Audio eyewear includes a front frame and at least one side frame member secured to the front frame for engaging a user's ear. The side frame members have speakers therein that are oriented to direct an audio port of the speaker face downwardly at an angle away from at least one side frame member, thereby directing sound downwardly and rearwardly into the user's ear generally along the vertical plane. Embodiments of the invention include microphones for use in, for example, noise cancellation.
FIG. 14

DVAD Module

Single Channel VAD 1414

Log(X1) 1408

Log(X2) 1410

X1

X2

Short-time Power 1404

Short-time Power 1406

DVAD Signal 1440

Main Signal 1420

Reference Signal 1422
FIG. 16
FIG. 17
EYEWEAR SPECTACLE WITH AUDIO SPEAKER IN THE TEMPLE

RELATED APPLICATION

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

[0002] This application is being co-filed on the same day, Feb. 14, 2014, with “Eye Glasses With Microphone Array” by Dushen Fan, Attorney Docket No. 0717.2220-001. This application is being co-filed on the same day, Feb. 14, 2014, with “Sound Induction Ear Speaker For Eye Glasses” by Dushen Fan, Attorney Docket No. 0717.2221-001. This application is being co-filed on the same day, Feb. 14, 2014, with “Noise Cancelling Microphone Apparatus” by Dushen 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 (RTA) 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 hear 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 or unreliable.

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

SUMMARY OF THE INVENTION

[0006] The present invention generally is directed to audio eyewear and methods of their use.

[0007] In one embodiment, the audio eyewear of the invention includes a front frame and at least one temple or side frame member secured to the front frame for engaging a user’s ear. The at least one side frame member has a speaker therein which can be oriented such that an audio port of the speaker faces downwardly at an angle away from the front frame and the at least one side frame member, thereby directing sound downwardly rearwardly into the user’s ear generally along a vertical plane.

[0008] In a particular embodiment, the eyewear device further includes an array of microphones coupled to at least one of the front frame and at least one side frame member. The array of microphones includes at least a first and second microphone. The first microphone is located at a temple region 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. The second microphone is located at an inner edge of the lens opening. This embodiment of the eyewear device also includes first and second audio channel outputs from the first and second microphones, respectively.

[0009] In a still more particular embodiment of the invention, the eyewear device additionally includes a beam-former electronically linked to the first and second microphones, for receiving at least the first and second audio channels and outputting the main channel and one or more reference channels. A voice activity detector is electronically linked to the beam-former for receiving the main and reference channels and outputting the desired voice activity channel. An adaptive noise canceler is 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. The noise reducer is electronically linked to the voice activity detector and the adaptive noise canceler for receiving the desired voice activity and adaptive noise cancellation channels and for outputting a desired speech channel.

[0010] Still another embodiment of the invention is a method of hearing audio, including the steps of providing audio eyewear having a front frame and at least one side frame member secured to the front frame for engaging a user’s ear, the at least one side frame member having a speaker therein, and orienting the speaker such that an audio port of the speaker faces downwardly rearwardly at an angle away from said at least one side frame member for directing sound downwardly rearwardly into said users’ ear generally along the vertical frame.

[0011] In one embodiment of the method, an array of microphones is coupled to the eyewear, wherein the array of microphones includes at least a first and second microphone. The first microphone is arranged to couple to the eyewear above the temple region, the temple region being located approximately between the top corner of a lens opening defined by the front frame and a support frame. The second microphone is coupled to the eyewear frame about an inner edge of the lens opening. First and second channel outputs are provided from the first and second microphones, respectively.

[0012] In yet another embodiment of the method, the method further includes the steps of forming beams at a beam-former, the beam-former receiving at least the first and second audio channels and outputting a main channel and one or more reference channels. Voice activities are detected by a voice activity detector, wherein the voice activity detector receives main and reference channels and outputs a desired voice activity channel. Noise is adaptively canceled at an adaptive noise canceler, the adaptive noise canceler receiving the main, reference and desired voice activity channels and outputting an adaptive noise cancellation channel. Noise is then reduced at a noise reducer receiving the desired voice activity and adaptive noise cancellation channels, and outputting a desired speech channel.

