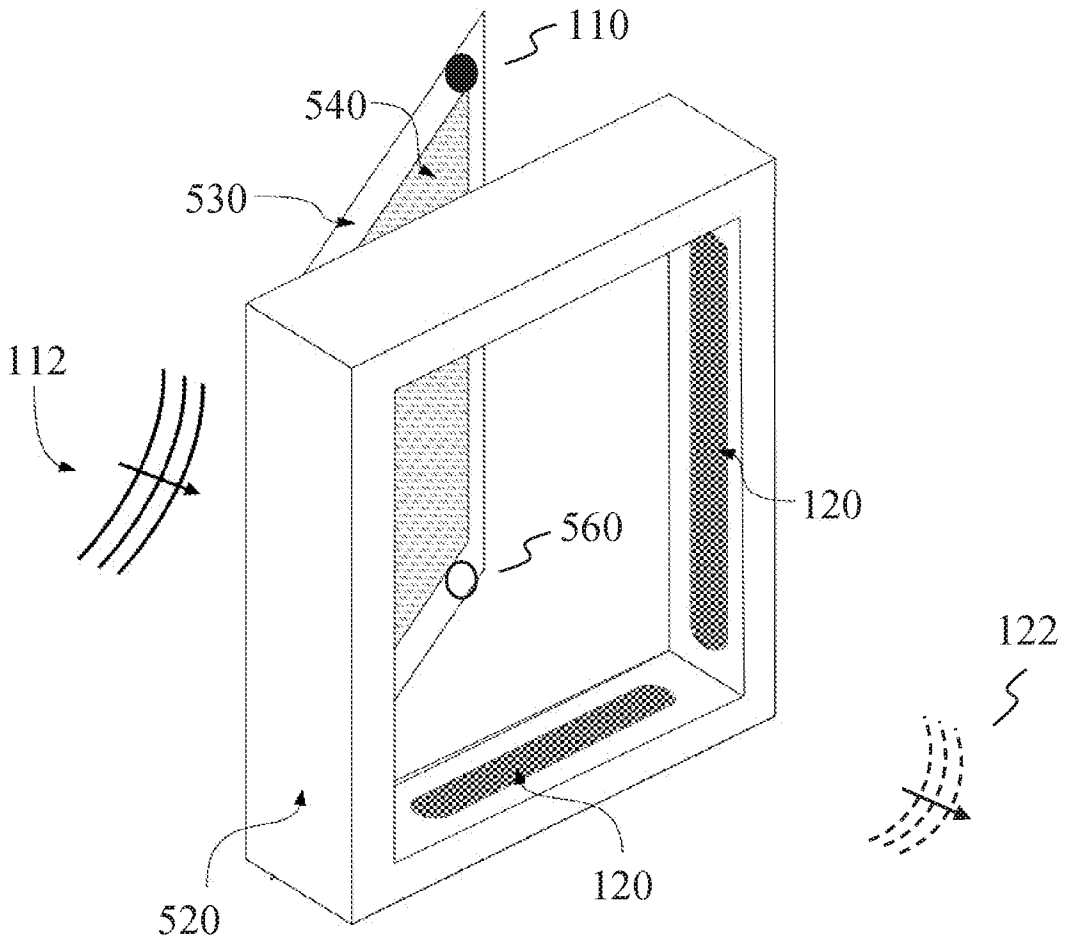


FIG. 5F

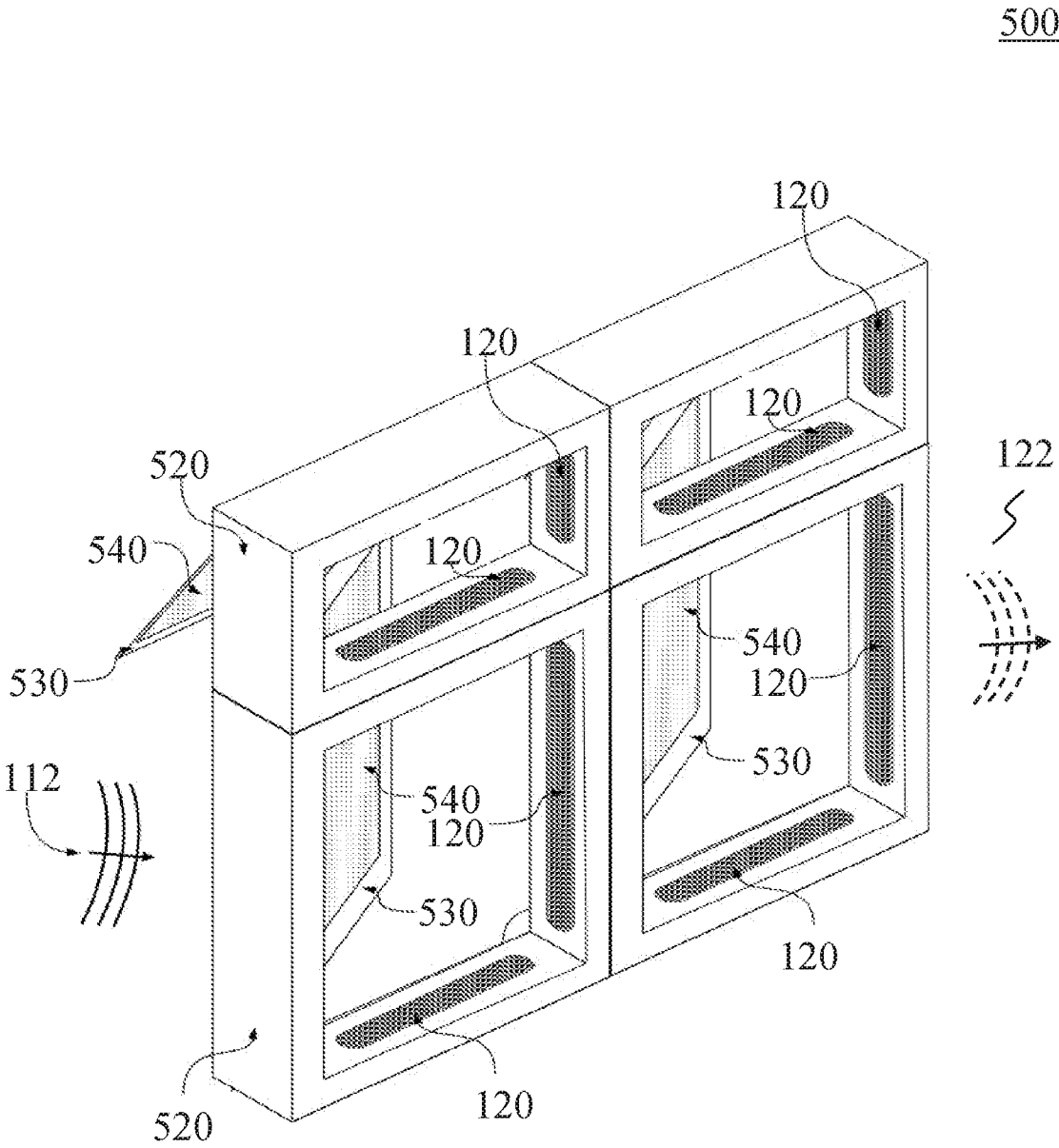

500G
120
120
120
122
520
540
120
530
540
120
530
112
540
120
530
120
520
120

FIG. 5G

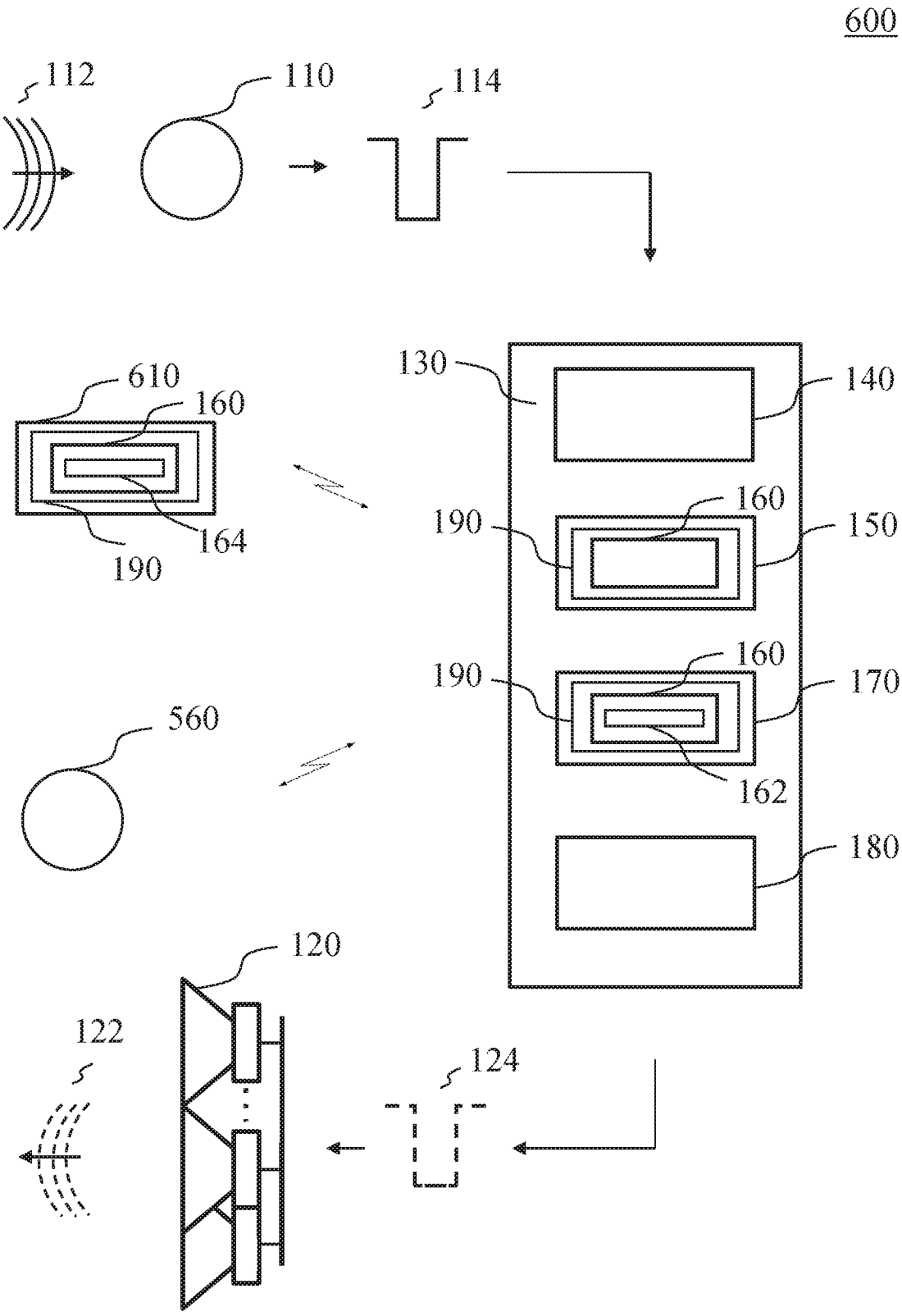

600
112
110
114
610
160
164
190
130
140
160
190
150
160
190
170
162
180
560
120
122
124

