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(54) SOUND INDUCTION EAR SPEAKER FOR EYE GLASSES

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(60) Provisional application No. 61/839,227, filed on Jun. 25, 2013, provisional application No. 61/780,108, filed on Mar. 13, 2013, provisional application No. 61/839,211, filed on Jun. 25, 2013, provisional application No. 61/912,844, filed on Dec. 6, 2013.

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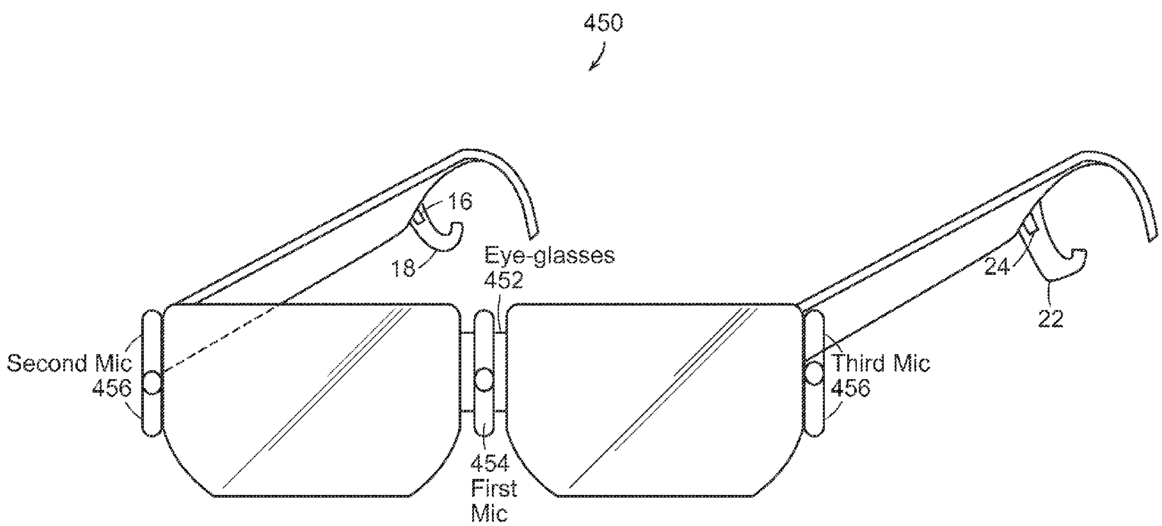
*H04R 1/02* (2006.01)

(52) **U.S. Cl.**
CPC .................................... ***H04R 1/028*** (2013.01)
USPC ........................................................ **381/381**

(57) **ABSTRACT**

An eyewear sound induction ear speaker device includes an eyewear frame, at least one speaker including an audio channel integrated with the eyewear frame and an acoustic duct coupled to the speaker and arranged to channel sound emitted by the speaker to an ear of the user wearing the eyewear frame. A method of providing sound for eyewear includes receiving an audio signal at a speaker integrated with an eyewear frame, inducing the speaker to produce an acoustic sound, and channeling the sound through an acoustic duct to be presented to a user wearing the eyewear frame. The eyewear can include microphones and at least one of a receiver and a transmitter that are integral to the eyewear frame and electronically linked to the at least one speaker. The microphones can be employed in noise cancellation.