[0013] 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, 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 earbuds blocking their ear. There are also no flimsy wires, and users do not have to tolerate the skin contact or pressure associated with the bone conduction speakers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1A is a perspective view of one embodiment of the invention.
[0015] FIG. 1B is a perspective view from below of the embodiment shown in FIG. 1A.
[0016] FIG. 1C is an elevated side-top view of perspective of the embodiment of the invention shown in FIG. 1A.
[0017] FIG. 2 is a side view of the embodiment of FIGS. 1A-1C shown being worn by a user.
[0018] FIG. 3 is a perspective view of a left side frame member of the embodiment shown in FIGS. 1A-1C, wherein an interior panel has been removed to show the speaker assembly within an audio chamber defined by the left side frame member.
[0019] FIG. 4 is an exploded view of the left side frame member of the embodiment shown in FIGS. 1A-1C, showing a speaker assembly, also exploded, and a compartment cover for the side frame member (missing from FIG. 3).
[0020] FIG. 5 is an elevated side view in perspective of another embodiment of the eyewear of the invention, including sound tubes to direct sound more approximately to the users audio canal.
[0021] FIG. 6 is a close-up view of the left side frame member of the embodiment shown in FIG. 5, showing more particularly an exit hole defined by the sound tube to direct sound toward the audio canal of the user.
[0022] FIG. 7 is still another embodiment of the audio eyewear of the invention, including a sound deflector for deflecting sound from speakers within the side frame members toward the audio canal of the wearer.
[0023] FIG. 8 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.

[0024] FIG. 9 is an illustration of another embodiment of eyewear of the invention that includes three remote microphones.
[0025] FIG. 10A is an exploded view of a rubber boot and microphone, the rubber boot being suitable for use with the microphone according to one embodiment of the invention.
[0026] FIG. 10B is a perspective view of the assembled rubber boot shown in FIG. 10A.
[0027] FIG. 11 is a representation of another embodiment of the invention showing alternate and optional placement positions of the microphones.
[0028] FIG. 12 is a block diagram illustrating an example embodiment of the noise cancellation circuit employed in one embodiment of the eyewear sound induction user speaker device of the invention.
[0029] FIG. 13 is a block diagram of a beam-forming module suitable for use in the embodiment of the invention illustrated in FIG. 12.
[0030] FIG. 14 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.
[0031] FIG. 15 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.
[0032] FIG. 16 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.
[0033] FIG. 17 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.
[0034] FIG. 18 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.
[0035] FIG. 19 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

[0036] The foregoing will be apparent from the following more particular description of example embodiments of the invention, as illustrated in the accompanied drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis being placed upon illustrating embodiments of the present invention.

[0037] The invention generally is directed to audio eyewear and methods of its use.

[0038] In one embodiment of the invention, shown in FIGS. 1A-1C, audio eyewear 10 includes front frame 12. Side frame members 14, 16 are secured to front frame member 12. Side frame members 14, 16 include speakers (not shown) therein. The speakers are configured so that audio ports of the speakers face downward at an angle away from side frame members 14, 16, thereby directing sound downwardly rearwardly into the users' ear generally along a vertical plane. FIGS. 1B and 1C show alternate views of audio eyewear 10 of FIG. 1A.

[0039] In particular embodiments, such as is shown in FIG. 2, side frame member 14, includes thick forward portion 24
containing speaker 18, and thin rearward portion 26 extending rearwardly from thick forward portion 24 for engaging the user’s ear. Speaker 18 can be positioned within cavity 20 formed within the at least one side frame member 14. As can be seen in FIG. 3 speaker 18 can be positioned at a downward facing lower transition surface 28 that narrows the thick forward portion 24 into the thin rearward portion 26 along a rearwardly extending upward angle 30, and angles audio port 22 of speaker 18 downwardly rearwardly. Referring back to FIG. 2, speaker 18 is in speaker plane 34 that is normal to a sound direction axis 36 of audio port 22 that is angled downwardly at least about 20 degrees or greater (preferably about 20 to 70 degrees) relative to the horizontal or longitudinal plane of the at least one side frame member 14, and represented by angle 30. Referring back to FIG. 2, speaker 18 is mounted against inner 42 side of lower transition surface 28 with sealing arrangement 48. Lower transition surface 28 defines audio openings 46 for allowing sound from speaker 18 to pass through, as shown in FIG. 4, which is an exploded view of left side frame 14. As shown therein, sealing arrangement 48 seals speaker 18 and printed circuit board 50 between mask 52 and audio openings 46 with gasket 54 and sticky gasket 56. Mask 52 is fabricated from a suitable material, such as is known in the art, including, for example, rubber or silicone. Gasket 54 and sticky gasket 56 are also fabricated from a suitable material, such as is known in the art. Compartment cover 58 overlays sealing arrangement 48 and is secured to the remainder of left side frame 14 by screws.