FIG. 6

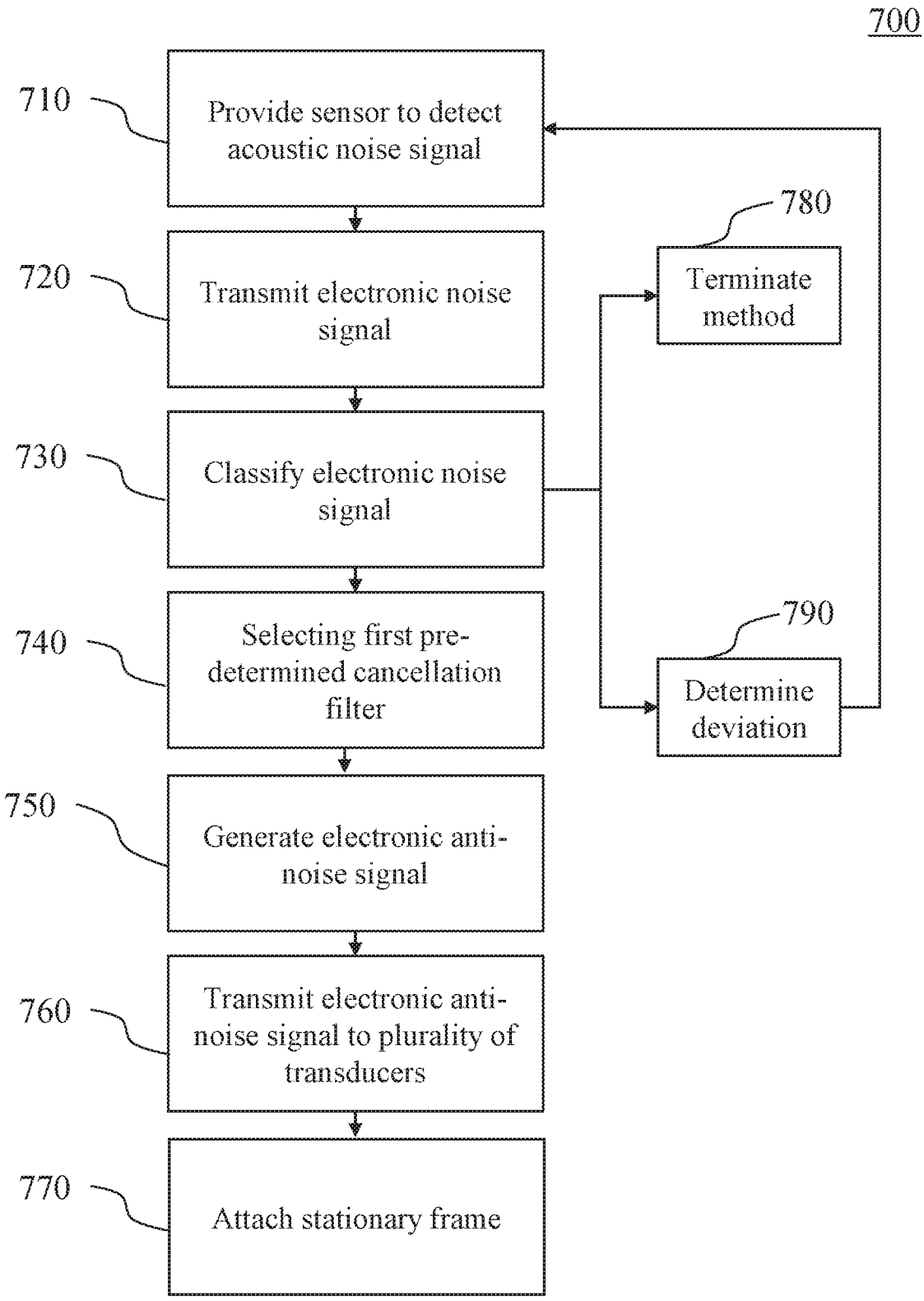

700
710
Provide sensor to detect acoustic noise signal
720
Transmit electronic noise signal
730
Classify electronic noise signal
740
Selecting first pre-determined cancellation filter
750
Generate electronic anti-noise signal
760
Transmit electronic anti-noise signal to plurality of transducers
770
Attach stationary frame
780
Terminate method
790
Determine deviation

FIG. 7

800A

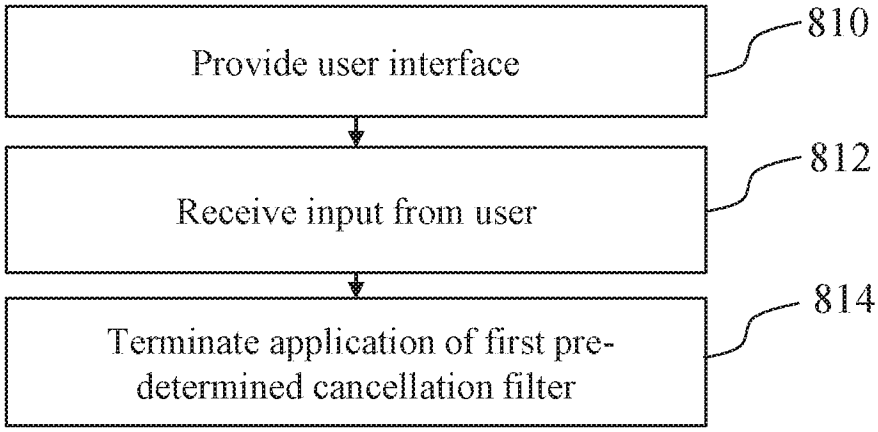


FIG. 8A

800B

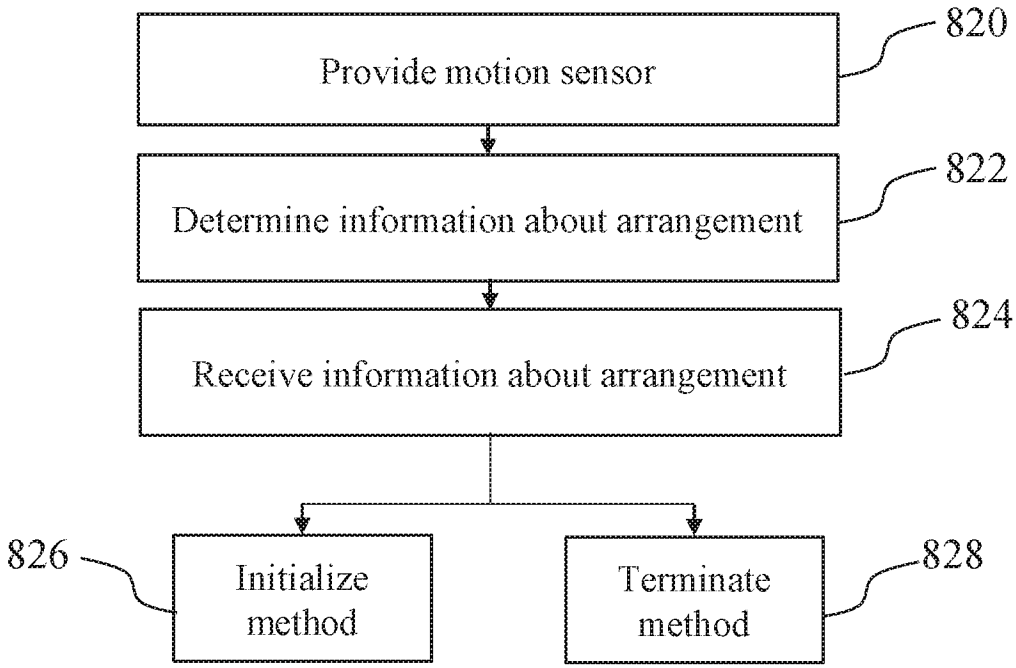


FIG. 8B

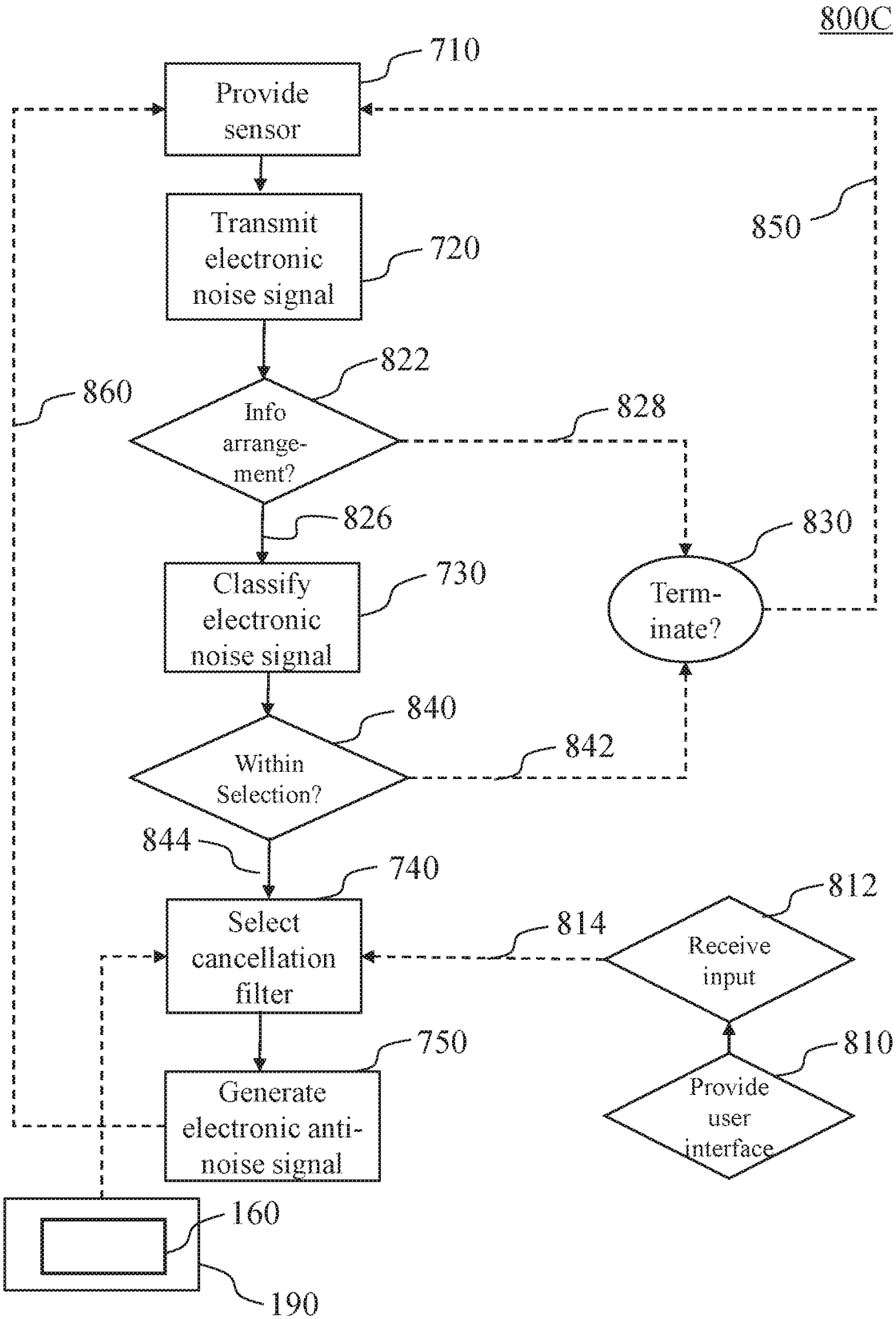

800C
710
Provide sensor
Transmit electronic noise signal
720
850
822
860
Info arrange-ment?
828
826
830
Classify electronic noise signal
730
Term-inate?
840
Within Selection?
842
844
740
812
Select cancellation filter
814
Receive input
750
810
Generate electronic anti-noise signal
Provide user interface
160
190