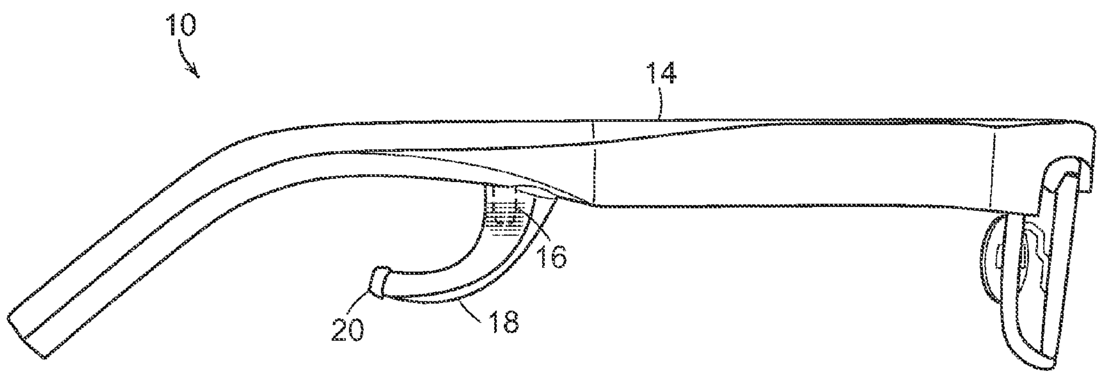



FIG. 1A

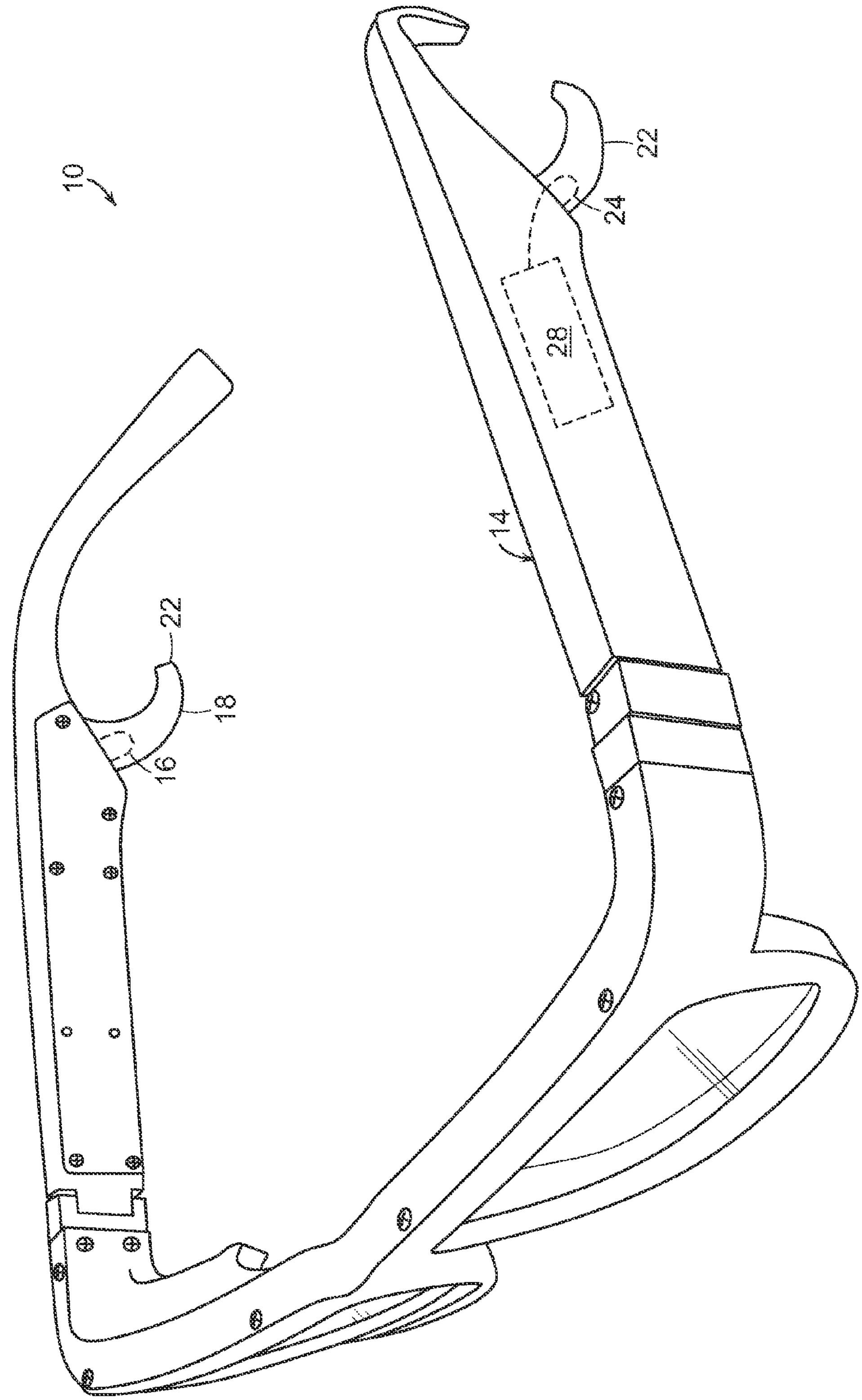



FIG. 1B

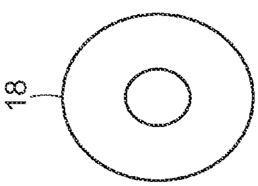



FIG. 1C

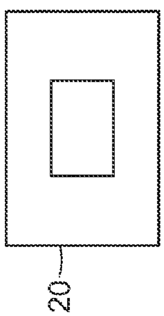



FIG. 2

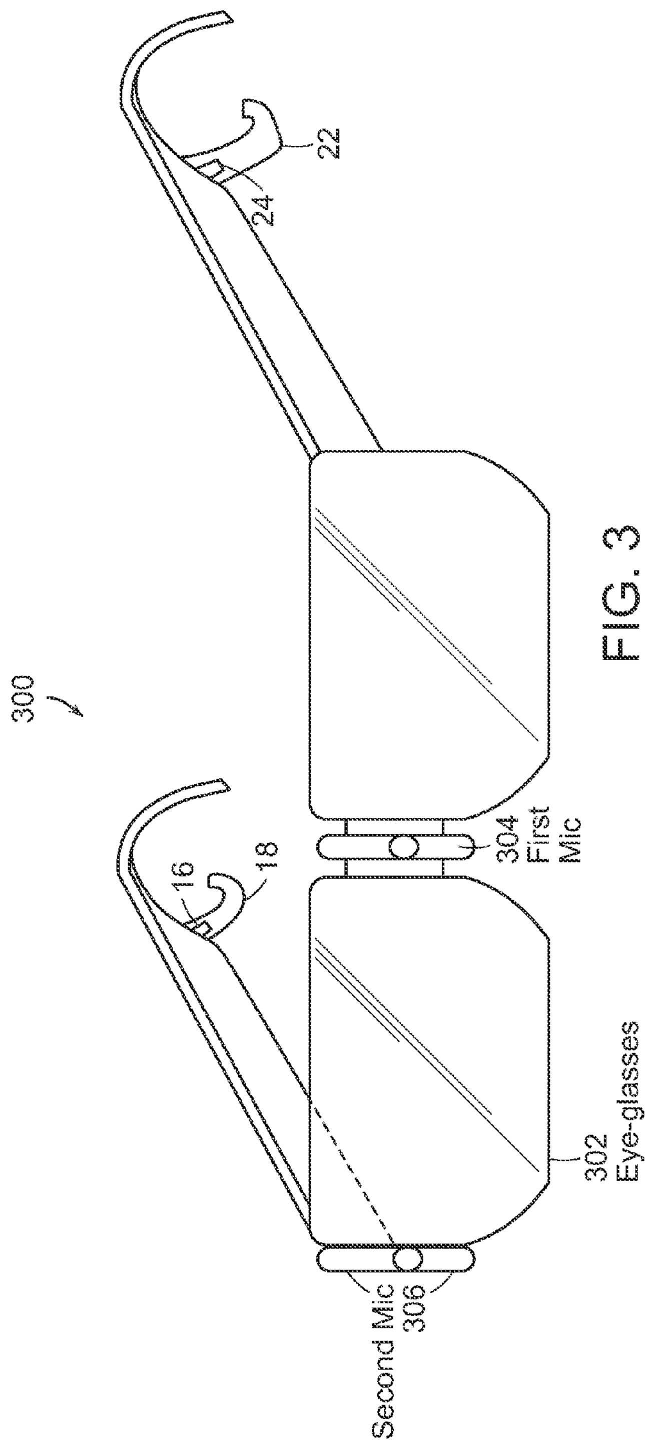



FIG. 3

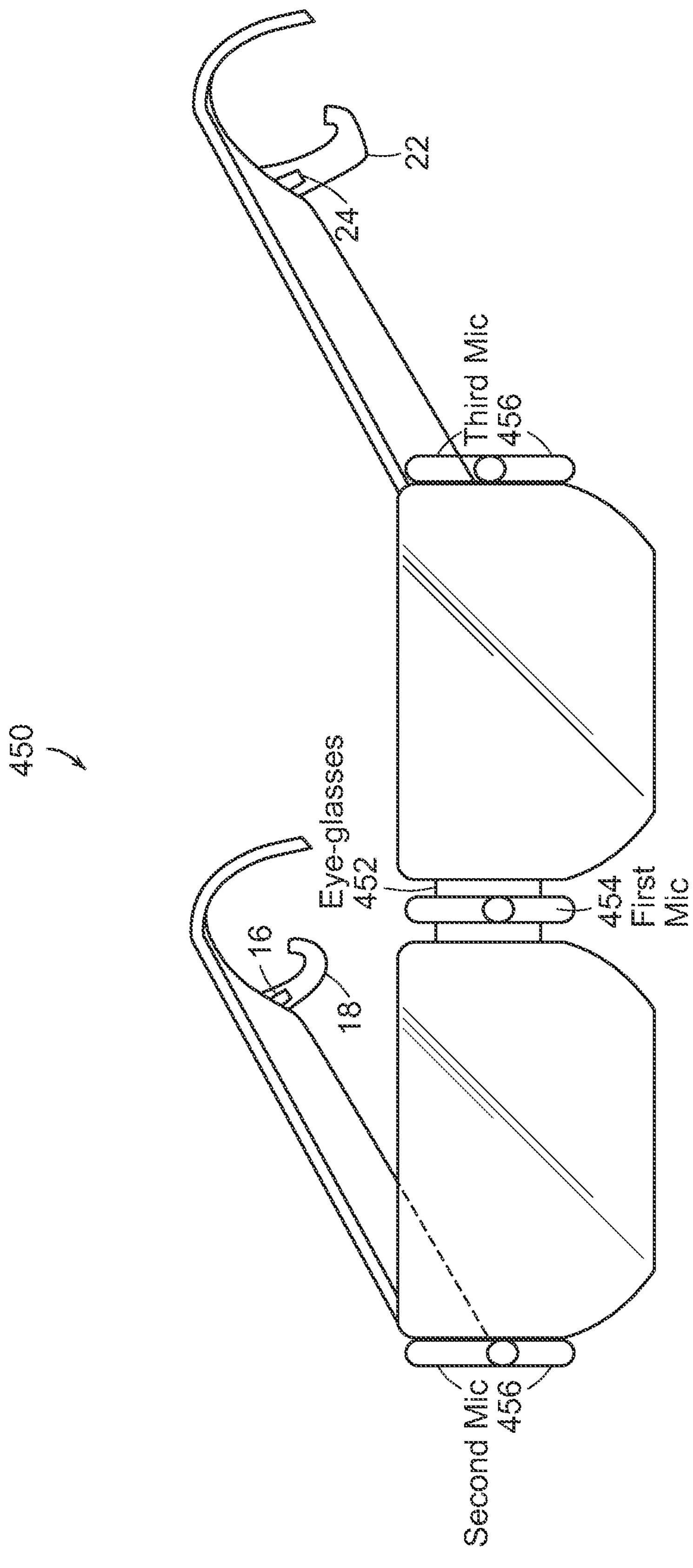

450
22
24
Third Mic
456
Eye-glasses
452
454
First Mic
16
18
Second Mic
456

FIG. 4

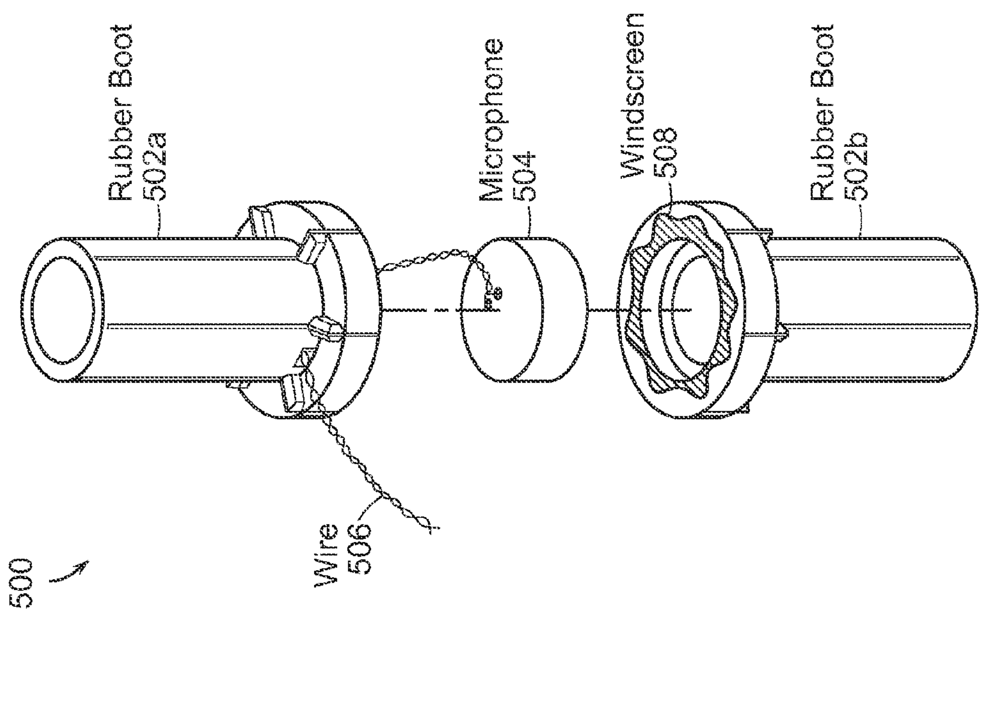

500
Rubber Boot
502a
Wire
506
Microphone
504
Windscreen
508
Rubber Boot
502b

FIG. 5A

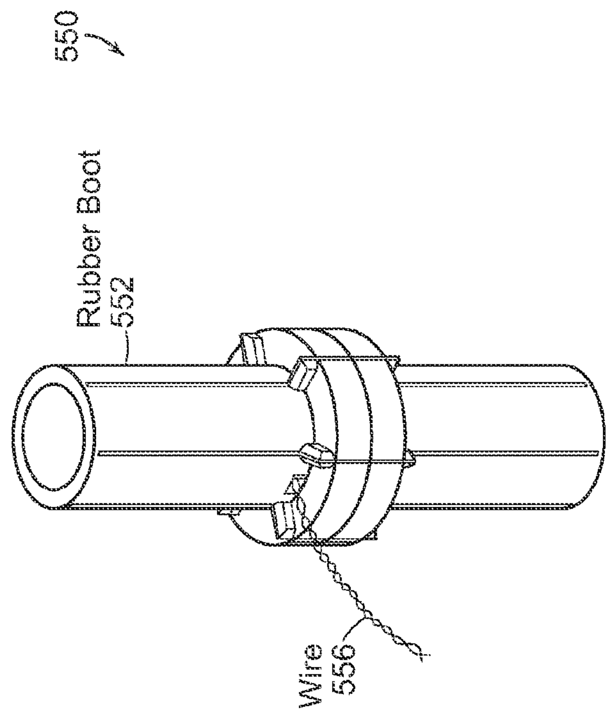

550
Rubber Boot
552
Wire
556

FIG. 5B

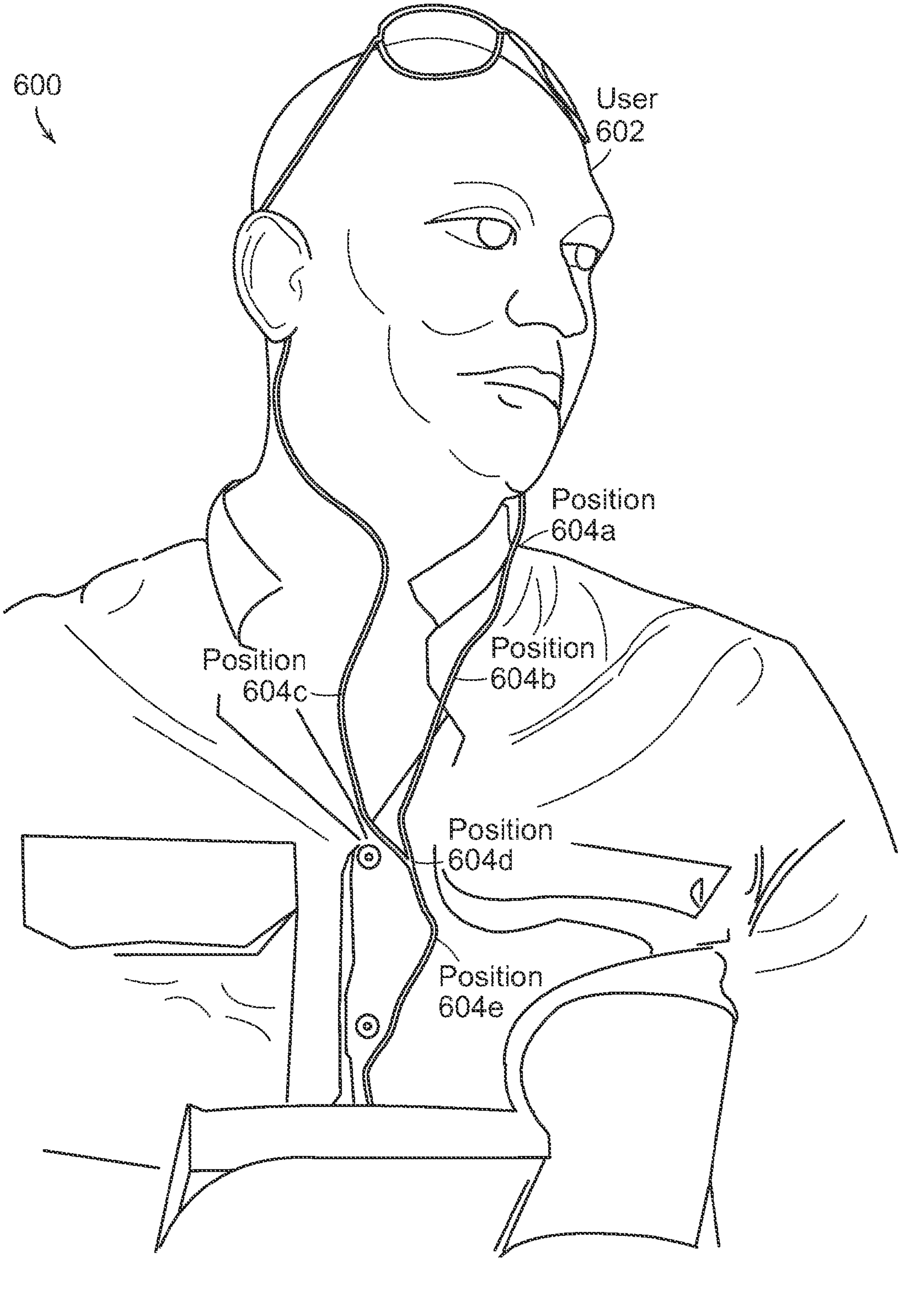

600
User
602
Position
604a
Position
604b
Position
604c
Position
604d
Position
604e

FIG. 6

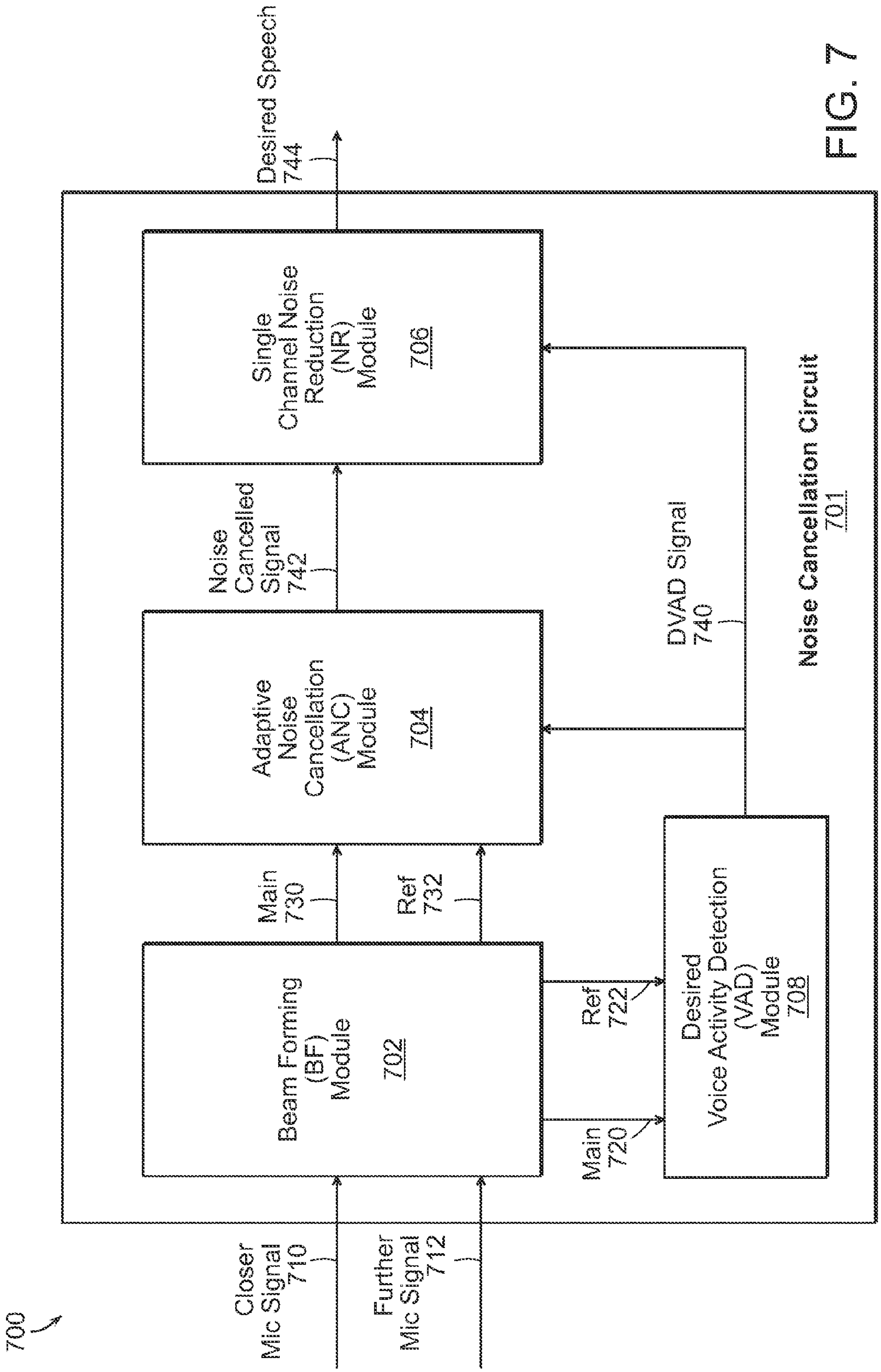

700
Closer Mic Signal 710