In some embodiments left 14 and right 16 frame members can be secured to opposite sides of front frame 12. Each side frame member 14, 16 has a respective speaker therein for providing sound to both ears of the user. At least one of the right 16 and left 14 side frame members and front frame 12 can contain electronics, microphones (not shown) and a battery (not shown). Electrical signals from the speakers and the microphones can be connected to a cellular phone (not shown). At least one of the electronics and software in at least one of eyewear 10 and the cellular phone can automatically adjust volume of the speakers according to ambient noise measured by the microphones.

In another embodiment, shown in FIGS. 5 and 6, a sound tube 60 is attached to the at least one side frame members 14, 16 for directing sound from a speaker (not shown) in side frame member 14, 16 into the user’s ear. Sound tube 60 is mounted at the at least one side frame member 62 and defines inlet 64 opening for receiving sound from the speaker, and an outlet opening facing the user’s ear for directing the sound from the speaker to the user’s ear or into the ear canal.

In another embodiment, shown in FIG. 7, sound deflecting surface 66 extends from an outer surface of the at least one side frame member 64 and over a portion of the user’s ear for channeling sound from a speaker (not shown) into the user’s ear while also allowing ambient sound to be heard. The sound channel members, whether a sound tube or a sound deflecting surface are, in one embodiment, removably attached by magnetic or mechanical attachment fittings, and can be attached to both right and left side frame members for directing sound to both ears.

The present invention can also provide a method of hearing audio signals including, with reference to FIGS. 1-4, providing audio eyewear 10 having a front frame 12 and at least one side frame member 14, 16 secured to front frame 12 for engaging a user’s ear. Speaker 18, for example, is oriented such that audio port 22 of speaker 18 faces downwardly rearwardly at an angle 30 away from the at least one side frame member 14, for directing sound downwardly rearwardly into the user’s ear generally along a vertical plane.

FIG. 8 is a diagram 800 illustrating another example embodiment of eyeglasses 802 of the invention having two embedded microphones, in addition to the speakers and side frame members discussed above. Eyeglasses 802 have two microphones 804 and 806, a first microphone 804 being arranged in the middle of eyeglasses 802 frame and second microphone 806 being arranged on the side of eyeglasses 802 frame. Microphones 804 and 806 can be pressure-gradient microphone elements, either bi- or uni-directional. Each microphone 804 and 806 is an assembly that includes a microphone (not shown) within a rubber boot as further described infra with reference to FIGS. 10A and 10B. The rubber boot provides an acoustic port on the front and the back side of the microphone with acoustic ducts. The two microphones 804 and 806, and their respective boots can be identical. Microphone elements 804 and 806 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 eyeglasses frame. Each microphone has top and bottom holes, being acoustic ports. In an embodiment, the two microphones 804 and 806, which can be pressure-gradient microphone elements, can each be replaced by two omni-directional microphones.

FIG. 9 is a diagram 950 illustrating an example embodiment of eyeglasses 952 having three embedded microphones. Each pressure-gradient microphone element can 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 microphones 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.

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.

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.
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.

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.

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.

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.

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.

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-canceling microphone on its inside.

The boom tube 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.

In an embodiment having dual-microphones, the two microphones enclosed in their respective rubber boots are placed in series along the inside of the tube.