FIG. 8C

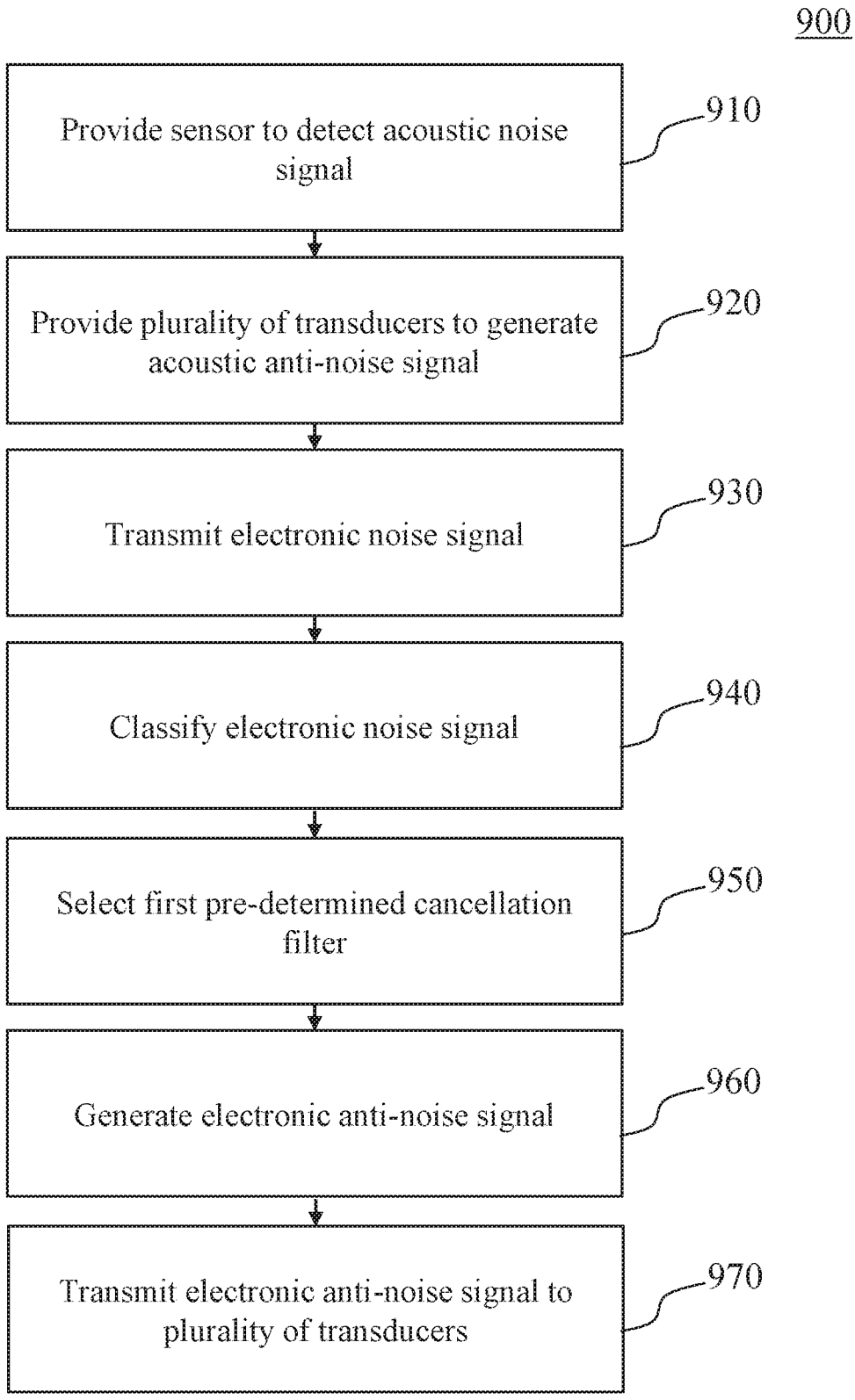
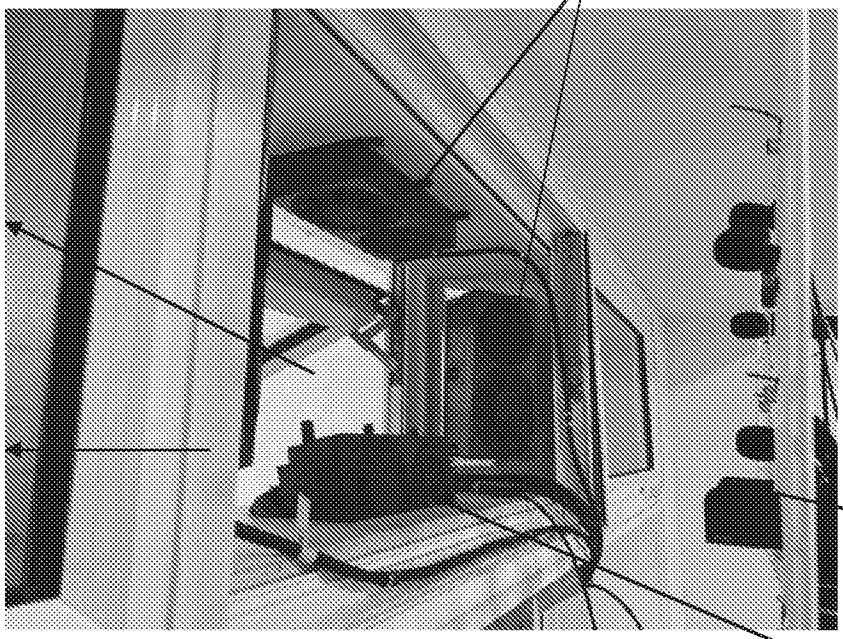

900
Provide sensor to detect acoustic noise signal
910
Provide plurality of transducers to generate acoustic anti-noise signal
920
Transmit electronic noise signal
930
Classify electronic noise signal
940
Select first pre-determined cancellation filter
950
Generate electronic anti-noise signal
960
Transmit electronic anti-noise signal to plurality of transducers
970

FIG. 9

(A)



(B)

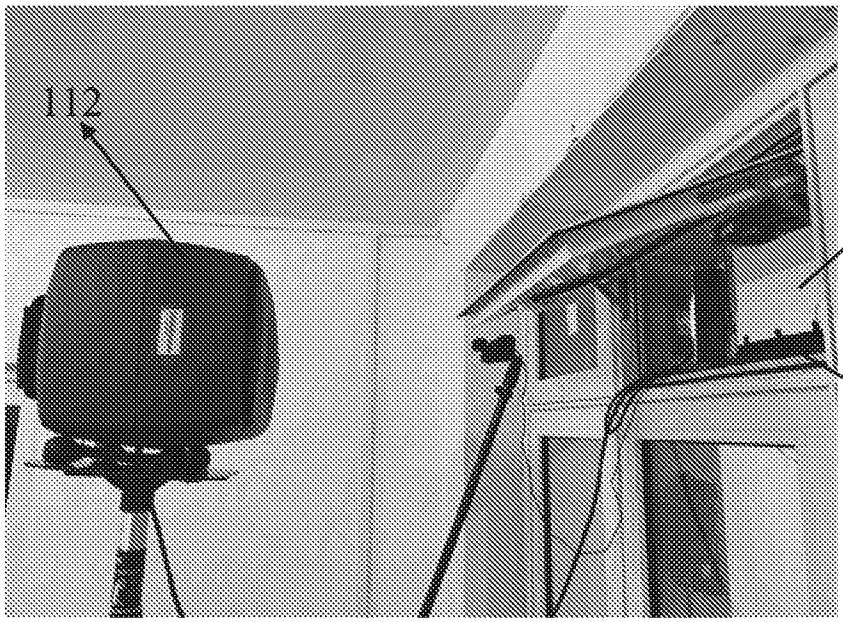


FIG. 10

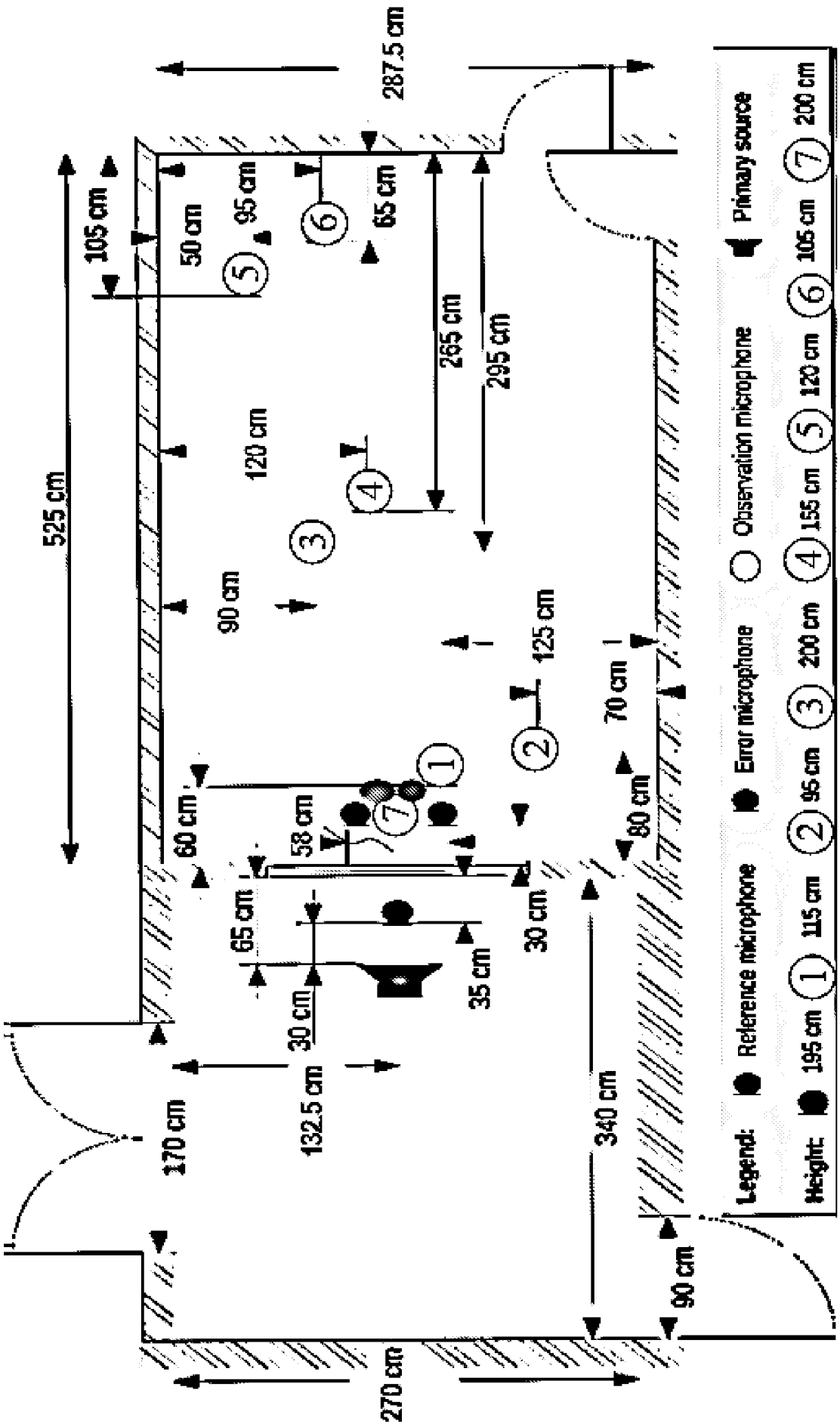
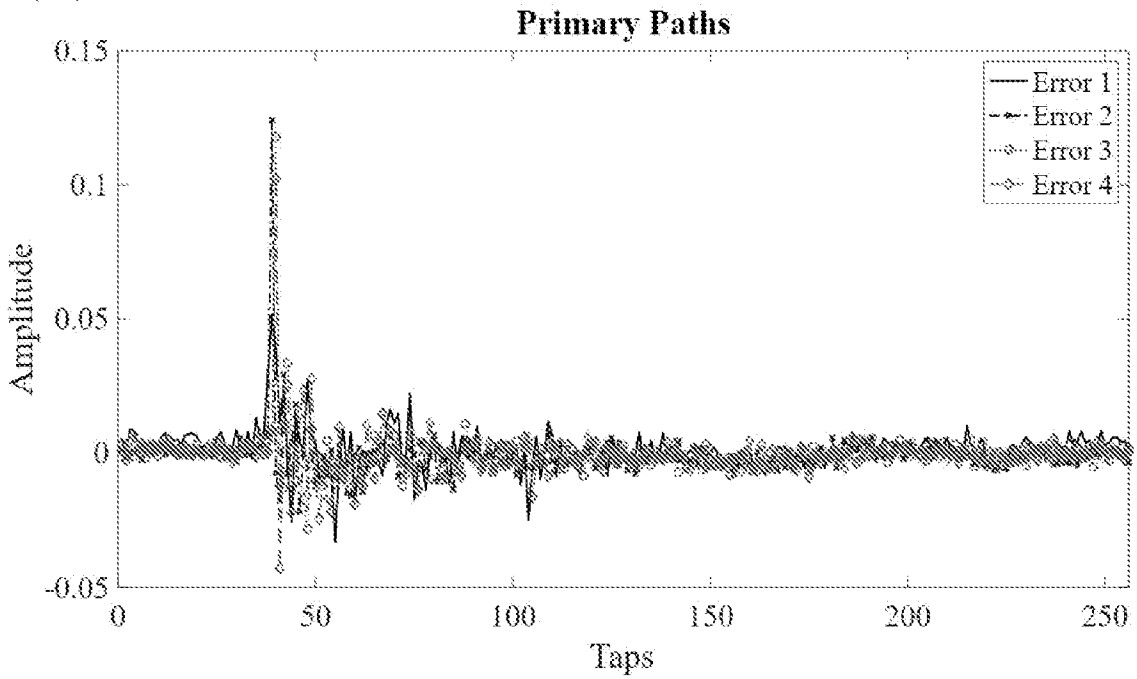