Further Mic Signal 712
Beam Forming (BF) Module 702
Main 720
Ref 722
Desired Voice Activity Detection (VAD) Module 708
Main 730
Ref 732
Adaptive Noise Cancellation (ANC) Module 704
DVAD Signal 740
Noise Cancelled Signal 742
Single Channel Noise Reduction (NR) Module 706
Desired Speech 744
Noise Cancellation Circuit 701

FIG. 7

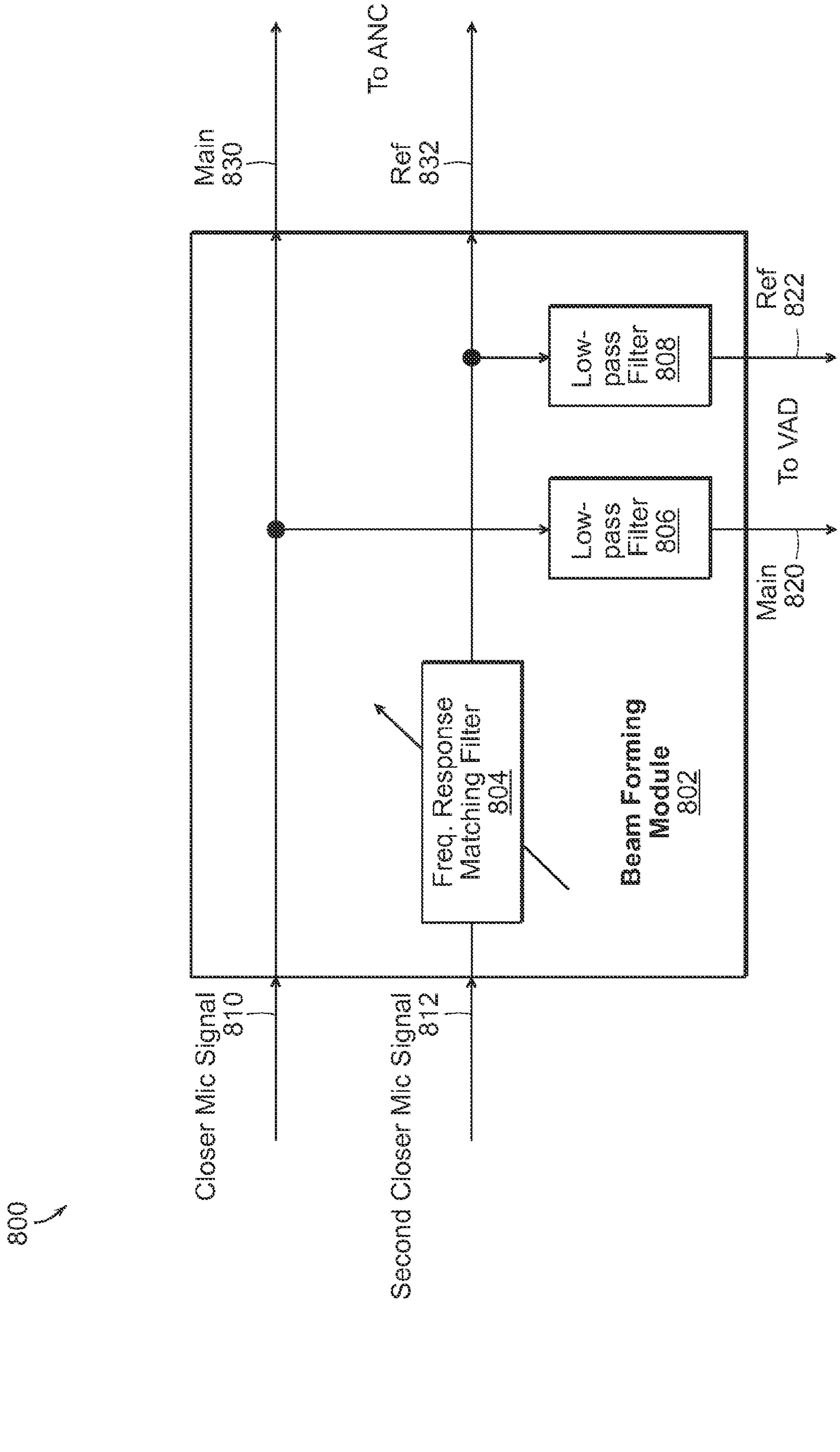

800
Closer Mic Signal
810
Second Closer Mic Signal
812
Freq. Response
Matching Filter
804
Beam Forming
Module
802
Low-
pass
Filter
806
Low-
pass
Filter
808
Main
820
Ref
822
To VAD
Main
830
Ref
832
To ANC

FIG. 8

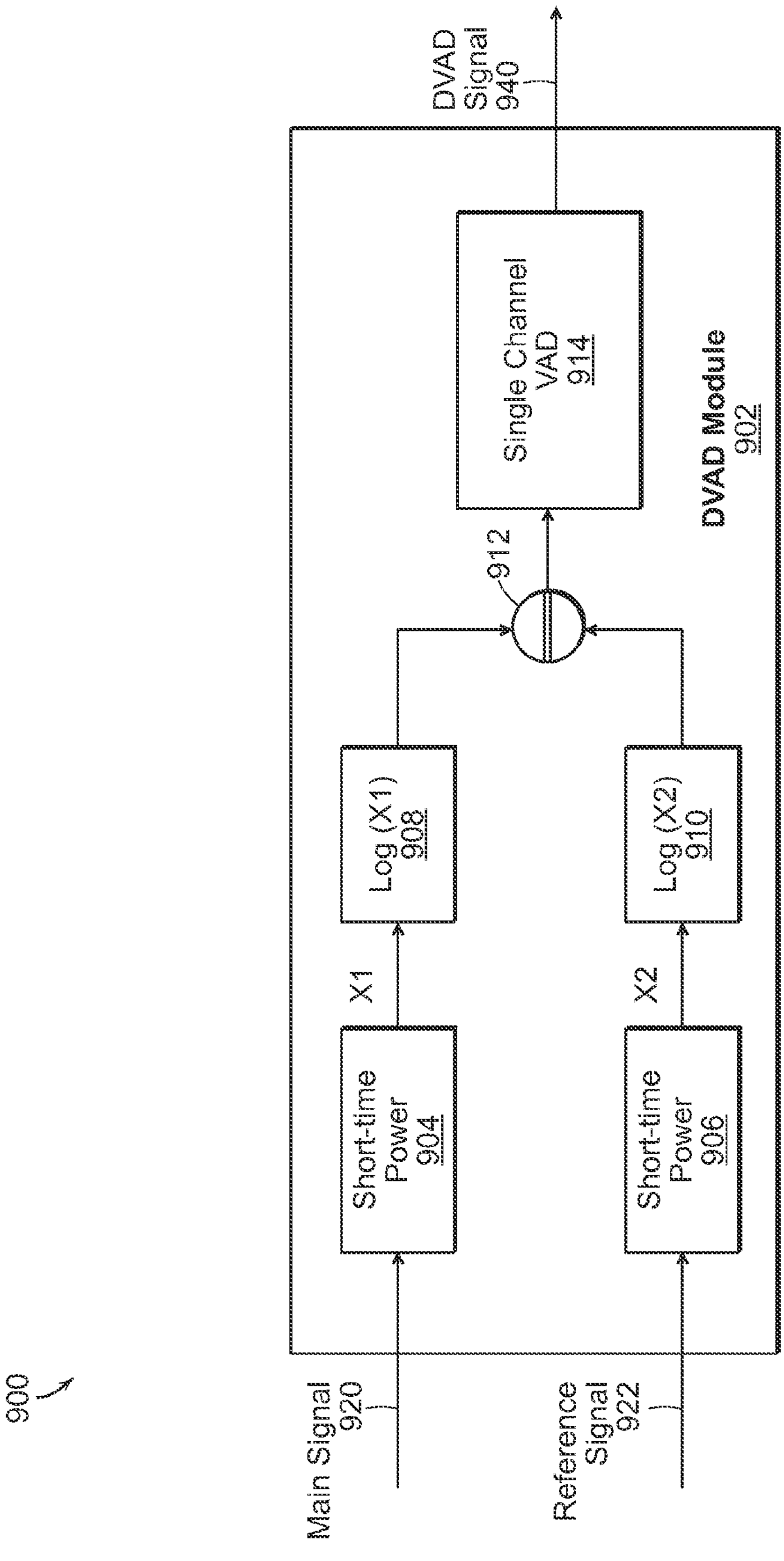

900
Main Signal
920
Reference
Signal
922
Short-time
Power
904
Short-time
Power
906
X1
X2
Log (X1)
908
Log (X2)
910
912
Single Channel
VAD
914
DVAD Module
902
DVAD
Signal
940