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 equably spaced, however, other a person of ordinary skill in the art can design other spacings.

The microphone in the tube boom is a bi-directional noise-canceling 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.

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-right, 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.

Referring to FIG. 9, the eye-glasses 952 of FIG. 9 are similar to the eye-glasses 802 of FIG. 8, but instead employs three microphones instead of two. The eye-glasses 952 of FIG. 9 have a first microphone 954 arranged in the middle of the eye-glasses 952, a second microphone 956 arranged on the left side of the eye-glasses 952, and a third microphone 958 arranged on the right side of the eye-glasses 952. The three microphones can be employed in the three-microphone embodiment described above.

Fig. 10A is a diagram 1000 illustrating an example embodiment of a rubber boot 1002a-b shown in an expanded view. The rubber boot 1002a-b is separated into a first half of the rubber boot 1002a and a second half of the rubber boot 1002b. Each rubber boot 1002a-b is lined by a wind-screen 1008 material, however FIG. 10A shows the wind-screen in the second half of the rubber boot 1002b. In 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.

A microphone 1004 is arranged to be played between the two halves of the rubber boot 1002a-b. The microphone 1004 and rubber boot 1002a-b are sized such that the microphone 1004 fits in a cavity within the halves of the rubber boot 1002a-b. The microphone is coupled with a wire 1006, that extends out of the rubber boot 1002a-b and can be connected to, for instance, the noise cancellation circuit described above.

Fig. 10B is a diagram 1050 illustrating an example of a rubber boot 1052. The rubber boot 1052 of FIG. 10B is shown to have both halves joined together, where a micro-
phone (not shown) is inside. A wire 1056 coupled to the microphone exist the rubber boot 1052 such that it can be connected to, for instance, the noise cancellation circuit described below, with reference to FIGS. 12 through 15.

[0063] FIG. 11 is an illustration of an embodiment of the invention 1100 showing various optional positions of placements of the microphones 1104a-e. As described above, the microphones are pressure-gradient. In an embodiment, microphones can be placed in any of the locations shown in FIG. 11, or any combination of the locations shown in FIG. 10. 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 1004a. In other embodiments, the microphones can be positioned as follows:

[0064] MIC1 at position 1 1104a and MIC2 at position 2 1104b.
[0065] MIC1 at position 1 1104a and MIC2 at position 3 1104c.
[0066] MIC1 at position 1 1104a and MIC2 at position 4 1104d.
[0067] MIC1 at position 4 1104d and MIC2 at position 5 1104e.
[0068] Both MIC1 and MIC2 at position 4 1104d.
[0069] If position 4 1104d has a microphone, it is employed within a pendant.
[0070] The microphones can also be employed at other combinations of positions 1104a-e, or at positions not shown in FIG. 11.

[0071] FIG. 12 is a block diagram 1200 illustrating an example embodiment of a noise cancellation circuit employed in the present invention. Signals 1210 and 1212 from two microphones are digitized and fed into the noise cancelling circuit 1201. The noise cancelling circuit 1201 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 1201 can be a digital signal processing (DSP) chip, a system-on-a-chip (SOC), a Bluetooth chip, a voice CODEC with DSP chip, etc. Noise cancellation circuit 1201 can be located in a Bluetooth headset near the user’s ear, in an inline control case with battery, or inside the connector, etc. Noise cancellation circuit 1201 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 battery, or power from a USB, micro-USB, or Lightning connector.

[0072] Noise cancellation circuit 1201 includes four functional blocks, all of which are electronically linked, either wirelessly or by hard-wire: beam-forming (BF) module 1202, Desired Voice Activity Detection (VAD) Module 1208, adaptive noise cancellation (ANC) module 1204 and single signal noise reduction (NR) module 1206. Two signals 1210 and 1212 are fed into the BF module 1202, which generates main signal 1230 and reference signal 1232 to the ANC module 1204. A closer microphone signal 1210 is collected from a microphone closer to the user’s mouth and a further microphone signal is collected from a microphone further from the user’s mouth, respectively. BF module 1202 also generates a main signal 1230 and reference signal 1232 for desired VAD module 1208. The main signal 1220 and reference signal 1222 can, in certain embodiments, be different from the main signal 1230 and reference signal 1232 generated for the ANC module 1204.