287.5 cm
105 cm
50 cm
95 cm
65 cm
265 cm
295 cm
525 cm
120 cm
90 cm
125 cm
70 cm
60 cm
58 cm
80 cm
65 cm
30 cm
35 cm
30 cm
132.5 cm
170 cm
340 cm
90 cm
270 cm
Legend:
Reference microphone
Error microphone
Observation microphone
Primary source
Height:
195 cm
115 cm
95 cm
200 cm
155 cm
120 cm
105 cm
200 cm

FIG. 11

(A)


Primary Paths
Error 1
Error 2
Error 3
Error 4
Amplitude
0.15
0.1
0.05
0
-0.05
0
50
100
150
200
250
Taps

(B)

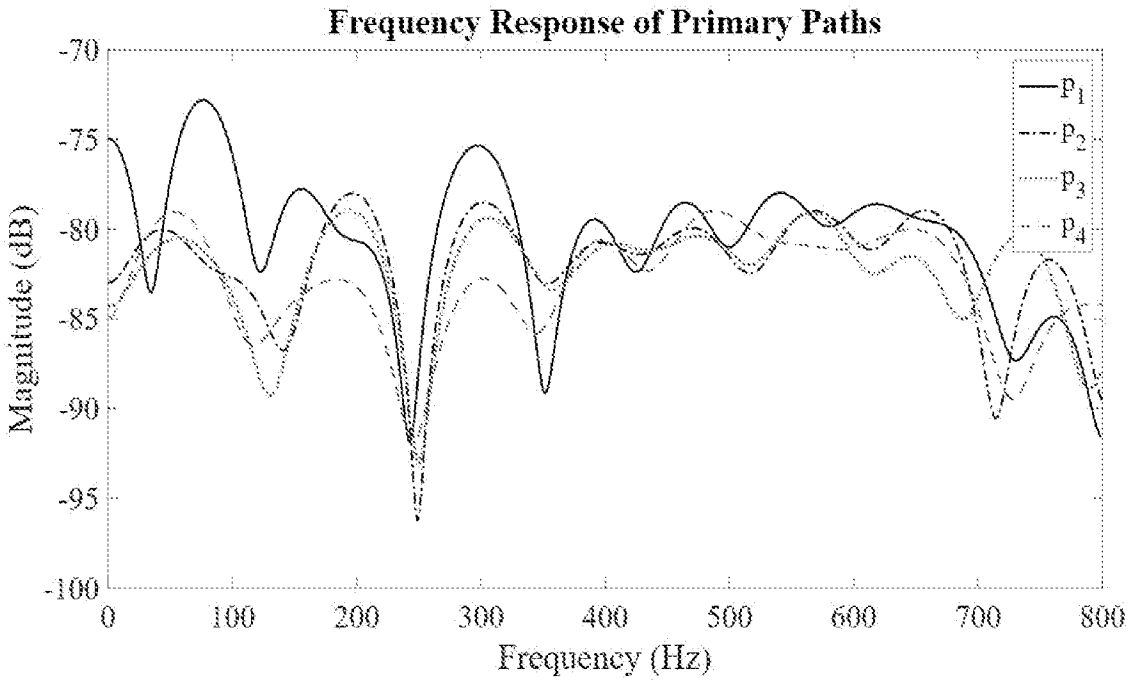

Frequency Response of Primary Paths
p_1
p_2
p_3
p_4
Magnitude (dB)
-70
-75
-80
-85
-90
-95
-100
0
100
200
300
400
500
600
700
800
Frequency (Hz)

FIG. 12

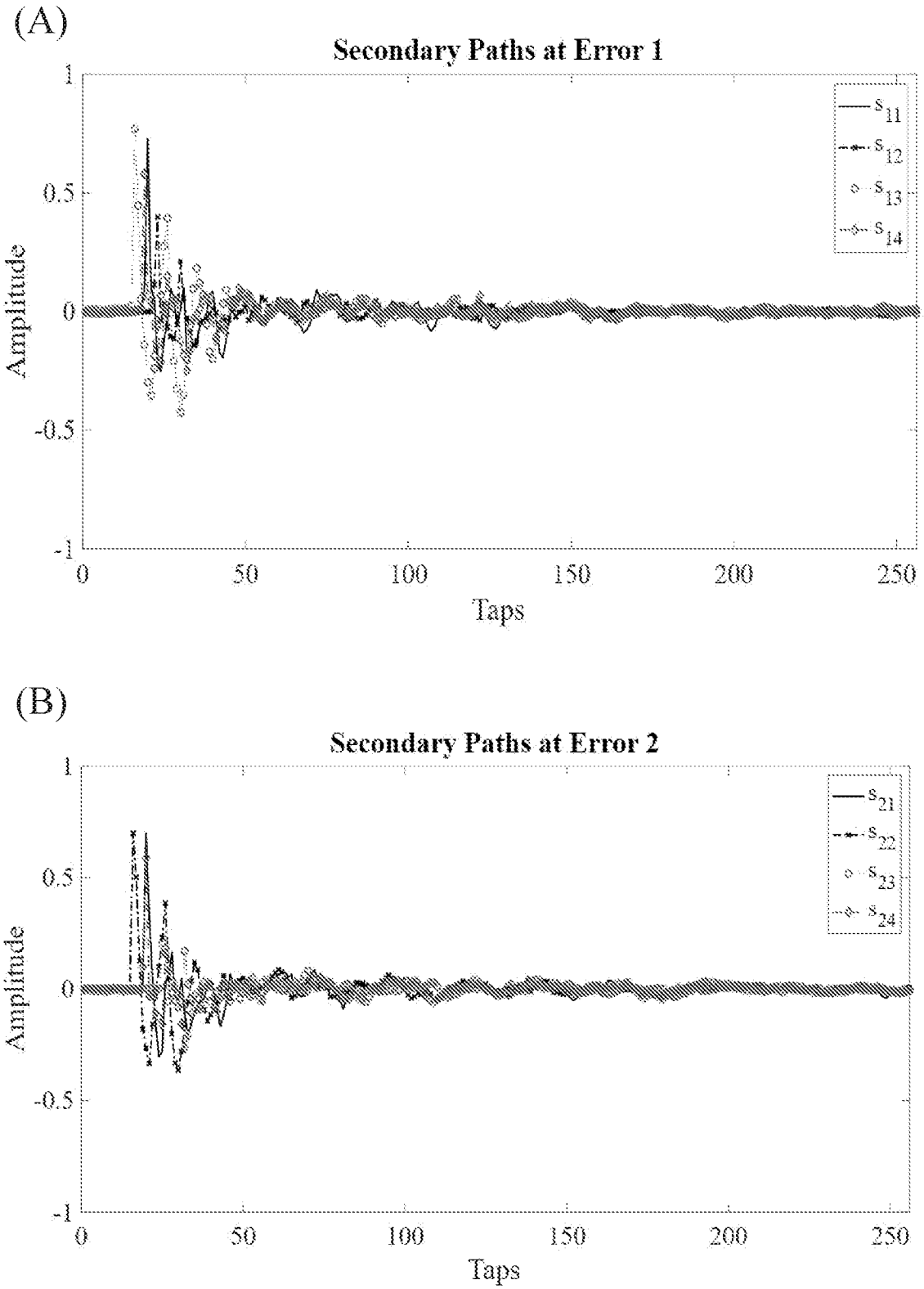
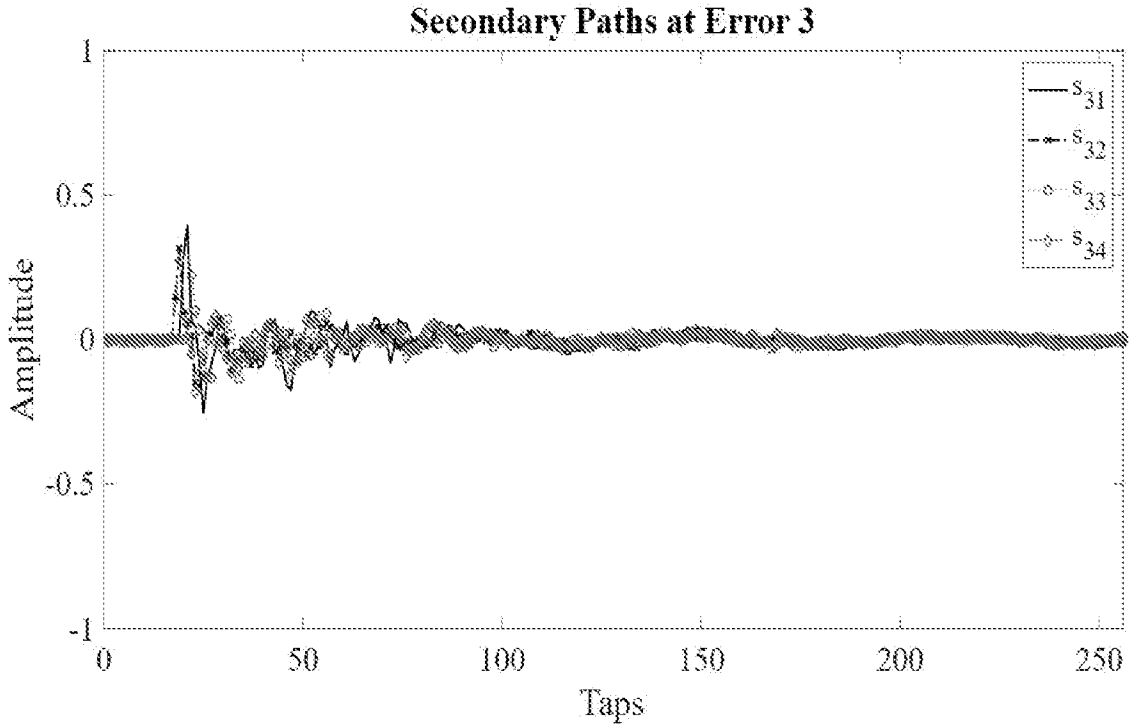

(A)
Secondary Paths at Error 1
Amplitude
Taps
s_{11}
s_{12}
s_{13}
s_{14}
(B)
Secondary Paths at Error 2
Amplitude
Taps
s_{21}
s_{22}
s_{23}
s_{24}

FIG. 13

(C)



(D)