FIG. 9

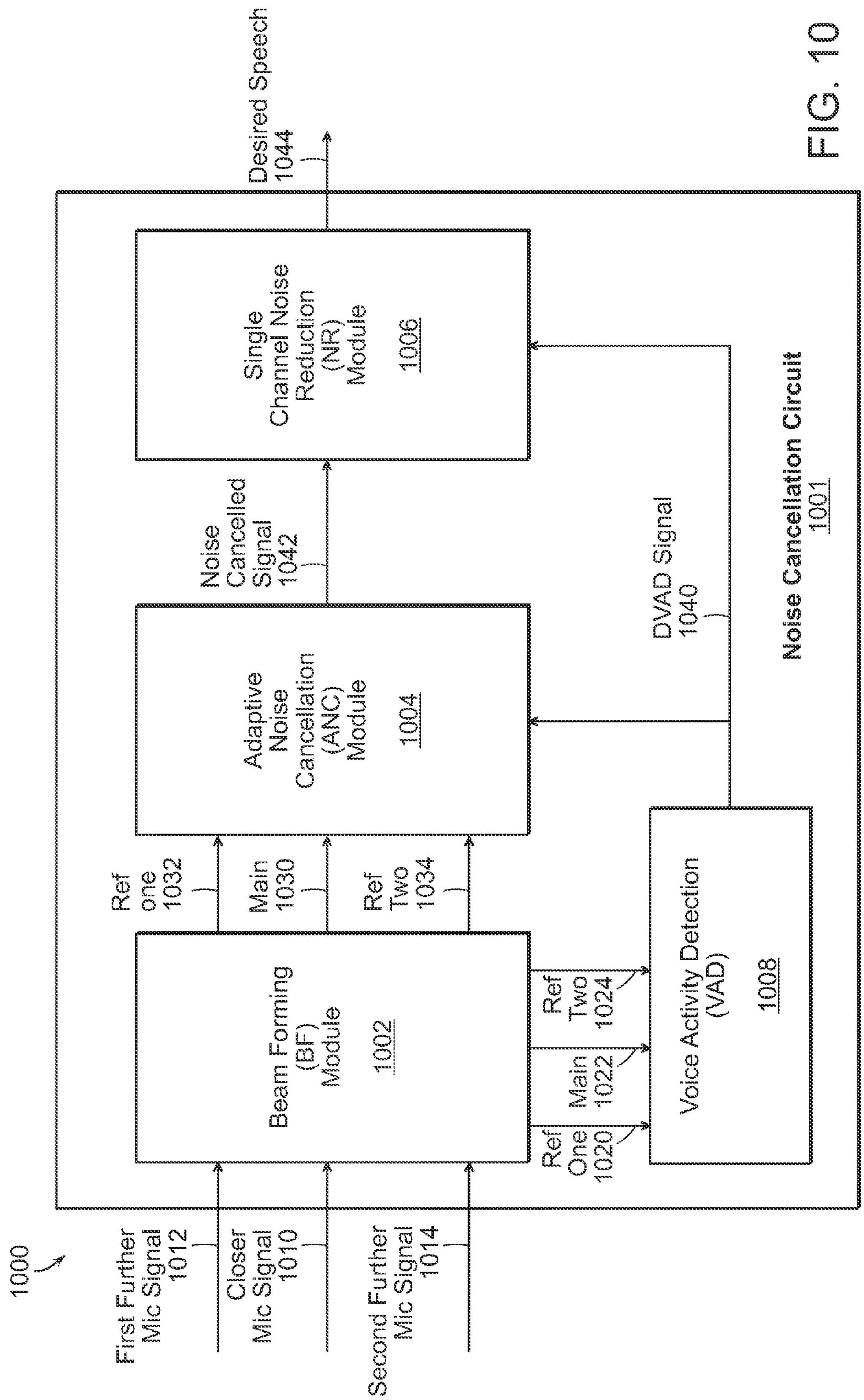

1000
First Further Mic Signal 1012
Closer Mic Signal 1010
Second Further Mic Signal 1014
Beam Forming (BF) Module 1002
Ref One 1020
Main 1022
Ref Two 1024
Voice Activity Detection (VAD) 1008
Ref one 1032
Main 1030
Ref Two 1034
Adaptive Noise Cancellation (ANC) Module 1004
Noise Cancelled Signal 1042
DVAD Signal 1040
Single Channel Noise Reduction (NR) Module 1006
Desired Speech 1044
Noise Cancellation Circuit 1001

FIG. 10

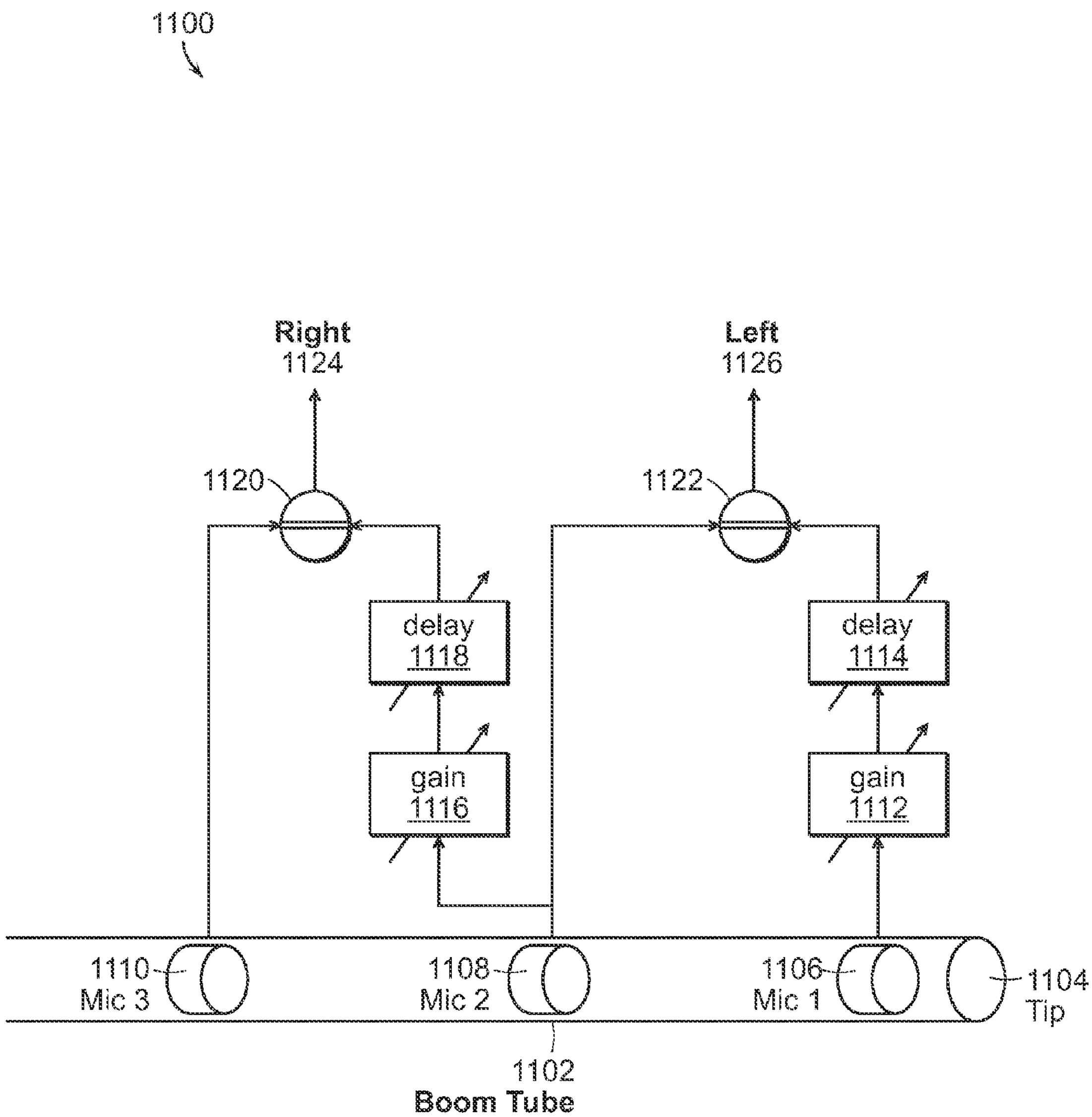

1100
Right
1124
Left
1126
1120
1122
delay
1118
delay
1114
gain
1116
gain
1112
1110
Mic 3
1108
Mic 2
1106
Mic 1
1104
Tip
1102
Boom Tube

FIG. 11

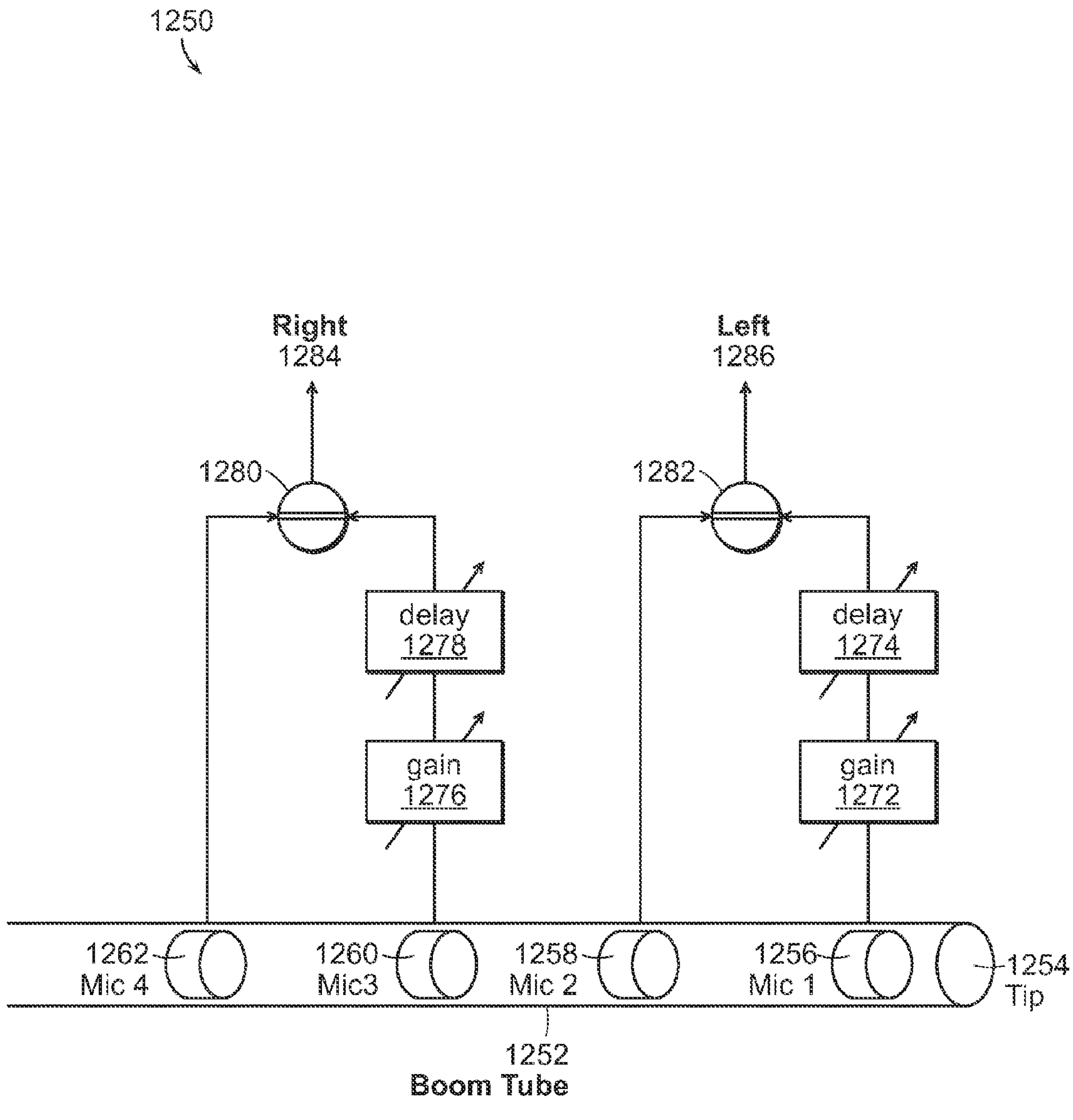

1250
Right
1284
Left
1286
1280
1282
delay
1278
delay
1274
gain
1276
gain
1272
1262
Mic 4
1260
Mic3
1258
Mic 2
1256
Mic 1
1254
Tip
1252
Boom Tube