[0073] The ANC module 1204 processes the main signal 1230 and the reference signal 1232 to cancel out noises from the two signals and output noise cancelled signal 1242 to single channel NR module 1206. Single signal NR module 1206 post-processes the noise cancelled signal 1242 from the ANC module 1204 to remove any further residue noise. Meanwhile, the VAD module 108 derives, from the main signal 1220 and reference signal 1222, a desired voice activity detection (DVAD) signal 1140 that indicates the presence or absence of speech in the main signal 1220 and reference signal 1222. The DVADs signal 1240 can then be used to control the ANC modules 1204 and the NR module 1206 from the result of BF modules 1202. The DVAD signal 1240 indicates to the ANC module 1204 and Single Channel NR module 106 which sections of the signal have voice data to analyze, which can increase the efficiency of processing of the ANC module 1204 and single channel NR modules 1206 by ignoring sections of the signal without voice data. Desired speech signal 1244 is generated by single channel NR module 1206.

[0074] In an embodiment, the BF modules 1202, ANC module 1204, single NR reduction module 1206, and desired VAD module 1208 employs 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 function if:

$$F(x_1, x_2, \ldots) = F(x_1) + F(x_2) + \ldots$$

[0075] A satisfies the properties 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 $\alpha$:

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

[0076] In contract, a non-linear function does not satisfy both of these conditions.

[0077] 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 noise-less voice recorded in quiet environment with no distortion. A linear noise cancellation algorithm does not introduce non-linear distortion to noise cancelled speech. Speech recognition can deal with linear distortion on speech, but not non-linear 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.

[0078] 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.

[0079] FIG. 13 is a block diagram 1300 illustrating an example embodiment of a beam-forming module 1302 that can be employed in noise cancelling circuit 1201 of FIG. 12.
The BF module 1302 receives closer microphone signal 1310 and further microphone signal 1312.  

[0080] A further microphone signal 1312 is input to a frequency response matching filter 1304. The frequency response matching filter 1304 adjusts gain, phase, and shapes the frequency response of the further microphone signal 1312. For example, the frequency response matching filter 1304 can adjust the signal for the distance between the two microphones, such that an outputted reference signal 1332 representative of the further microphone signal 1312 can be processed with the main signal 1330, representative of the closer microphone signal 1310. The main signal 1330 and reference signal 1332 are sent to the ANC module.  

[0081] Closer microphone signal 1310 is outputted to the ANC module as a main signal 1330. Closer microphone signal 1310 is also input to a low-pass filter 1306. Reference signal 1332 is input to a low-pass filter 1308 to create reference signal 1322 sent to the Desired VAD module. Low-pass filters 1306 and 1308 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.  

[0082] FIG. 14 is a block diagram illustrating an example embodiment of a Desired Voice Activity Detection Module 1402. The DVAD module 1402 receives a main signal 1420 and a reference signal 1422 from the beam-forming module. The main signal 1420 and reference signal 1422 are processed by respective short-time power modules 1404 and 1406. The short-time power modules 1404 and 1406 can include a root mean square (RMS) detector, a power (PWR) detector, or an energy detector. The short-time power modules 1404 and 1406 output signals to respective amplifiers 1408 and 1410. The amplifiers can be logarithmic converters (or log/logarithmic amplifiers). The logarithmic converters 1408 and 1410 output to a combiner 1412. The combiner 1412 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 1414. The single channel VAD module can be a conventional VAD module. The single channel VAD module 1414 outputs the desired voice activity signal.  

[0083] FIG. 15 is a block diagram 1500 illustrating an example embodiment of a noise cancellation circuit 1501 employed to receive a closer microphone signal 1510 and a first and second further microphone signal 1512 and 1514, respectively. The noise cancellation circuit 1501 is similar to the noise cancellation circuit 1201, described in relation to FIG. 12. However, the noise cancellation circuit 1501 is employed to receive three signals instead of two. A beam-forming (BF) module 1502 is arranged to receive the signals 1510, 1512 and 1514 and output a main signal 1530, a first reference signal 1532 and second reference signal 1534 to an adaptive noise cancellation module 1504. The beam-forming module is further configured to output a main signal 1522, first reference signal 1520 and second reference signal 1524 to a voice activity detection (VAD) module 1508.  