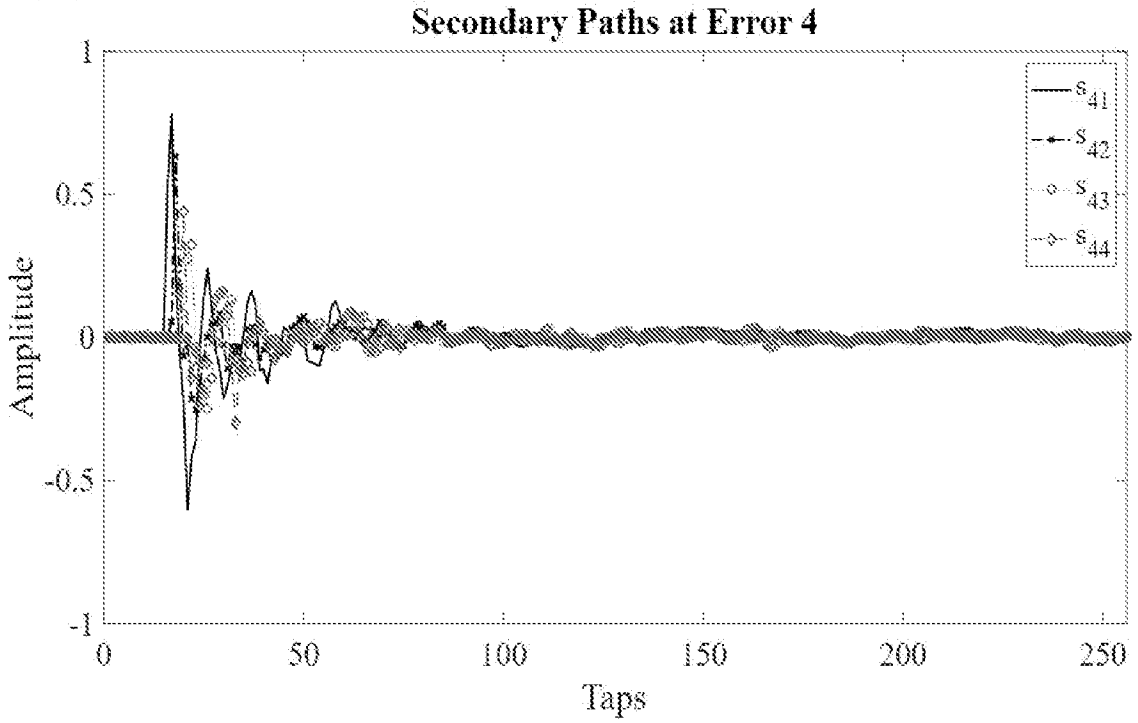
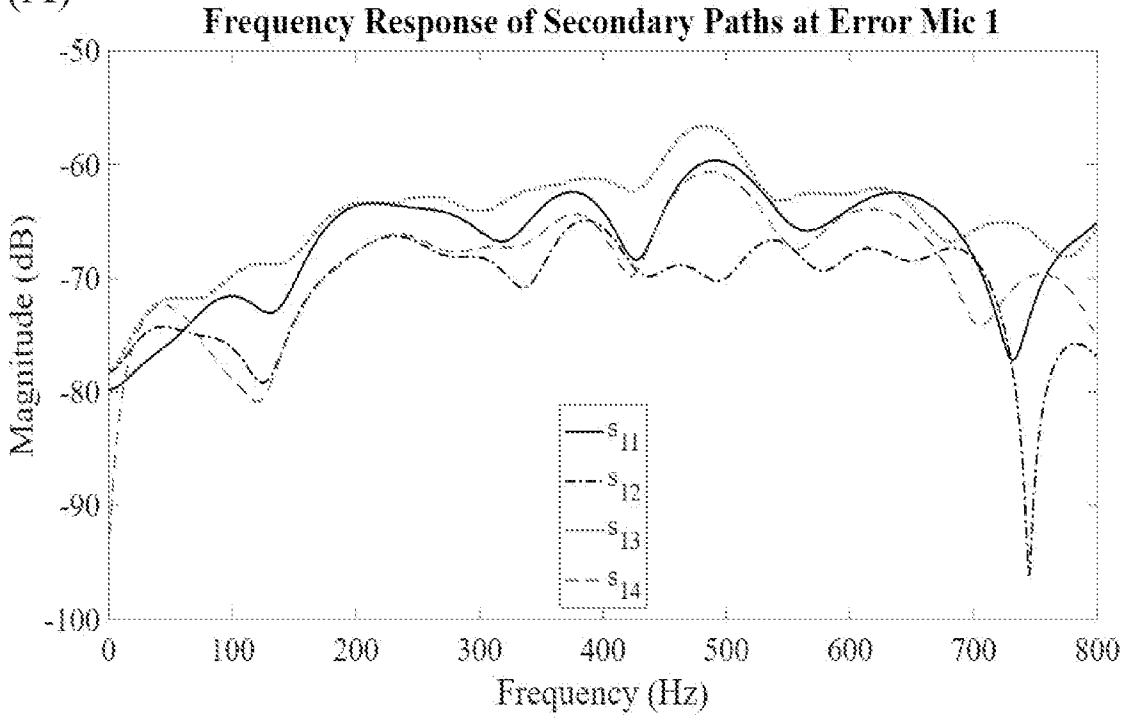


FIG. 13 (continued)

(A)


Frequency Response of Secondary Paths at Error Mic 1
Magnitude (dB)
-50
-60
-70
-80
-90
-100
0
100
200
300
400
500
600
700
800
Frequency (Hz)
s11
s12
s13
s14

(B)

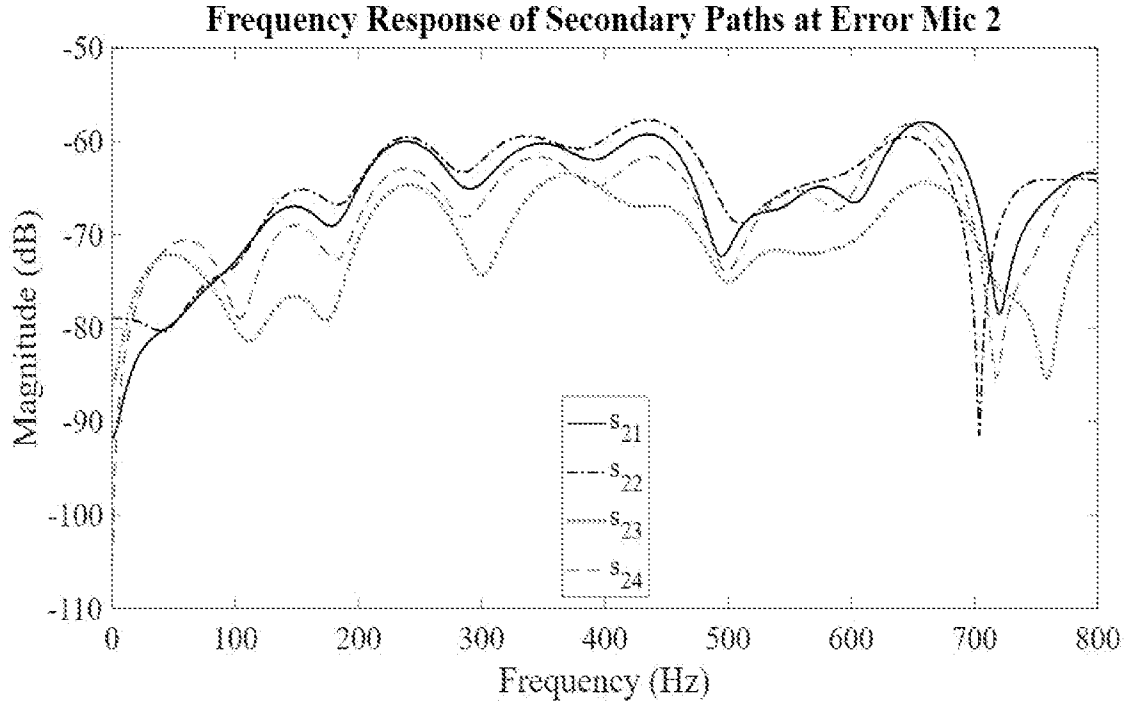
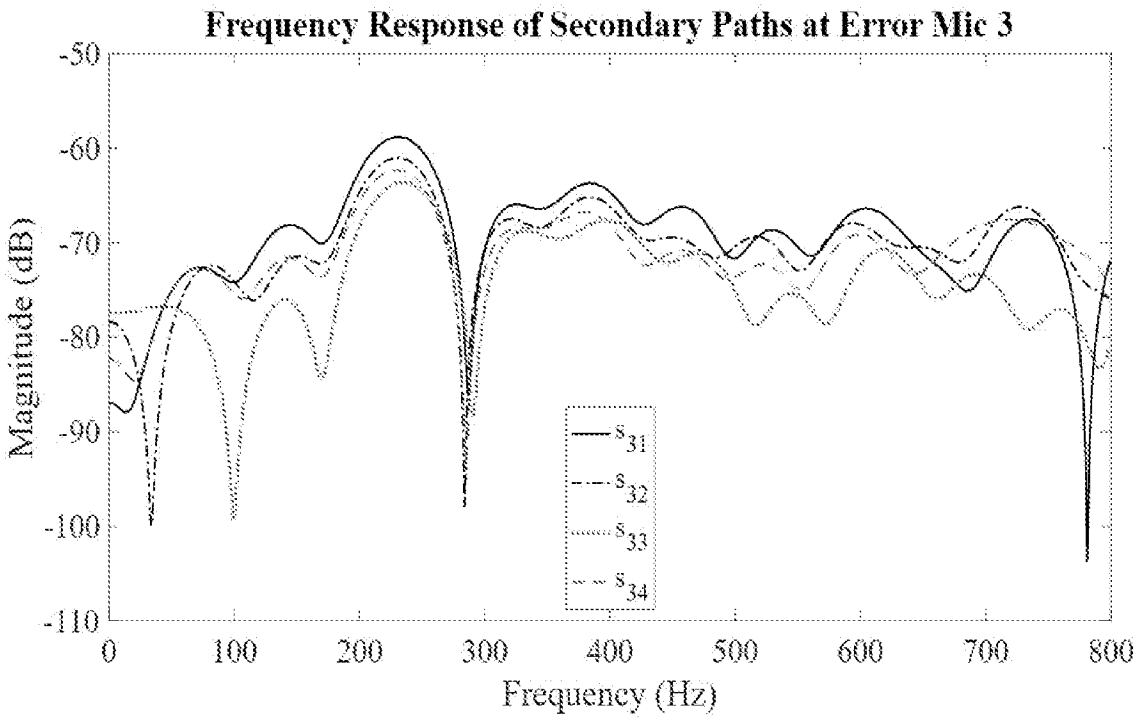

Frequency Response of Secondary Paths at Error Mic 2
Magnitude (dB)
-50
-60
-70
-80
-90
-100
-110
0
100
200
300
400
500
600
700
800
Frequency (Hz)
s21
s22
s23
s24

FIG. 14

(C)



(D)

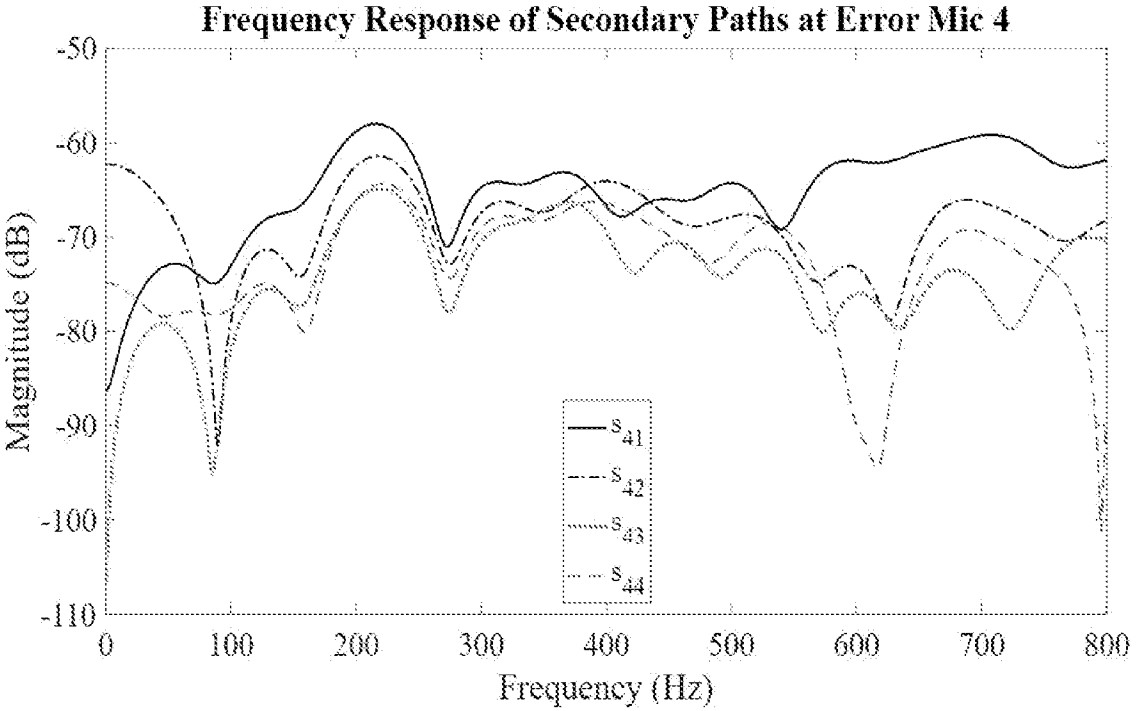
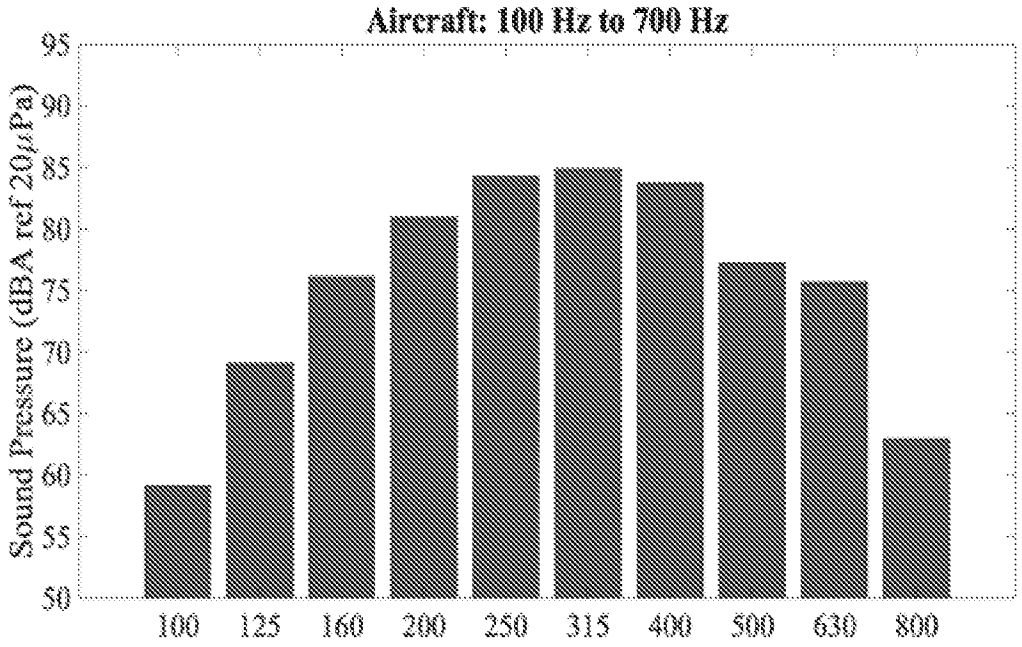