FIG. 12

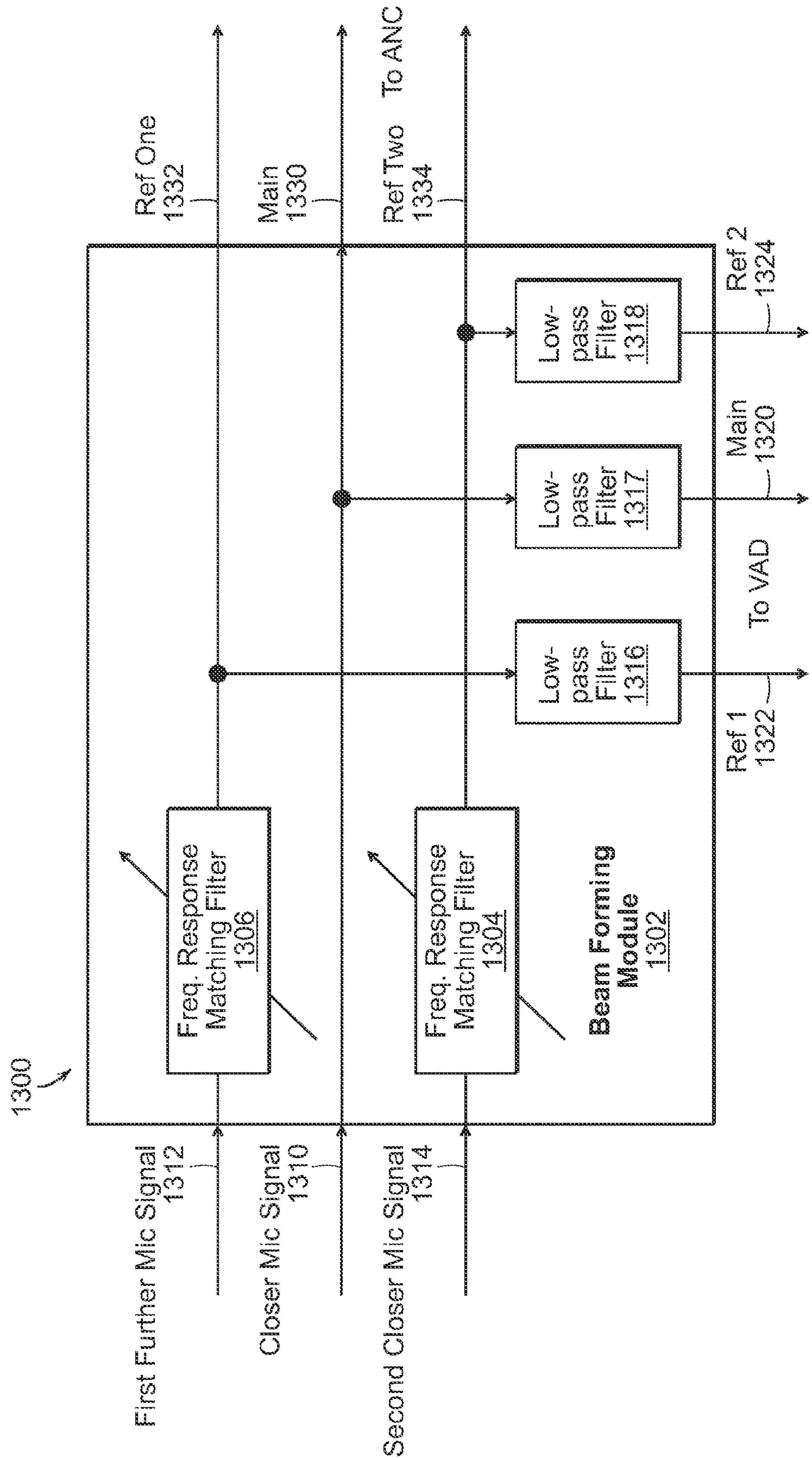

1300
First Further Mic Signal 1312
Closer Mic Signal 1310
Second Closer Mic Signal 1314
Freq. Response Matching Filter 1306
Freq. Response Matching Filter 1304
Beam Forming Module 1302
Low-pass Filter 1316
Low-pass Filter 1317
Low-pass Filter 1318
Ref 1 1322
Main 1320
Ref 2 1324
To VAD
Ref One 1332
Main 1330
Ref Two 1334
To ANC

FIG. 13

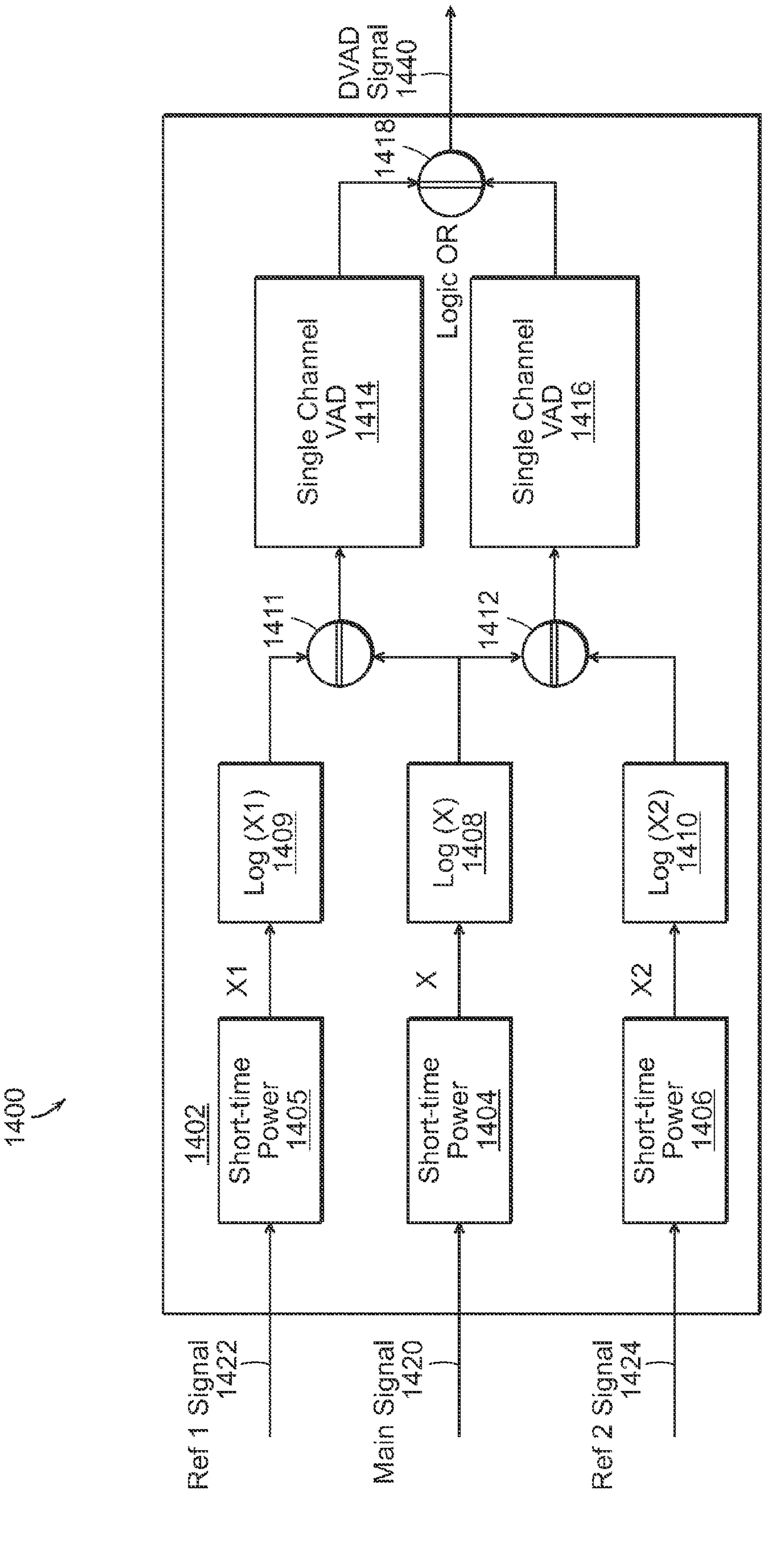

1400
Ref 1 Signal 1422
Main Signal 1420
Ref 2 Signal 1424
1402
Short-time Power 1405
Short-time Power 1404
Short-time Power 1406
X1
X
X2
Log (X1) 1409
Log (X) 1408
Log (X2) 1410
1411
1412
Single Channel VAD 1414
Single Channel VAD 1416
Logic OR
1418
DVAD Signal 1440

FIG. 14

# SOUND INDUCTION EAR SPEAKER FOR EYE GLASSES

## RELATED APPLICATIONS

**[0001]** This application also claims the benefit of U.S. Provisional Application No. 61/839,227, filed on Jun. 25, 2013. This application claims the benefit of U.S. Provisional Application No. 61/780,108, filed on Mar. 13, 2013. This application also claims the benefit of U.S. Provisional Application No. 61/839,211, filed on Jun. 25, 2013. This application also claims the benefit of U.S. Provisional Application No. 61/912,844, filed on Dec. 6, 2013.

**[0002]** This application is being co-filed on the same day, Feb. 14, 2014, with "Eye Glasses With Microphone Array" by Dashen Fan, Attorney Docket No. 0717.2220-001. This application is being co-filed on the same day, Feb. 14, 2014, with "Eyewear Spectacle With Audio Speaker In The Temple" by Kenny W. Y. Chow, et al., Attorney Docket No. 0717.2229-001. This application is being co-filed on the same day, Feb. 14, 2014, with "Noise Cancelling Microphone Apparatus" by Dashen Fan, Attorney Docket No. 0717.2216-001.

**[0003]** The entire teachings of the above applications are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

**[0004]** Traditionally, earphones have been used to present acoustic sounds to an individual when privacy is desired or it is desired not to disturb others. Examples of traditional earphone devices include over-the-head headphones having an ear cup speaker (e.g. Beats® by Dr. Dre headphones), ear bud style earphones (e.g., Apple iPod® earphones and Bluetooth® headsets), bone-conducting speakers (e.g., Google Glass). Another known way to achieve the desired privacy or peace and quiet for others is by using directional multi-speaker beam-forming. Also well-known but not conventionally used to present acoustic sounds to an individual that is not hearing-impaired are hearing aids. An example of which is the open ear mini-Behind-the-Ear (BTE) with Receiver-In-The-Aid (RITA) device. Such a hearing aid typically includes a clear "hook" that acts as an acoustic duct tube to channel audio speaker (also referred to as a receiver in telephony applications) sound to the inner ear of a user and act as the mechanical support so that the user can wear the hearing aid, the speaker being housed in the behind-the-ear portion of the hearing aid body. However, the aforementioned techniques all have drawbacks, namely, they are either bulky, cumbersome, unreliable, or immature.

**[0005]** Therefore, a need exists for earphones that overcome or minimize the above-referenced problem.

## SUMMARY OF THE INVENTION

**[0006]** The present invention related in general to eyewear, and more particularly to eyewear devices and corresponding methods for presenting sound to a user of the eyewear.

**[0007]** In one embodiment, an eyewear sound induction ear speaker device of the invention includes an eyewear frame, a speaker including an audio channel integrated with the eyewear frame, and an acoustic duct coupled to the speaker and arranged to channel sound emitted by the speaker to an ear of the user wearing the eyewear frame.

**[0008]** In another embodiment, the invention is an eyewear sound induction ear speaker device that includes means for receiving an audio sound, means for processing and amplifying the audio sound, and means for channeling the amplified and processed audio sound to an ear of a user wearing an eyewear frame.

**[0009]** In still another embodiment, the invention is a method of providing sound for eyewear, including the steps of receiving a processed electrical audio signal at a speaker integrated with an eyewear frame, wherein the speaker includes an audio channel. The speaker is induced to produce acoustic sound at the audio channel, and the acoustic sound is channeled through an acoustic duct to be presented to a user wearing the eyewear frame.

**[0010]** In yet another embodiment, the invention is a method of channeling sound from eyewear device that includes the steps of receiving an electrical audio signal from electrical audio source at speaker integrated with an eyewear device, inducing audible sound from the electrical audio signal at the speaker, and channeling the audio sound to an ear of the user of the eyewear using the audio duct, the audio duct not blogging the ear canal of the ear.

**[0011]** The present invention has many advantages. For example, the eyewear spectacle of the invention is relatively compact, unobtrusive, and durable. Further, the device and method can be integrated with noise cancellation apparatus and methods that are also, optionally, components of the eyewear itself. In one embodiment, the noise cancellation apparatus, including microphones, electrical circuitry, and software can be integrated with and, optionally, on board the eyewear worn by the user. In another embodiment, microphones mounted on board the eyewear can be integrated with the speakers and with circuitry, such as a computer, receiver or transmitter to thereby process signals received from an external source or the microphones, or to process and transmit signals from the microphone, and to selectively transmit those signals, whether processed or unprocessed, to the user of the eyewear through the speakers mounted in the eyewear. For example, human-machine interaction through the use of a speech recognition user interface is becoming increasingly popular. To facilitate such human-machine interaction, accurate recognition of speech is useful. It is also useful as a machine that can present information to the user through spoken words, for example by reading a text to the user. Such a machine output presentation facilitates hands-free activities of a user, which is increasingly popular. Users also do not have to hold a speaker or device in place, nor do they need to have electronics behind their ear or an ear bud blocking their ear. There are also no flimsy wires, and users do not have to tolerate the skin contact or pressure associated with bone condition speakers.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** FIG. **1**A is a side view of one embodiment of an eyewear sound induction ear speaker device of the invention

**[0013]** FIG. **1**B is a perspective view of the embodiment of the invention shown in FIG. **1**A

**[0014]** FIG. **1**C is a cross-sectional view of one embodiment of an acoustic duct of the embodiment of the invention shown in FIG. **1**A

**[0015]** FIG. **2** is a cross-sectional view of an alternative embodiment of an acoustic duct of the invention

**[0016]** FIG. **3** is an illustration of an embodiment of an eyewear and sound induction ear speaker device of the invention that includes two remote microphones that are electronically linked with the eyewear frame of the eyewear sound induction ear speaker device.

**[0017]** FIG. **4** is an illustration of another embodiment of eyewear of the invention that includes three remote microphones.

**[0018]** FIG. **5**A is an exploded view of a rubber boot and microphone according to one embodiment of the invention.

**[0019]** FIG. **5**B is a perspective view of the assembled rubber boot shown in FIG. **5**A.

**[0020]** FIG. **6** is a representation of another embodiment of the invention showing alternate and optional positions of placements of the microphones.