[0084] The ANC module 1504 produces a noise cancelled signal 1542 to a Single Channel Noise Reduction (NR) module 406, similar to the ANC module 1204 of FIG. 12. The single NR module 1506 then outputs desired speech 1544. The VAD module 1508 outputs the DVAD signal to the ANC module 1504 and the single channel NR module 1506.  

[0085] FIG. 16 is an example embodiment of beam-forming from a boom tube 1602 housing three microphones 1606, 1608, and 1610. A first microphone 1606 is arranged closest to a tip 1604 of the boom tube 1602, a second microphone 1608 is arranged in the boom tube 1602 further away from the tip 1604, and a third microphone 1610 is arranged in the boom tube 1602 even further away from the tip 1604. The first microphone 1606 and second microphone 1608 are arranged to provide data to output a left signal 1626. The first microphone is arranged to output its signal to a gain module 1612 and a delay module 1614, which is outputted to a combiner 1622. The second microphone is connected directly to the combiner 1622. The combiner 1622 subtracts the two provided signals to cancel noise, which creates the left signal 1626.  

[0086] Likewise, the second microphone 1608 is connected to a gain module 1616 and a delay module 1618, which is outputted to a combiner 1620. The third microphone 1610 is connected directly to the combiner 1620. The combiner 1620 subtracts the two provided signals to cancel noise, which creates the right signal 1620.  

[0087] FIG. 17 is an example embodiment of beam-forming from a boom tube 1752 housing four microphones 1756, 1758, 1760 and 1762. A first microphone 1756 is arranged closest to a tip 1754 of the boom tube 1752, a second microphone 1758 is arranged in the boom tube 1752 further away from the tip 1754, a third microphone 1760 is arranged in the boom tube 1752 even further away from the tip 1754, and a fourth microphone 1762 is arranged in the boom tube 1752 away from the tip 1754. The first microphone 1756 and second microphone 1758 are arranged to provide data to output a left signal 1786. The first microphone is arranged to output its signal to a gain module 1772 and a delay module 1774, which is outputted to a combiner 1782. The second microphone is connected directly to the combiner 1782. The combiner 1782 subtracts the two provided signals to cancel noise, which creates the left signal 1786.  

[0088] Likewise, the third microphone 1760 is connected to a gain module 1776 and a delay module 1778, which is outputted to a combiner 1780. The fourth microphone 1762 is connected directly to the combiner 1780. The combiner 1780 subtracts the two provided signals to cancel noise, which creates the right signal 1784.  

[0089] FIG. 18 is a block diagram 1800 illustrating an example embodiment of a beam-forming module 1802 accepting three signals 1810, 1812 and 1814. A closer microphone signal 1810 is output as a main signal 1830 to the ANC module and also inputted to a low-pass filter 1817, to be outputted as a main signal 1820 to the VAD module. A first further microphone signal 1812 and second closer microphone signal 1814 are inputted to respective frequency response matching filter 1806 and 1804, the outputs of which are outputted to be a first reference signal 1832 and second reference signal 1834 to the ANC module. The outputs of the frequency response matching filters 1806 and 1804 are also outputted to low-pass filters 1816 and 1818, respectively, which output a first reference signal 1822 and second reference signal 1824, respectively.  

[0090] FIG. 19 is a block diagram 1900 illustrating an example embodiment of a desired voice activity detection (VAD) module 1902 accepting three signals 1920, 1922 and 1924. The VAD module 1902 receives a main signal 1920, a
The relevant teachings of all patents, published applications and references cited herein are incorporated by reference in their entirety. 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 without departing from the scope of the invention encompassed by the appended claims.

What is claimed is:

1. Audio eyewear, comprising:
   a) a front frame; and
   b) at least one side frame member secured to the front frame for engaging a user's ear, the at least one side frame member having a speaker therein, the speaker being oriented such that an audio port of the speaker faces downwardly at an angle away from said at least one side frame member, whereby directing sound downwardly rearwardly into said user's ear generally along a vertical plane.