FIG. 14 (continued)

(A)


Aircraft: 100 Hz to 700 Hz
Sound Pressure (dBA ref 20μPa)
95
90
85
80
75
70
65
60
55
50
100
125
160
200
250
315
400
500
630
800

(B)

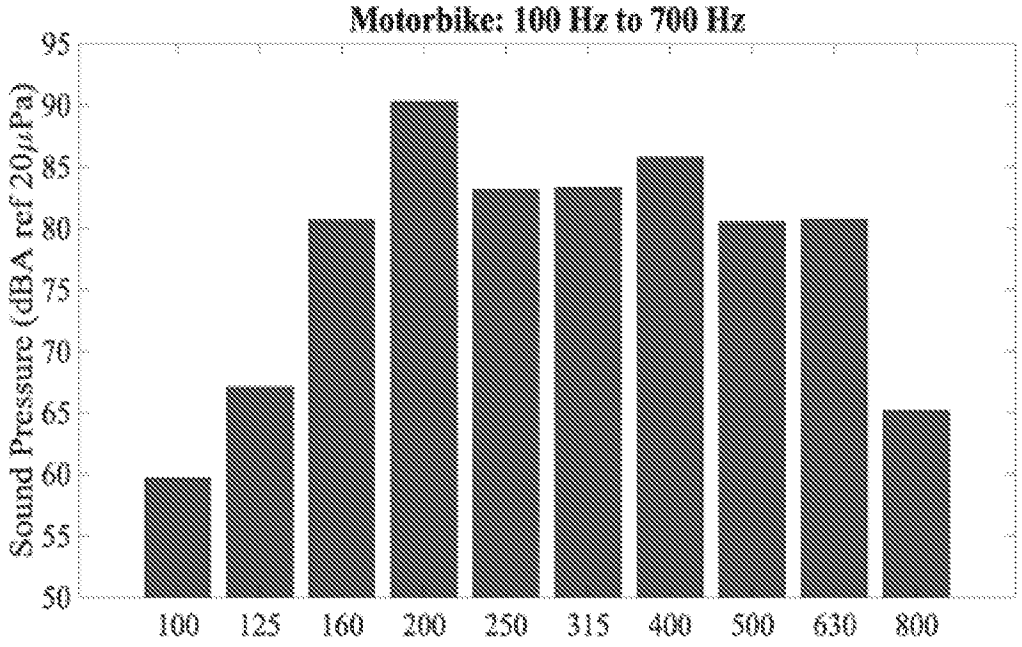
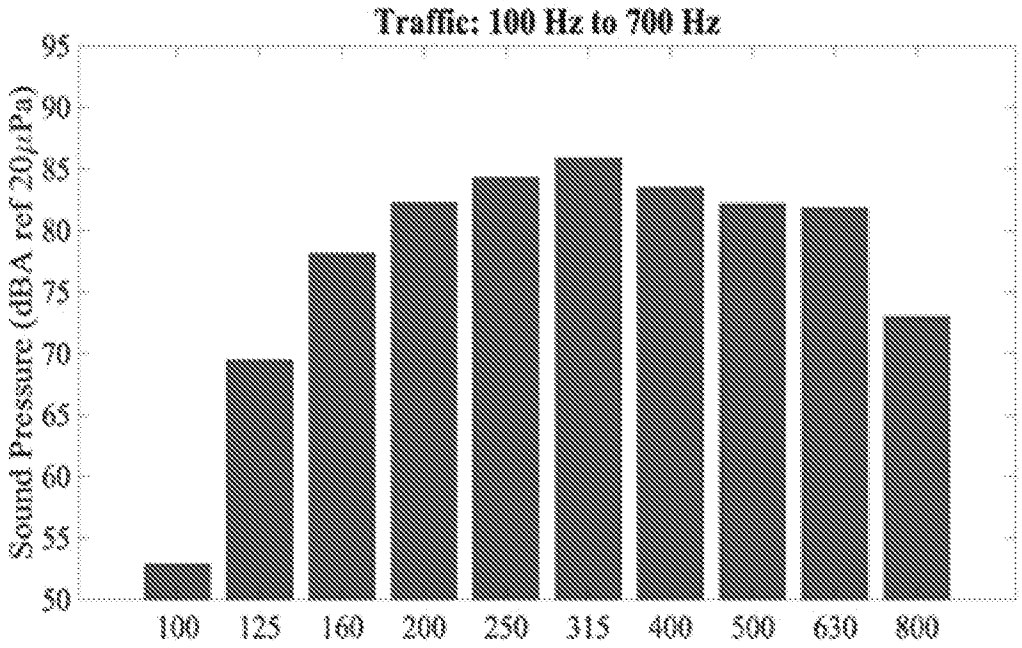

Motorbike: 100 Hz to 700 Hz
Sound Pressure (dBA ref 20μPa)
95
90
85
80
75
70
65
60
55
50
100
125
160
200
250
315
400
500
630
800

FIG. 15

(C)



(D)

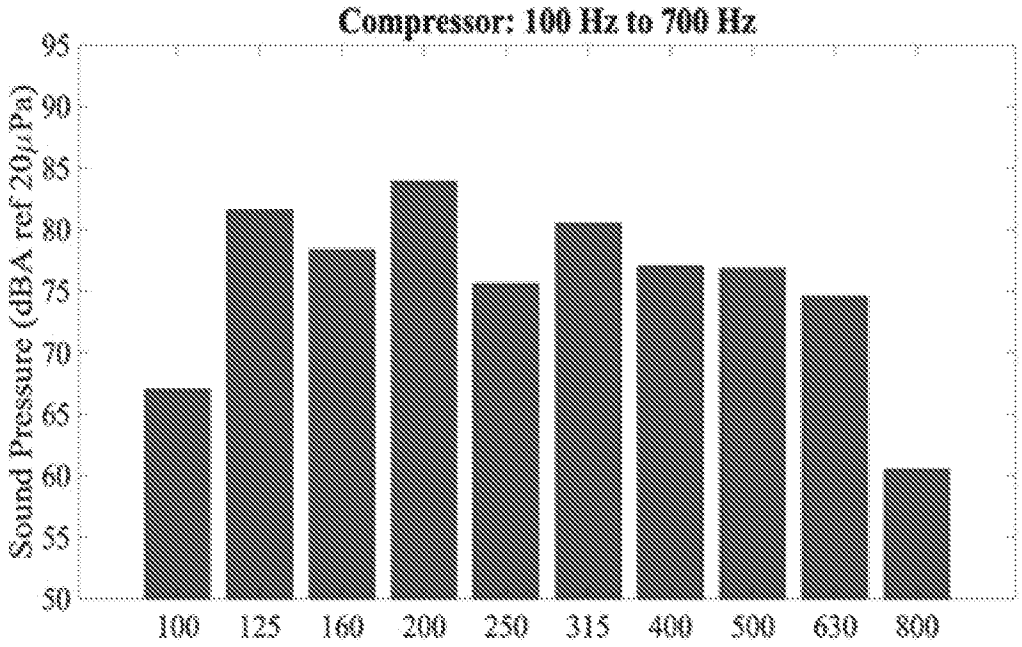
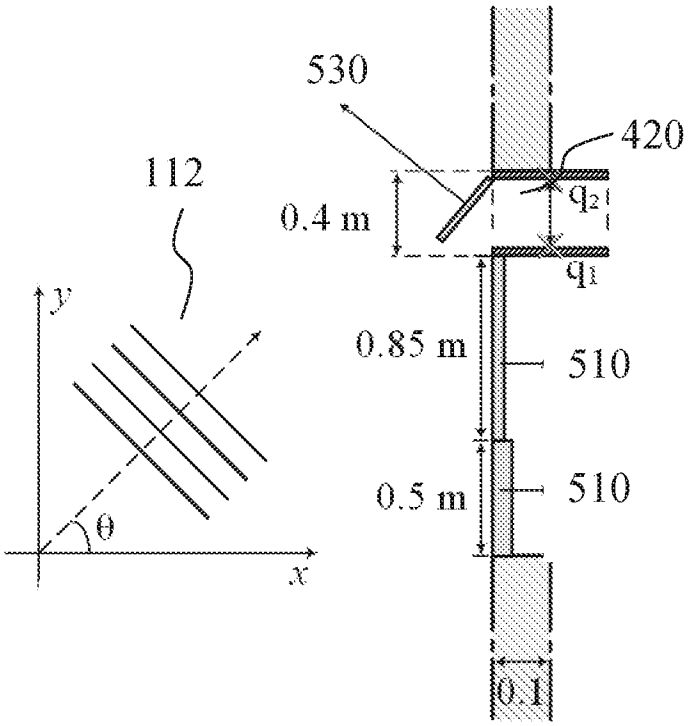


FIG. 15 (continued)

(A)


530
420
112
0.4 m
q_2
q_1
y
0.85 m
510
0.5 m
510
θ
x
0.1

(B)