**[0021]** FIG. **7** is an embodiment of a noise cancellation circuit employed in one embodiment of the eyewear sound induction user speaker device of the invention.

**[0022]** FIG. **8** is an illustration of a beam-forming module suitable for use in the embodiment of the invention illustrated in FIG. **8**.

**[0023]** FIG. **9** is a block diagram illustrating an example embodiment of a desired voice activity detection module employed in another embodiment of the eyewear sound induction ear speaker device of the invention.

**[0024]** FIG. **10** is a block diagram illustrating an example embodiment of a noise cancellation circuit employed in an embodiment of the eyewear sound induction ear speaker device of the invention.

**[0025]** FIG. **11** is an example embodiment of a boom tube housing three microphones, in an arrangement of one embodiment of the eyewear sound induction ear speaker device of the invention.

**[0026]** FIG. **12** is an example embodiment of a boom tube housing four microphones in an arrangement of another embodiment of the eyewear sound induction ear speaker device of the invention.

**[0027]** FIG. **13** is a block diagram illustrating an example embodiment of a beam-forming module accepting three signals and another embodiment of the eyewear sound induction ear speaker device of the invention.

**[0028]** FIG. **14** is a block diagram illustrating an example embodiment of a desired voice activation detection module of yet another embodiment of the eyewear sound induction ear speaker device of the invention.

## DETAILED DESCRIPTION OF THE INVENTION

**[0029]** The foregoing will be apparent from the following more particular description of example embodiments invention, as illustrated in the accompanying drawings in which like references refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments of the present invention.

**[0030]** The terms "speaker" and "audio speaker" are used interchangeably throughout the present application and are used to refer to a small, relative to the size of a human ear, narrow band (e.g., voice-band, for example 300 Hz-20 KHz) speaker receiver or that converts electrical signals at audio frequencies into acoustic signals.

**[0031]** In one embodiment of the present invention, shown in FIGS. **1**A and **1**B eyewear **10**, for example, a pair of prescription glasses, includes eyewear frame **14**. Audio speaker **16** is integrated with eyewear frame **14**, and acoustic duct **18** is coupled to audio speaker **16** and arranged to channel sound emitted by speaker **16** to an ear of a user wearing eyewear frame **14**. Speaker **16** is operatively linked, for example, to embedded receiver **28**. "Operatively coupled," as that term as used herein, means electronically linked, such as by a wireless or hardwire connection.

**[0032]** Acoustic duct **18** can be made from a pliable material and further arranged such that acoustic duct **18** does not block the ear canal of the user **20**. Acoustic duct **18** can include point **22** and be horn-shaped, as shown in FIG. **1**A. A cross-section of acoustic duct **18**, shown in FIG. **1**C, can be oval-shaped or, as shown in FIG. **2**, acoustic duct **20** can be rectangular shaped. Acoustic duct **18** does not have to be weight-bearing and is not designed to be weight-bearing since eyewear frame **14** is used to support the weight.

**[0033]** As shown in FIG. **1**B, eyewear **10** further includes a second, acoustic duct **22** and second audio speaker **24** coupled to audio duct **26** and, like speaker **16**, operatively coupled to an electrical audio source, such as receiver **28**, which is integrated within eyewear frame **14**. Second acoustic duct **22** is coupled to second audio speaker **24** and is arranged to channel sound emitted by audio speaker **24** to a second ear of a user wearing eyewear frame **14**. In an alternative example embodiment, speaker **24** can further include a second audio channel, the second audio channel being coupled through second speaker **24** to second acoustic duct **22** to provide stereo sound to the user wearing eyewear frame **14**.

**[0034]** Receiver **28** is operatively coupled to first speaker **16**, either alone or in conjunction with second audio speaker **24**. Receiver **28** can be a wired or a wireless receiver, and receive an electrical audio signal from any electrical audio source. For example, the receiver can be operatively coupled to a 3.5 mm audio jack, Bluetooth wireless radio, memory storage device or other such source. The wireless receiver can include an audio codec, digital signal processor, and amplifiers, the audio codec can be coupled to the audio speaker and coupled to at least one microphone. The microphone can be an analog microphone coupled to an analog-to-digital (A/D) converter, which can in turn be coupled to a DSP. The audio microphone can be a micro-electro-mechanical system (MEMS) microphone. Further example embodiments can include a digital microphone, such as a digital MEMs microphone, coupled to an all-digital voice processing chip, obviating the need for a CODEC all together. The speaker can be driven by a digital-to-analog (D/A) driver, or can be driven by a pulse width modulation (PWM) digital signal.

**[0035]** Alternatively, or in addition to receiver **26**, eyewear **10** of the invention can include a transmitter, whereby sounds captured electronically by microphones of eyewear that are thereby processed for transmission to an extend receiver or to at least one of audio speakers **16** and **24**.

**[0036]** An example method of the present invention includes channeling sound from an eyewear device. The method includes receiving an electrical audio signal from an electrical audio source at a speaker integrated with an eyewear device, inducing audio sound from the electrical audio signal at the speaker, and channeling the audio sound to an ear of a user of the eyewear using an audio duct, the audio duct not blocking an ear canal of the ear. The electrical audio signal can be supplied from any electrical audio source, for example, a 3.5 mm audio-jack, Bluetooth® wireless radio, and a media storage device, such as a hard disk or solid-state memory device.

**[0037]** A corresponding example method of providing sound for eyewear **10** can include: receiving and electrically processing sound at at least one of speakers **16** and **24**, integrated with eyewear frame **14**, speakers **16** and **24** including audio channels; inducing the electrically processed sound at audio speakers **16** and **24** integrated within eyewear frame **14** to produce acoustic processed sound; and, channeling the acoustic processed sound through acoustic ducts **18**, **22** to be presented to a user wearing eyewear **10**.

**[0038]** Example methods can further include arranging at least one of acoustic ducts **18**, **30** such that at least one of acoustic ducts **18**, **22** do not block the ear canal of the user, acoustic ducts **18**, **22** being comprised of a pliable non-load bearing material.

**[0039]** The processing can include preamplifying sound received from a wired or wireless receiver **28** using a preamplifier (not shown), further processing the amplified sound using a digital signal processor (not shown), converting the further processed sound into an analog signal, and postamplifying the analog signal to produce the electrically processed sound. The processing can further include processing sound in a second audio channel, inducing the electrically processed sound of the second audio channel at second audio speaker **24** integrated with eyewear frame **14** to produce stereo acoustic processed sound and, channeling the second acoustic processed sound through second acoustic duct **30** to present stereo sound to a user wearing eyewear frame **14**.

**[0040]** In a further example embodiment, an eyewear sound induction ear speaker device can include a means for receiving an audio sound, a means for amplifying and processing the audio sound, and a means for channeling the audio sound to an ear of a user wearing an eyewear frame.

**[0041]** Horn-shaped acoustic ducts **18**, **22** will amplify the sound coming out of respective speakers **16**, **24**, thereby bringing the sound to the users ear and increasing the effective sound volume. The larger acoustic port can be oval shaped, thinner in the thickness dimension of the acoustic duct wall, to fit it better to ear, or act as a clamp shaped position holder.

**[0042]** FIG. **3** is an illustration of an example embodiment of an eyewear sound induction speaker device of the invention **300**. As shown in FIG. **3**, eyewear sound induction speaker device of the invention includes eye-glasses **302** having embedded pressure-gradient microphones. Each pressure-gradient microphone element can, optionally, and independently, be replaced with two omni-directional microphones at the location of each acoustic port, resulting in four total microphones. The signal from these two omni-directional microphone can be processed by electronic or digital beam-forming circuitry described above to produce a pressure gradient beam pattern. This pressure gradient beam pattern replaces the equivalent pressure-gradient microphone.

**[0043]** In an embodiment of the present invention, if a pressure-gradient microphone is employed, each microphone is within a rubber boot that extends an acoustic port on the front and the back side of the microphone with acoustic ducts. At the end of rubber boot, the new acoustic port is aligned with the opening in the tube, where empty space is filled with wind-screen material. If two omni-directional microphones are employed in place of one pressure-gradient microphone, then the acoustic port of each microphone is aligned with the opening.

**[0044]** In an embodiment, a long boom dual-microphone headset can look like a conventional close-talk boom microphone, but is a big boom with two-microphones in parallel. An end microphone of the boom is placed in front of user's mouth. The close-talk long boom dual-microphone design targets heavy noise usage in military, aviation, industrial and has unparalleled noise cancellation performance. For example, one main microphone can be positioned directly in front of mouth. A second microphone can be positioned at the side of the mouth. The two microphones can be identical with identical casing. The two microphones can be placed in parallel, perpendicular to the boom. Each microphone has front and back openings. DSP circuitry can be in the housing between the two microphones.

**[0045]** Microphone is housed in a rubber or silicon holder (e.g., the rubber boot) with an air duct extending to the acoustic ports as needed. The housing keeps the microphone in an air-tight container and provides shock absorption. The microphone front and back ports are covered with a wind-screen layer made of woven fabric layers to reduce wind noise or wind-screen foam material. The outlet holes on the microphone plastic housing can be covered with water-resistant thin film material or special water-resistant coating.

**[0046]** In another embodiment, a conference gooseneck microphone can provide noise cancellation. In large conference hall, echoes can be a problem for sound recording. Echoes recorded by a microphone can cause howling. Severe echo prevents the user from tuning up speaker volume and causes limited audibility. Conference hall and conference room can be decorated with expensive sound absorbing materials on their walls to reduce echo to achieve higher speaker volume and provide an even distribution of sound field across the entire audience. Electronic echo cancellation equipment is used to reduce echo and increase speaker volume, but such equipment is expensive, can be difficult to setup and often requires an acoustic expert.

**[0047]** In an embodiment, a dual-microphone noise cancellation conference microphone can provide an inexpensive, easy to implement solution to the problem of echo in a conference hall or conference room. The dual-microphone system described above can be placed in a desktop gooseneck microphone. Each microphone in the tube is a pressure-gradient bi-directional, uni-directional, or super-directional microphone.

**[0048]** In a head mounted computer, a user can desire a noise-canceling close-talk microphone without a boom microphone in front of his or her mouth. The microphone in front of the user's mouth can be viewed as annoying. In addition, moisture from the user's mouth can condense on the surface of the Electret Condenser Microphone (ECM) membrane, which after long usage can deteriorate microphone sensitivity.

**[0049]** In an embodiment, a short tube boom headset can solve these problems by shortening the boom, moving the ECM away from the user's mouth and using a rubber boot to extend the acoustic port of the noise-canceling microphone. This can extend the effective close-talk range of the ECM. This maintains the noise-canceling ECM property for far away noises. In addition, the boom tube can be lined with wind-screen form material. This solution further allows the headset computer to be suitable for enterprise call center, industrial, and general mobile usage. In an embodiment with identical dual-microphones within the tube boom, the respective rubber boots of each microphone can also be identical.

**[0050]** In an embodiment, the short tube boom headset can be a wired or wireless headset. The headset includes the short microphone (e.g., and ECM) tube boom. The tube boom can extend from the housing of the headset along the user's cheek, where the tube boom is either straight or curved. The tube boom can extend the length of the cheek to the side of the user's mouth, for instance. The tube boom can include a single noise-cancelling microphone on its inside.

**[0051]** The tube boom can further include a dual microphone inside of the tube. A dual microphone can be more effective in cancelling out non-stationary noise, human noise, music, and high frequency noises. A dual microphone can be more suitable for mobile communication, speech recognition, or a Bluetooth headset. The two microphones can be identical, however a person of ordinary skill in the art can also design a tube boom having microphones of different models.

**[0052]** In an embodiment having dual-microphones, the two microphones enclosed in their respective rubber boats are placed in series along the inside of the tube.

**[0053]** The tube can have a cylindrical shape, although other shapes are possible (e.g., a rectangular prism, etc.). The short tube boom can have two openings, one at the tip, and a second at the back. The tube surface can be covered with a pattern of one or more holes or slits to allow sound to reach the microphone inside the tube boom. In another embodiment, the short tube boom can have three openings, one at the tip, another in the middle, and another in the back. The openings can be equally spaced, however, other a person of ordinary skill in the art can design other spacings.

**[0054]** The microphone in the tube boom is a bi-directional noise-cancelling microphone having pressure-gradient microphone elements. The microphone can be enclosed in a rubber boot extending acoustic port on the front and the back side of the microphone with acoustic ducts. Inside of the boot, the microphone element is sealed in the air-tight rubber boot.