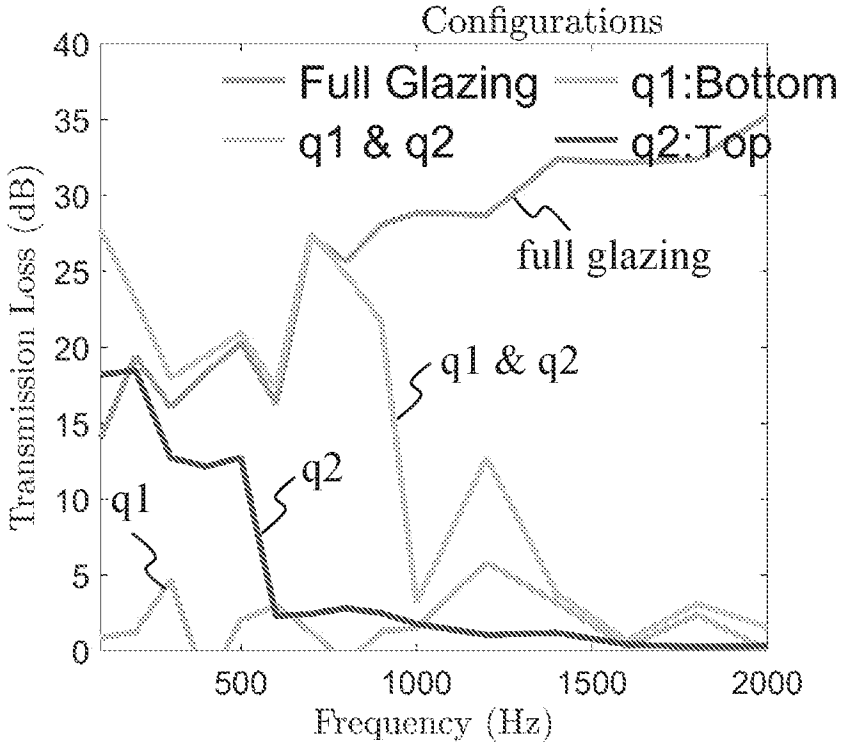
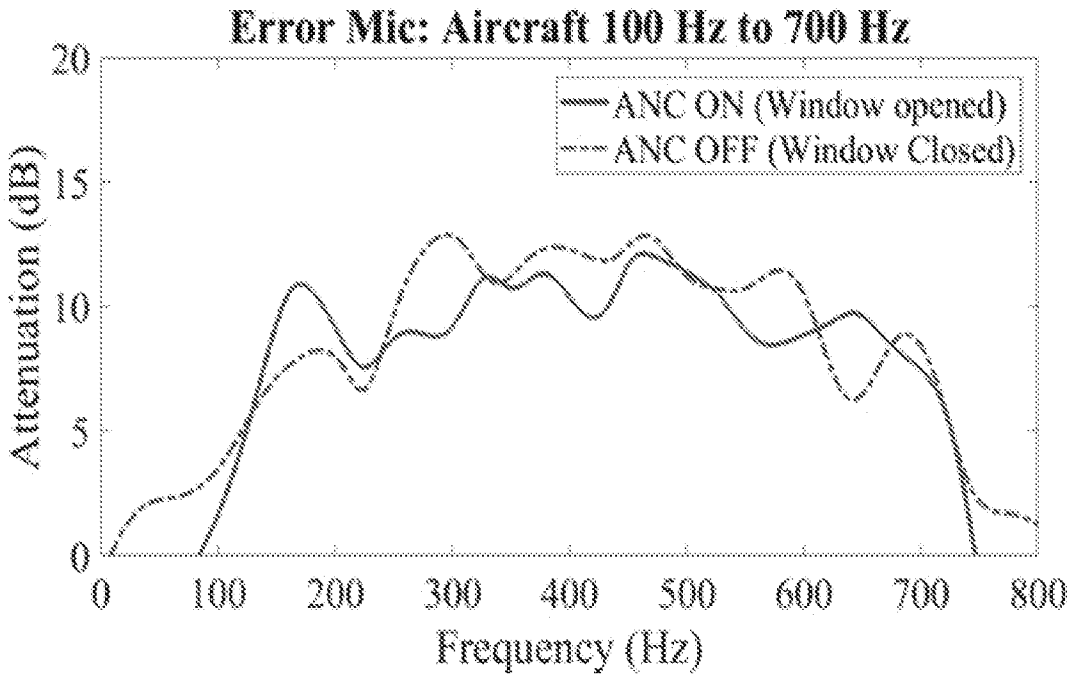

Configurations
Full Glazing
q1:Bottom
q1 & q2
q2:Top
full glazing
q1 & q2
q2
q1
Transmission Loss (dB)
Frequency (Hz)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000

FIG. 16

(A)


Error Mic: Aircraft 100 Hz to 700 Hz
ANC ON (Window opened)
ANC OFF (Window Closed)
Attenuation (dB)
Frequency (Hz)
0
5
10
15
20
0
100
200
300
400
500
600
700
800

(B)

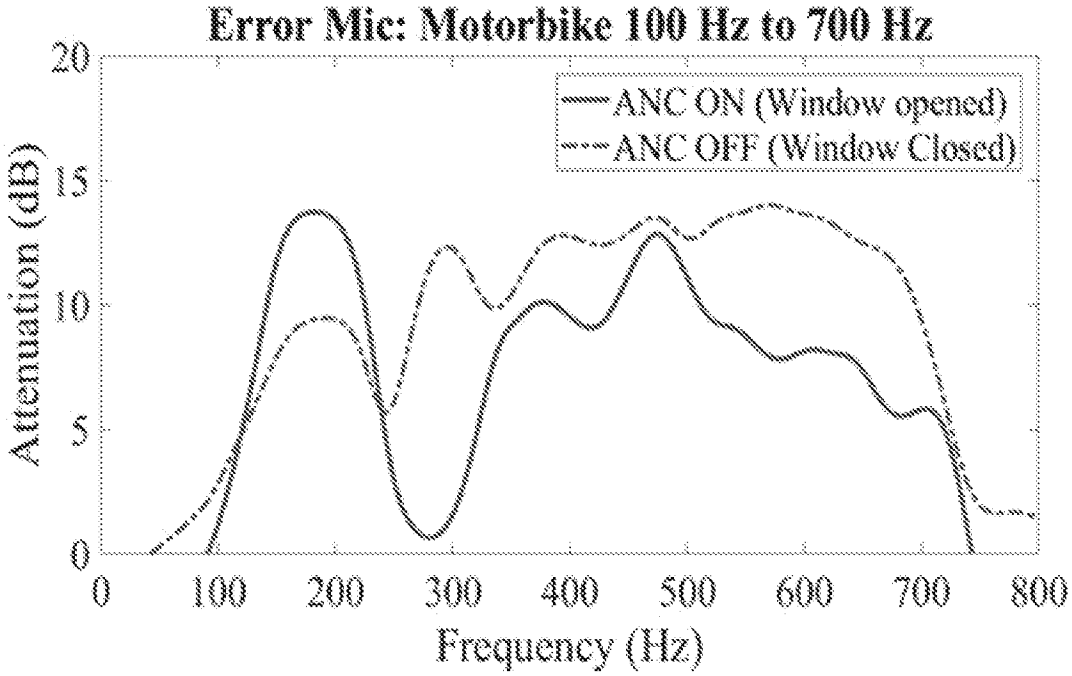
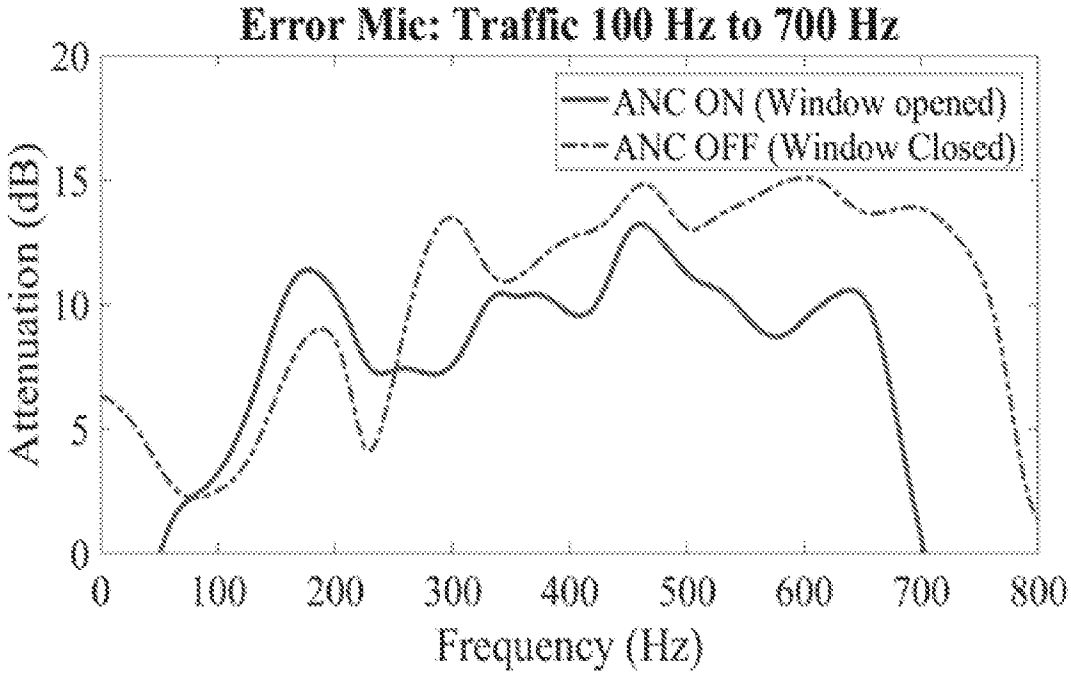

Error Mic: Motorbike 100 Hz to 700 Hz
ANC ON (Window opened)
ANC OFF (Window Closed)
Attenuation (dB)
Frequency (Hz)
0
5
10
15
20
0
100
200
300
400
500
600
700
800

FIG. 17

(C)



(D)

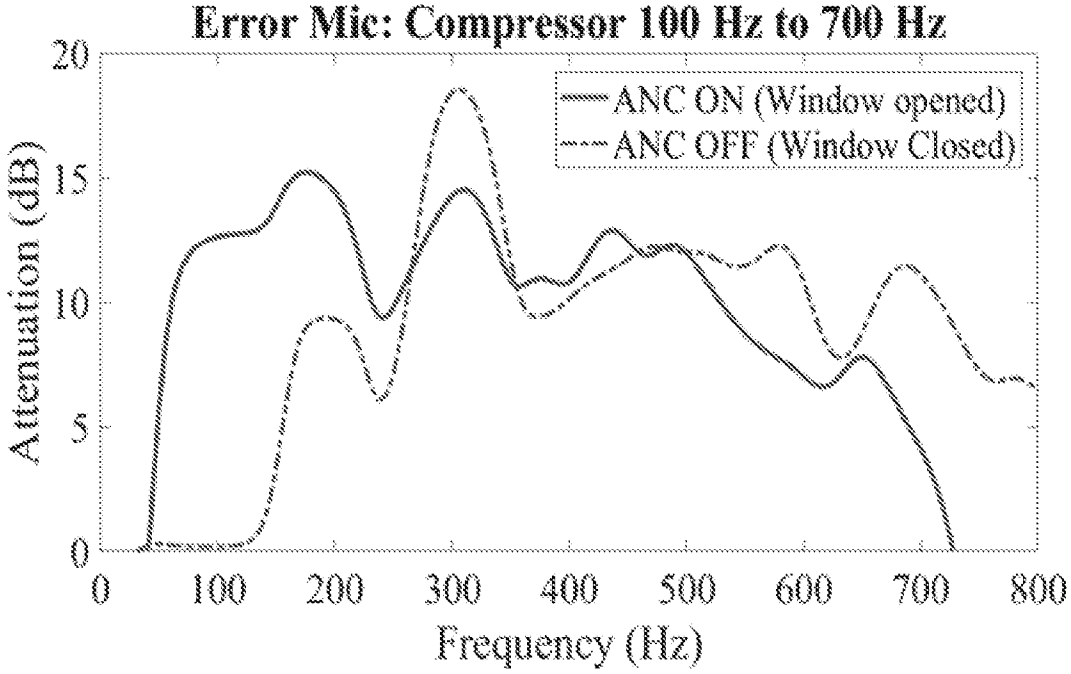
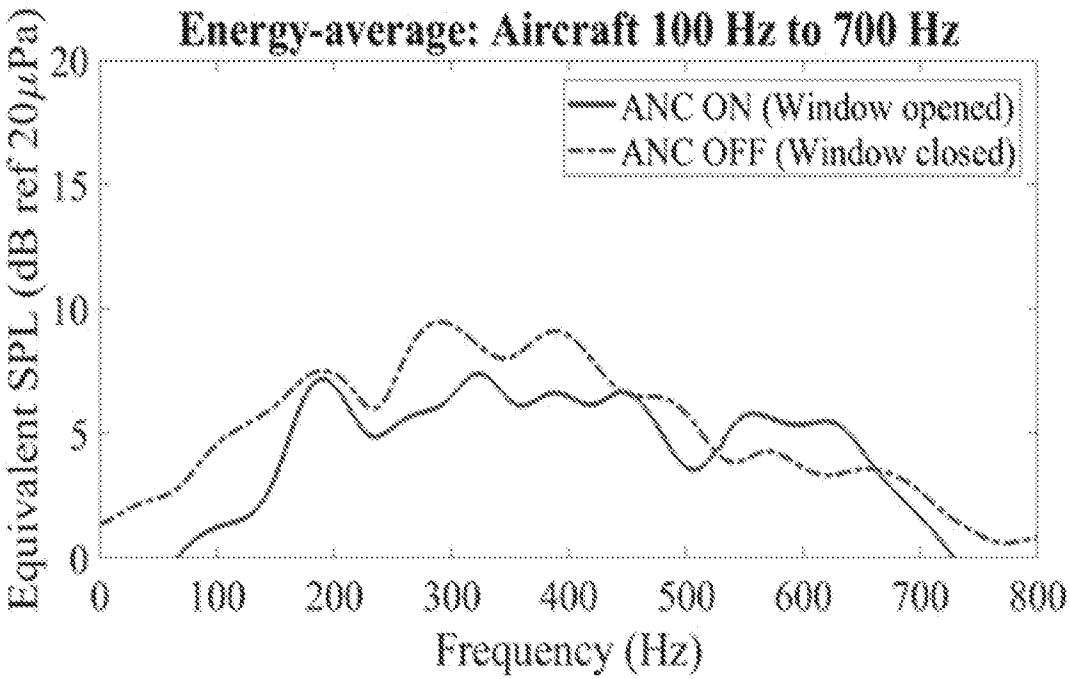


FIG. 17 (continued)

(A)


Energy-average: Aircraft 100 Hz to 700 Hz
ANC ON (Window opened)
ANC OFF (Window closed)
Equivalent SPL (dB ref 20μPa)
0
5
10
15
20
0
100
200
300
400
500
600
700
800
Frequency (Hz)

(B)

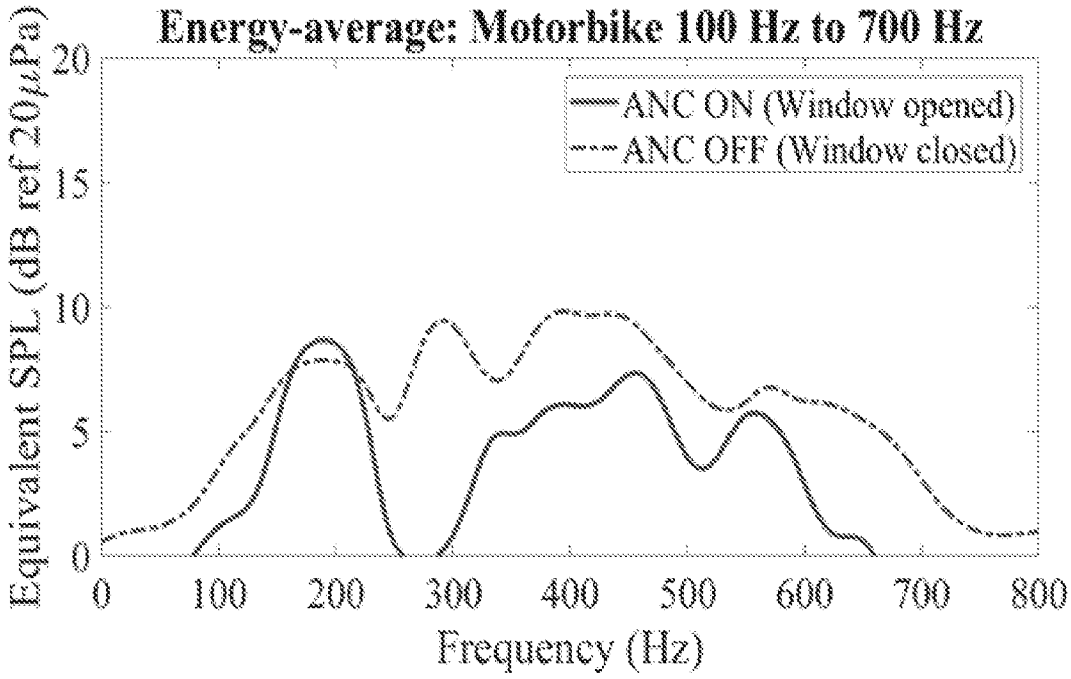
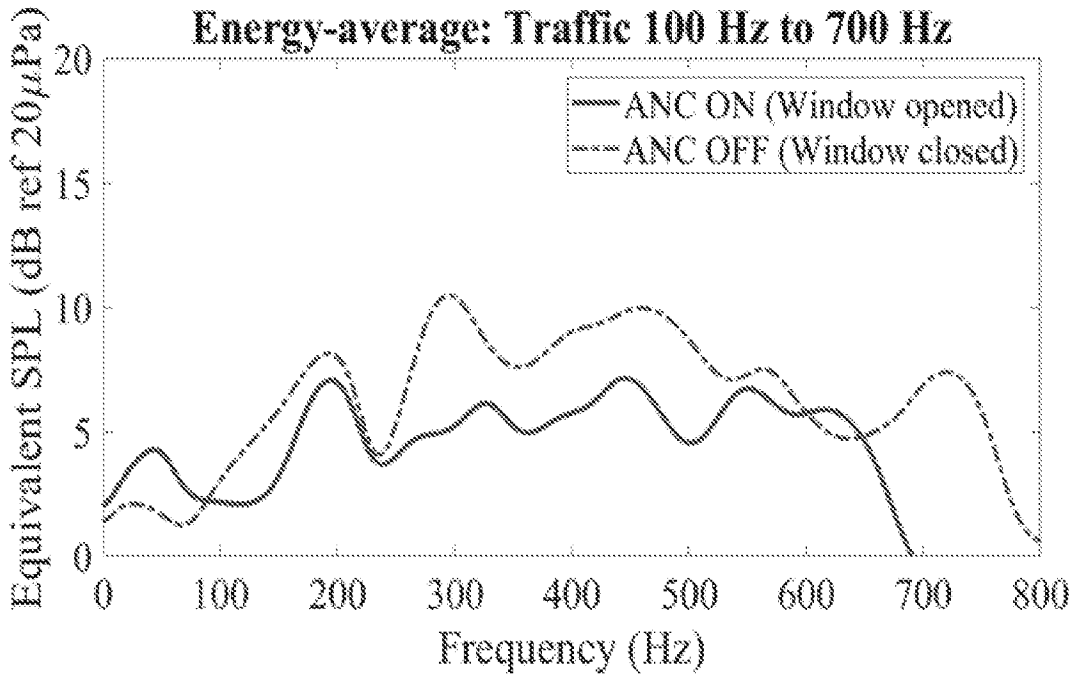

Energy-average: Motorbike 100 Hz to 700 Hz
ANC ON (Window opened)
ANC OFF (Window closed)
Equivalent SPL (dB ref 20μPa)
0
5
10
15
20
0
100
200
300
400
500
600
700
800
Frequency (Hz)

FIG. 18

(C)



(D)

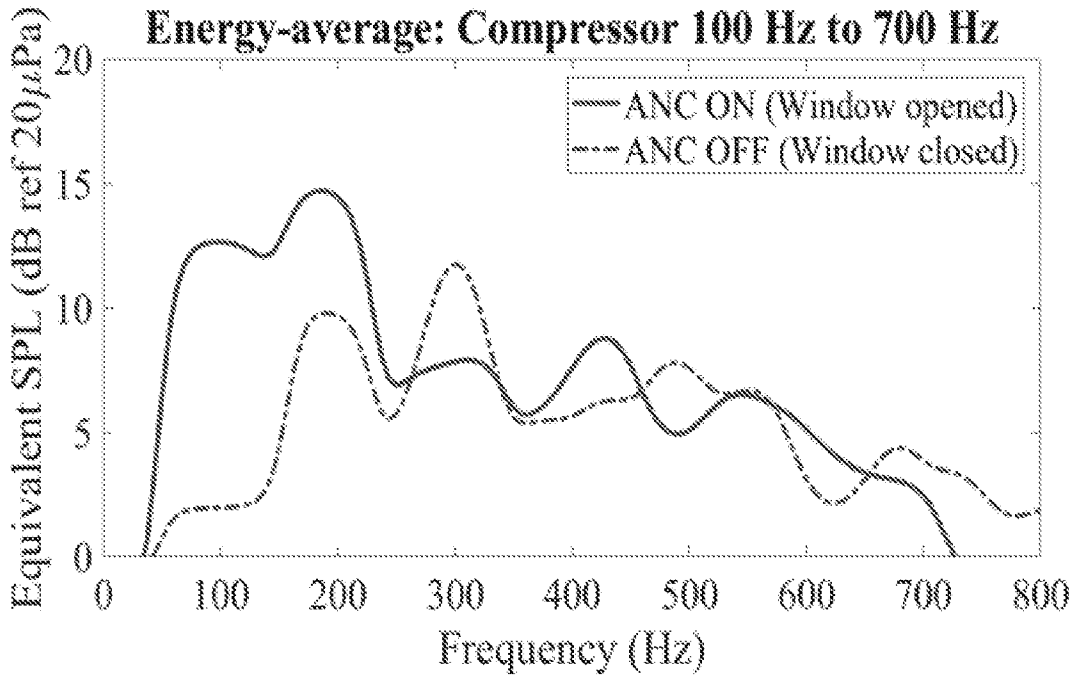


FIG. 18 (continued)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2021/050549

A. CLASSIFICATION OF SUBJECT MATTER

G10K 11/178 (2006.01) *G10K 11/16 (2006.01)* *G10L 21/0208 (2013.01)*

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G10K; G10L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

FAMPAT, IEEE, CNKI: reduce, eliminate, cancel, prevent, noise, sound, sensor, detector, acoustic, select, match, map, choose, filter, anti-noise, produce, generate, emit, anti-phase, 减少, 降低, 取消, 阻止,噪音, 声音, 传感器, 检测器, 声学, 选择, 选取, 映射, 过滤器, 防噪音, 抗噪, 产生, 发出, 发射, 反相 and other related terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/0170764 A1 (SHRIDHAR V. ET AL.) 5 July 2012 Fig. 1; Paras. [0022]-[0027], [0039], [0042]	1-34
X	US 2010/0124337 A1 (WERTZ D. ET AL.) 20 May 2010 Figs. 1-2; Paras. [0007]-[0013], [0026]-[0039]	1-34
X	US 2016/0171966 A1 (MOLINARI L. ET AL.) 16 June 2016 Paras. [0018]-[0064]	1-34

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18/11/2021 *(day/month/year)*	*21/11/2021* *(day/month/year)*

Name and mailing address of the ISA/SG

Intellectual Property Office of Singapore
1 Paya Lebar Link, #11-03
PLQ 1, Paya Lebar Quarter
Singapore 408533

Email: pct@ipos.gov.sg

Authorized officer

Hong Lei (Dr)

IPOS Customer Service Tel. No.: (+65) 6339 8616

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2021/050549

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/0207585 A1 (CHRISTOPH M.) 22 September 2005 Paras. [0014]-[0016], [0050]-[0076]	1-34
A	US 2018/0040315 A1 (KWATRA N. ET AL.) 8 February 2018 The whole document, especially Paras. [0013], [0018]	
A	US 2020/0160827 A1 (ZAFEIROPOULOS N.) 21 May 2020 The whole document, especially Para. [0015]	
A	US 10593317 B1 (BASTYR K. J. ET AL.) 17 March 2020 The whole document, especially Col. 2 lines 36-48	
A	CN 107948789 A (BEIJING SABINETEK) 20 April 2018 The whole document of the original non-English language document (a machine translation is enclosed **only** for your reference)	

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG2021/050549

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012/0170764 A1	05/07/2012	US 2012/0170763 A1	05/07/2012
		JP 2010120633 A	03/06/2010
		CN 101740023 A	16/06/2010
		JP 2015028639 A	12/02/2015
		EP 2189974 A2	26/05/2010
		US 2010/0124336 A1	20/05/2010
		JP 2012212161 A	01/11/2012
US 2010/0124337 A1	20/05/2010	JP 2013210679 A	10/10/2013
		EP 2239729 A2	13/10/2010
		JP 2010244053 A	28/10/2010
		CN 101877808 A	03/11/2010
US 2016/0171966 A1	16/06/2016	NONE	
US 2005/0207585 A1	22/09/2005	EP 1577879 A1	21/09/2005
		AT 402468 T	15/08/2008
US 2018/0040315 A1	08/02/2018	JP 2014517351 A	17/07/2014
		EP 2715720 A2	09/04/2014
		CN 103597541 A	19/02/2014
		WO 2012/166507 A2	06/12/2012
		US 2012/0308028 A1	06/12/2012
		KR 20140039002 A	31/03/2014
US 2020/0160827 A1	21/05/2020	KR 20200035399 A	03/04/2020
		CN 110998712 A	10/04/2020
		EP 3662464 A1	10/06/2020
		WO 2019/024985 A1	07/02/2019
US 10593317 B1	17/03/2020	CN 111354331 A	30/06/2020
		KR 20200077397 A	30/06/2020
		EP 3678129 A1	08/07/2020
CN 107948789 A	20/04/2018	NONE	