**[0055]** Within the tube, the microphone with the rubber boot is placed along the inside of the tube. An acoustic port at the tube tip aligns with the boom opening, and an acoustic port at the tube back aligns with boom opening. The rubber boot can be offset from the tube ends to allow for spacing between the tube ends and the rubber boot. The spacing further allows breathing room and for room to place a wind-screen of appropriate thickness. The rubber boot and inner wall of the tube remain air-tight, however. A wind-screen foam material (e.g., wind guard sleeves over the rubber boot) fills the air-duct and the open space between acoustic port and tube interior/opening.

**[0056]** Referring back to FIG. **3** the eye-glasses **302** have two microphones **304** and **306**, a first microphone **304** being arranged in the middle of the eye-glasses **302** frame and a second microphone **306** being arranged on the side of the eye-glasses **302** frame. The microphones **304** and **306** can be pressure-gradient microphone elements, either bi- or uni-directional. Each microphone **304** and **306** is a microphone assembly that includes a microphone (not shown) within a rubber boot, as further described infra with reference to FIGS. **5**A-**5**B. The rubber boot provides an acoustic port on the front and the back side of the microphone with acoustic ducts. The two microphones **304** and **306** and their respective boots can be identical. The microphone elements **304** and **306** can be sealed air-tight (e.g., hermetically sealed) inside the rubber boots. The acoustic ducts are filled with wind-screen material. The ports are sealed with woven fabric layers. The lower and upper acoustic ports are sealed with a water-proof membrane. The microphones can be built into the structure of the eye glasses frame. Each microphone has top and bottom holes, being acoustic ports. In an embodiment, the two microphones **304** and **306**, which can be pressure-gradient microphone elements, can each be replaced by two omni-directional microphones.

**[0057]** FIG. **4** is an illustration of another embodiment of an eyewear sound induction ear speaker device **450** of the invention. As shown therein, eyewear sound induction ear speaker **450** includes eye-glasses **452** having three embedded microphones. The eye-glasses **452** of FIG. **4** are similar to the eye-glasses **302** of FIG. **3**, but instead employs three microphones instead of two. The eye-glasses **452** of FIG. **4** have a first microphone **454** arranged in the middle of the eye-glasses **452**, a second microphone **456** arranged on the left side of the eye-glasses **4**, and a third microphone **458** arranged on the right side of the eye-glasses **452**. The three microphones can be employed in the three-microphone embodiment described above.

**[0058]** FIG. **5**A is an exploded view of a microphone assembly **500** of the invention. As shown therein, the rubber boot **502***a*-*b* is separated into a first half of the rubber boot **502***a* and a second half of the rubber boot **502***b*. Microphone **501** is between the rubber boot halves. Each rubber boot **502***a*-*b* is lined by a wind-screen **508** material, however FIG. **5** shows the wind-screen in the second half of the rubber boot **502***b*. In the case of a pressure-gradient microphone, the air-duct and the open space between acoustic port and boom interior is filled with wind-screen foam material, such as wind guard sleeves over the rubber boots.

**[0059]** A microphone **504** is arranged to be played between the two halves of the rubber boot **502***a*-*b*. The microphone **504** and rubber boot **502***a*-*b* are sized such that the microphone **504** fits in a cavity within the halves of the rubber boot **502***a*-*b*. The microphone is coupled with a wire **506**, that extends out of the rubber boot **502***a*-*b* and can be connected to, for instance, the noise cancellation circuit described above.

**[0060]** FIG. **5**B is a perspective view of microphone assembly **500** when assembled. The rubber boot **552** of FIG. **5** is shown to have both halves **502***a*-*b* joined together, where a microphone (not shown) is inside. A wire **556** coupled to the microphone exist the rubber boot **552** such that it can be connected to, for instance, the noise cancellation circuit described below with reference to FIGS. **7** through **10**.

**[0061]** FIG. **6** is an illustration of an embodiment of the invention **600** showing various optional positions of placement of the microphones **604***a*-*e*. As described above, the microphones are pressure-gradient. In an embodiment, microphones can be placed in any of the locations shown in FIG. **6**, or any combination of the locations shown in FIG. **6**. In a two-microphone system, the microphone closest to the user's mouth is referred to as MIC1, the microphone further from the user's mouth is referred to as MIC2. In an embodiment, both MIC1 & MIC2 can be inline at position 1 **604***a*. In other embodiments, the microphones can be positioned as follows:

**[0062]** MIC1 at position 1 **604***a* and MIC2 at position 2 **604***b;*

**[0063]** MIC1 at position 1 **604***a* and MIC2 at position 3 **604***c;*

**[0064]** MIC1 at position 1 **604***a* and MIC2 at position 4 **604***d;*

**[0065]** MIC1 at position 4 **604***d* and MIC2 at position 5 **604***e;*

**[0066]** Both MIC1 and MIC2 at position 4 **604***d.*

**[0067]** If position 4 **604***d* has a microphone, it is employed within a pendant.

**[0068]** The microphones can also be employed at other combinations of positions **604***a-e*, or at positions not shown in FIG. **6**.

**[0069]** FIG. **7** is a block diagram **700** illustrating an example embodiment of a noise cancellation circuit employed in the present invention. Signals **710** and **712** from two microphones are digitized and fed into the noise cancelling circuit **701**. The noise cancelling circuit **701** can be a digital signal processing (DSP) unit (e.g., software executing on a processor, hardware block, or multiple hardware blocks). In an embodiment, the noise cancellation circuit **701** can be a digital signal processing (DSP) chip, a system-on-a-chip (SOC), a Bluetooth chip, a voice CODEC with DSP chip, etc. The noise cancellation circuit **701** can be located in a Bluetooth headset near the user's ear, in an inline control case with battery, or inside the connector, etc. The noise cancellation circuit **701** can be powered by a battery or by a power source of the device that the headset is connected to, such as the device's batter, or power from a USB, micro-USB, or Lightening connector.

**[0070]** The noise cancellation circuit **701** includes four functional blocks all of which are electronically linked, either wirelessly or by hardwire: a beam-forming (BF) module **702**, a Desired Voice Activity Detection (VAD) Module **708**, an adaptive noise cancellation (ANC) module **704** and a single signal noise reduction (NR) module **706**. The two signals **710** and **712** are fed into the BF module **702**, which generates a main signal **730** and a reference signal **732** to the ANC module **704**. A closer (i.e., relatively close to the desired sound) microphone signal **710** is collected from a microphone closer to the user's mouth and a further (i.e., relatively distant from the desired sound) microphone signal is collected from a microphone further from the user's mouth, relatively. The BF module **702** also generates a main signal **720** and reference signal **722** for the desired VAD module **708**. The main signal **720** and reference signal **722** can, in certain embodiments, be different from the main signal **730** and reference signal **732** generated for the for ANC module **704**.

**[0071]** The ANC module **704** processes the main signal **730** and the reference signal **732** to cancel out noises from the two signals and output a noise cancelled signal **742** to the single channel NR module **706**. The single signal NR module **706** post-processes the noise cancelled signal **742** from the ANC module **704** to remove any further residue noises. Meanwhile, the VAD module **708** derives, from the main signal **720** and reference signal **722**, a desired voice activity detection (DVAD) signal **740** that indicates the presence or absence of speech in the main signal **720** and reference signal **722**. The DVAD signal **740** can then be used to control the ANC module **704** and the NR module **706** from the result of BF module **702**. The DVAD signal **740** indicates to the ANC module **704** and the Single Channel NR module **706** which sections of the signal have voice data to analyze, which can increase the efficiency of processing of the ANC module **704** and single channel NR module **706** by ignoring sections of the signal without voice data. Desired speech signal **744** is generated by single channel NR module **706**.

**[0072]** In an embodiment, the BF module **702**, ANC module **704**, single NR reduction module **706**, and desired VAD module **708** employ linear processing (e.g., linear filters). A linear system (which employs linear processing) satisfies the properties of superposition and scaling or homogeneity. The property of superposition means that the output of the system is directly proportional to the input. For example, a function F(x) is a linear system if:

$$F(x_1+x_2+\dots)=F(x_1)+F(x_2)+\dots$$

**[0073]** A satisfies the property of scaling or homogeneity of degree one if the output scales proportional to the input. For example, a function F(x) satisfies the properties of scaling or homogeneity if, for a scalar α:

$$F(\alpha x)=\alpha F(x)$$

**[0074]** In contract, a non-linear function does not satisfy both of these conditions.

**[0075]** Prior noise cancellation systems employ non-linear processing. By using linear processing, increasing the input changes the output proportionally. However, in non-linear processing, increasing the input changes the output non-proportionally. Using linear processing provides an advantage for speech recognition by improving feature extraction. Speaker recognition algorithm is developed based on noiseless voice recorded in quiet environment with no distortion. A linear noise cancellation algorithm does not introduce nonlinear distortion to noise cancelled speech. Speech recognition can deal with linear distortion on speech, but not nonlinear distortion of speech. Linear noise cancellation algorithm is "transparent" to the speech recognition engine. Training speech recognition on the variations of nonlinear distorted noise is impossible. Non-linear distortion can disrupt the feature extraction necessary for speech recognition.

**[0076]** An example of a linear system is a Weiner Filter, which is a linear single channel noise removal filter. The Wiener filter is a filter used to produce an estimate of a desired or target random process by linear time-invariant filtering an observed noisy process, assuming known stationary signal, noise spectra, and additive noise. The Wiener filter minimizes the mean square error between the estimated random process and the desired process.

**[0077]** FIG. **8** is a block diagram **800** illustrating an example embodiment of a beam-forming module **802** that can be employed in the noise cancelling circuit **701** of FIG. **7**. The BF module **802** receives the closer microphone signal **810** and further microphone signal **812**.

**[0078]** A further microphone signal **812** is inputted to a frequency response matching filter **804**. The frequency response matching filter **804** adjusts gain, phase, and shapes the frequency response of the further microphone signal **812**. For example, the frequency response matching filter **804** can adjust the signal for the distance between the two microphones, such that an outputted reference signal **832** representative of the further microphone signal **812** can be processed with the main signal **830**, representative of the closer microphone signal **810**. The main signal **830** and reference signal **832** are sent to the ANC module.

**[0079]** A closer microphone signal **810** is outputted to the ANC module as a main signal **830**. The closer microphone signal **810** is also inputted to a low-pass filter **806**. The reference signal **832** is inputted to a low-pass filter **808** to create a reference signal **822** sent to the Desired VAD module. The low-pass filters **806** and **808** adjust the signal for a "close talk case" by, for example, having a gradual low off from 2 kHz to 4 kHz, in one embodiment. Other frequencies can be used for different designs and distances of the microphones to the user's mouth, however.

**[0080]** FIG. **9** is a block diagram illustrating an example embodiment of a Desired Voice Activity Detection Module

**902**. The DVAD module **902** receives a main signal **920** and a reference signal **922** from the beam-forming module. The main signal **920** and reference signal **922** are processed by respective short-time power modules **904** and **906**. The short-time power modules **904** and **906** can include a root mean square (RMS) detector, a power (PWR) detector, or an energy detector. The short-time power modules **904** and **906** output signals to respective amplifiers **908** and **910**. The amplifiers can be logarithmic converters (or log/logarithmic amplifiers). The logarithmic converters **908** and **910** output to a combiner **912**. The combiner **912** is configured to combine signals, such as the main signal and one of the at least one reference signals, to produce a voice activity difference signal by subtracting the detection(s) of the reference signal from the main signal (or vice-versa). The voice activity difference signal is inputted into a single channel VAD module **914**. The single channel VAD module can be a conventional VAD module. The single channel VAD **914** outputs the desired voice activity signal.

**[0081]** FIG. **10** is a block diagram **1000** illustrating an example embodiment of a noise cancellation circuit **1001** employed to receive a closer microphone signal **1010** and a first and second further microphone signal **1012** and **1014**, respectively. The noise cancellation circuit **1001** is similar to the noise cancellation circuit **701** described in relation to FIG. **7**, however, the noise cancellation circuit **1001** is employed to receive three signals instead of two. A beam-forming (BF) module **1002** is arranged to receive the signals **1010**, **1012** and **1014** and output a main signal **1030**, a first reference signal **1032** and second reference signal **1034** to an adaptive noise cancellation module **1004**. The beam-forming module is further configured to output a main signal **1022**, first reference signal **1020** and second reference signal **1024** to a voice activity detection (VAD) module **1008**.

**[0082]** The ANC module **1004** produces a noise cancelled signal **1042** to a Single Channel Noise Reduction (NR) module **1006**, similar to the ANC module **1004** of FIG. **7**. The single NR module **1006** then outputs desired speech **1044**. The VAD module **1008** outputs the DVAD signal to the ANC module **1004** and the single channel NR module **1006**.

**[0083]** FIG. **11** is an example embodiment of beam-forming from a boom tube **1102** housing three microphones **1106**, **1108**, and **1110**. A first microphone **1106** is arranged closest to a tip **1104** of the boom tube **1102**, a second microphone **1108** is arranged in the boom tube **1102** further away from the tip **1104**, and a third microphone **1110** is arranged in the boom tube **1102** even further away from the tip **1104**. The first microphone **1106** and second microphone **1108** are arranged to provide data to output a left signal **1126**. The first microphone is arranged to output its signal to a gain module **1112** and a delay module **1114**, which is outputted to a combiner **1122**. The second microphone is connected directly to the combiner **1122**. The combiner **1122** subtracts the two provided signals to cancel noise, which creates the left signal **1126**.

**[0084]** Likewise, the second microphone **1108** is connected to a gain module **1116** and a delay module **1118**, which is outputted to a combiner **1120**. The third microphone **1110** is connected directly to the combiner **1120**. The combiner **1120** subtracts the two provided signals to cancel noise, which creates the right signal **1120**.

**[0085]** FIG. **12** is an example embodiment of beam-forming from a boom tube **1252** housing four microphones **1256**, **1258**, **1260** and **1262**. A first microphone **1256** is arranged closest to a tip **1254** of the boom tube **1252**, a second microphone **1258** is arranged in the boom tube **1252** further away from the tip **1254**, a third microphone **1260** is arranged in the boom tube **1252** even further away from the tip **1254**, and a fourth microphone **1262** is arranged in the boom tube **1252** away from the tip **1254**. The first microphone **1256** and second microphone **1258** are arranged to provide data to output a left signal **1286**. The first microphone is arranged to output its signal to a gain module **1272** and a delay module **1274**, which is outputted to a combiner **1282**. The second microphone is connected directly to the combiner **1258**. The combiner **1282** subtracts the two provided signals to cancel noise, which creates the left signal **1286**.

**[0086]** Likewise, the third microphone **1260** is connected to a gain module **1276** and a delay module **1278**, which is outputted to a combiner **1280**. The fourth microphone **1262** is connected directly to the combiner **1280**. The combiner **1280** subtracts the two provided signals to cancel noise, which creates the right signal **1284**.

**[0087]** FIG. **13** is a block diagram **1300** illustrating an example embodiment of a beam-forming module **1302** accepting three signals **1310**, **1312** and **1314**. A closer microphone signal **1310** is output as a main signal **1330** to the ANC module and also inputted to a low-pass filter **1317**, to be outputted as a main signal **1320** to the VAD module. A first further microphone signal **1312** and second closer microphone signal **1314** are inputted to respective frequency response matching filters **1306** and **1304**, the outputs of which are outputted to be a first reference signal **1332** and second reference signal **1334** to the ANC module. The outputs of the frequency response matching filters **1306** and **1304** are also outputted to low-pass filters **1316** and **1318**, respectively, which output a first reference signal **1322** and second reference signal **1324**, respectively.

**[0088]** FIG. **14** is a block diagram **1400** illustrating an example embodiment of a desired voice activity detection (VAD) module **1402** accepting three signals **1420**, **1422** and **1424**. The VAD module **1402** receives a main signal **1420**, a first reference signal **1422** and a second reference signal **1424** at short-time power modules **1404**, **1405** and **1406**, respectively. The short-time power modules **1404**, **1405**, and **1406** are similar to the short-time power modules described in relation to FIG. **9**. The short-time power modules **1404**, **1405**, and **1406** output to respective amplifiers **1408**, **1409** and **1410**, which can each be a logarithmic converter. Amplifiers **1408** and **1409** output to a combiner module **1411**, which subtracts the two signals and outputs the difference to a single channel VAD module **1414**. Amplifiers **1410** and **1408** output to a combiner module **1412**, which subtracts the two signals and outputs the difference to a single channel VAD module **1416**. The single channel VAD modules **14114** and **1416** output to a logical OR-gate **1418**, which outputs a DVAD signal **1440**.

**[0089]** Further example embodiments of the present invention may be configured using a computer program product; for example, controls may be programmed in software for implementing example embodiments of the present invention. Further example embodiments of the present invention may include a non-transitory computer readable medium containing instruction that may be executed by a processor, and, when executed, cause the processor to complete methods described herein. It should be understood that elements of the block and flow diagrams described herein may be implemented in software, hardware, firmware, or other similar implementation determined in the future. In addition, the elements of the block and flow diagrams described herein may be combined or divided in any manner in software, hardware, or firmware. If implemented in software, the software may be written in any language that can support the example embodiments disclosed herein. The software may be stored in any form of computer readable medium, such as random access memory (RAM), read only memory (ROM), compact disk read only memory (CD-ROM), and so forth. In operation, a general purpose or application specific processor loads and executes software in a manner well understood in the art. It should be understood further that the block and flow diagrams may include more or fewer elements, be arranged or oriented differently, or be represented differently. It should be understood that implementation may dictate the block, flow, and/or network diagrams and the number of block and flow diagrams illustrating the execution of embodiments of the invention.

**[0090]** The relevant teachings of all patents, published applications and references cited herein are incorporated by reference in their entirety.

**[0091]** While this invention has been particularly shown and described with references to example embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

What is claimed is:

**1**. An eyewear sound induction ear speaker device, comprising:

a) an eyewear frame;

b) a speaker including an audio channel integrated with the eyewear frame; and

c) an acoustic duct coupled to the speaker and arranged to channel sound emitted by the speaker to an ear of a user wearing the eyewear frame.

**2**. The device of claim **1**, wherein the acoustic duct is comprised of a pliable non-load bearing material and further arranged such that the acoustic duct is not blocking the ear canal of the user.

**3**. The device of claim **1**, wherein the acoustic duct is pointed.

**4**. The device of claim **1**, wherein the acoustic duct is horn-shaped and includes an acoustic port.

**5**. The device of claim **4**, wherein the acoustic port is oval-shaped or rectangular-shaped.

**6**. The device of claim **1**, further including a wireless receiver operatively coupled to the speaker.

**7**. The device of claim **6**, wherein the wireless receiver includes an audio codec, digital signal processor, and amplifiers, the audio codec being coupled to an audio speaker and coupled to at least one microphone.

**8**. The device of claim **6**, further including an all-digital voice processing integrated circuit coupled to a digital micro-electro-mechanical system (MEMs) microphone, and the speaker is modulated by a pulse-width modulation (PWM) digital signal.

**9**. The device of claim **1**, further including:

a) a second speaker integrated with the eyewear frame; and

b) a second acoustic duct coupled to the second speaker and arranged to channel sound emitted by the second speaker to a second ear of a user wearing the eyewear frame.

**10**. The device of claim **1**, wherein the speaker further includes a second audio channel, the second audio channel being coupled to a second acoustic port to provide stereo sound to the user wearing the eyewear frame.

**11**. The device of claim **1**, further including a noise-cancelling digital signal processor integrated into the eyewear frame.

**12**. The eyewear device of claim **1**, further including an array of microphones coupled to at least one of the front frame and the at least one side frame member, the array of microphones including at least a first and second microphone, the first microphone coupled to the eyewear at a temple region, the temple region being located approximately between a top corner of a lens opening defined by the front frame and having an inner edge, and the at least one side frame member, and the second microphone at an inner edge of the lens opening, and a first and second audio channel output from the first and second microphones, respectively.

**13**. The eyewear device of claim **20**, further including a digital signal processor having:

a) a beam-former electronically linked to the first and second microphones, for receiving at least the first and second audio channels and outputting a main channel and one or more reference channels;

b) a voice activity detector electronically linked to the beam-former, for receiving the main and reference channels and outputting a desired voice activity channel;

c) an adaptive noise canceller electronically linked to the beam-former and the voice activity detector for receiving the main, reference, and desired voice activity channels and outputting an adaptive noise cancellation channel; and

d) a noise reducer electronically linked to the voice activity detector and the adaptive noise canceller for receiving the desired voice activity and adaptive noise cancellation channels and outputting a desired speech channel.

**14**. The device of claim **13**, wherein the array of microphones includes two pressure-gradient microphone elements, each pressure-gradient microphone element including two acoustic ports.

**15**. The device of claim **14**, wherein the two pressure-gradient microphone elements are bi-directional and identical.

**16**. The device of claim **15**, wherein the two pressure-gradient microphone elements are each sealed within an acoustic extension, the acoustic extension including an acoustic duct for each acoustic port, the acoustic duct extending a range of each acoustic port, respectively.

**17**. The device of claim **16**, wherein the two acoustic extension sealed pressure-gradient microphone elements are mounted air-tight in series within a substantially cylindrical tube, the tube further including:

a) three or more acoustic openings, being longitudinally equally spaced at a distance equal to or greater than the range of each acoustic port; and

b) a wind-screen material, filling the tube interior between the acoustic openings and the acoustic ports.

**18**. The device of claim **13**, wherein at least a first and a second microphone of the array of microphones is located within a housing of an eyeglasses frame, the first microphone being located proximate to a bridge support and having a first top and a first bottom acoustic port, and the second microphone being located proximate to an end piece between a lens and a support arm and having a second top and a second bottom acoustic port.

**19**. The device of claim **18**, further including a third microphone located within the housing proximate to an opposite end piece and having a third top and third bottom acoustic port.

**20**. The device of claim **13**, wherein the array of microphones includes three or more omni-directional microphone elements and the beam-former is further configured to receive an audio channel for each respective microphone element.

**21**. The device of claim **20**, wherein the beam-former further includes splitters, combiners, amplifiers, and phase shifters.

**22**. The device of claim **20**, wherein the beam-former is further arranged such that adjacent audio channels are combined to produce two or more audio difference channels, wherein the two or more audio difference channels have equivalent phase lengths.

**23**. The device of claim **12**, wherein the DSP is a system on a chip (SoC), a Bluetooth chip, a DSP chip, or codec with DSP integrated circuit.

**24**. An eyewear sound induction ear speaker device, comprising:

a) means for receiving an audio sound;

b) means for processing and amplifying the audio sound; and

c) means for channeling the amplified and processed audio sound to an ear of a user wearing an eyewear frame.

**25**. A method of providing sound for eyewear, comprising the steps of:

a) receiving a processed electrical audio signal at a speaker integrated with an eyewear frame, the speaker including an audio channel;

b) inducing the speaker to produce acoustic sound at the audio channel; and

c) channeling the acoustic sound through an acoustic duct to be presented to a user wearing the eyewear frame.

**26**. The method of claim **25**, further including arranging the acoustic duct such that the acoustic duct does not block the ear canal of the user, the acoustic duct being comprised of a pliable non-load bearing material.

**27**. The method of claim **25**, further including the steps of receiving an unprocessed electrical audio signal at a receiver integrated with the eyewear frame, processing the electrical audio signal at the receiver to produce a processed electrical audio signal, and transmitting the processed electrical audio signal to the speaker.

**28**. The method of claim **25**, further including the steps of:

a) preamplifying sound received at the speaker using a pre-amplifier to produce an amplified electrical audio signal;

b) further processing the amplified electrical audio signal using a digital signal processor to produce a digital electrical audio signal;

c) converting the digital electrical audio signal into an analog signal; and

d) postamplifying the analog signal to produce the processed electrical audio signal.

**29**. The method of claim **25**, wherein the acoustic signal is a first acoustic sound and the processing step further includes the steps of:

a) receiving a second processed electrical audio signal at a second speaker integrated with the eyewear frame, the second speaker including an audio channel;

b) inducing the second speaker to produce a second acoustic sound independent of and distinct from the first acoustic sound;

c) channeling the second acoustic sound through a second acoustic duct to present stereo sound to a user wearing the eyewear frame.

**30**. The method of claim **25**, further including the steps of:

a) forming beams at a beam-former, the beam-former receiving at least two audio channels and outputting a main channel and one or more reference channels;

b) detecting voice activity at a voice activity detector, the voice activity detector receiving the main and reference channels and outputting a desired voice activity channel;

c) adaptively cancelling noise at an adaptive noise canceller, adaptive noise canceller receiving the main, reference, and desired voice activity channels and outputting an adaptive noise cancellation channel; and

d) reducing noise at a noise reducer receiving the desired voice activity and adaptive noise cancellation channels and outputting a desired speech channel.

**31**. A method of channeling sound from an eyewear device, comprising the steps of:

a) receiving an electrical audio signal from an electrical audio source at a speaker integrated with an eyewear device;

b) inducing audible sound from the electrical audio signal at the speaker; and

c) channeling the audio sound to an ear of a user of the eyewear using an audio duct, the audio duct not blocking an ear canal of the ear.

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