2. The eyewear of claim 1 in which said at least one side frame member includes a relatively thick forward portion containing the speaker, and a relatively thin rearward portion extending rearwardly from the thick forward portion for engaging said user's ear, the speaker being positioned at a downward facing lower transition surface that narrows from the thick forward portion into the thin rearward portion along a rearwardly extending upward angle, and angles the audio port of speaker downwardly rearwardly.

3. The eyewear of claim 2 in which the speaker is positioned within a cavity defined by said at least one side frame member.

4. The eyewear of claim 2 in which the speaker defines a speaker plane that is angled downwardly at least about 20 degrees relative to a longitudinal plane of said at least one side frame member.

5. The eyewear of claim 3 in which the speaker is mounted against an inner side of the lower transition surface with a sealing arrangement, the lower transition surface defining audio openings to thereby cause sound from the speaker to pass through.

6. The eyewear of claim 1 in which said at least one side frame member includes right and left side frame members secured to opposite sides of the front frame, each side frame member having a respective speaker therein.

7. The eyewear of claim 6 in which at least one of the right and left side frame members and front frame contains at least one of electronics, at least one microphone, and at least one battery.

8. The eyewear of claim 7 in which electrical signals from the speakers and the at least one microphone are functionally linked to a cell phone, and at least one of the electronics and software in at least one of the eyewear and cell phone are capable of automatically adjusting volume of the speakers according to ambient noise measured by the microphones.

9. The eyewear of claim 8, wherein at least one of the left and right side frame members and front frame includes an array of the microphones, including at least a first microphone and a second microphone, the first microphone coupled to at least one of the left and right side frame members and the front frame about a temple region of the user, the temple region being located approximately between a top corner of a lens opening defined by the front frame, and providing a first audio channel output, and the second microphone coupled to at least one of the left and right side frame members and front frame about an inner edge of the lens opening and providing a second audio channel output.

10. The eyewear of claim 9, further including a digital signal processor located at least one of the left and right side frame members and the front frame member, the digital signal processor including:
   a) a beam-former electronically linked to at least the first and second audio channel outputs and output a main channel and one or more reference channels;
   b) a voice activity detector electronically linked to the main and reference channels and output a desired voice activity channel;
   c) an adaptive noise canceller electronically linked to the main, reference, and desired voice activity channels and output an adaptive noise cancellation channel; and
   d) a noise reducer electronically linked to the voice activity detector of adaptive noise canceller to thereby receive the desired voice activity and adaptive noise cancellation channels and output a desired speech channel.

11. The eyewear device of claim 10, wherein the array of microphones are digital microphones and the beam-former is a digital beam-former.

12. The eyewear device of claim 9, wherein the array of microphones further includes:
   a) a third microphone coupled to the eyeglasses frame about an outer lower corner of the lens opening below the first microphone and providing a third audio channel output; and
   b) a fourth microphone coupled to the glasses frame about a bridge support region above the second microphone and providing a fourth audio channel output.

13. The eyewear device of claim 12, wherein the array of microphones are omni-directional microphones.

14. The eyewear device of claim 13, wherein the omni-directional microphones are any combination of the following: electret condenser microphones, analog microelectromechanical systems (MEMS) microphones, or digital MEMS microphones.

15. The eyewear device of claim 12, wherein the array of microphones is coupled to the eyeglasses frame using at least one flexible printed circuit board (PCB) strip.

16. The eyewear device of claim 15, wherein the array of microphones is coupled to the eyeglasses frame using an upper flexible PCB strip including the first and fourth microphones and a lower flexible PCB strip including the second and third microphones.
17. The eyewear device of claim 16, wherein:
a) the eyeglasses frame further includes an array of vents corresponding to the array of microphones;
b) the array of microphones are bottom port microelectromechanical systems (MEMS) microphones;
c) the first and fourth MEMS microphones are coupled to the upper flexible PCB strip;
d) the second and third MEMS microphones are coupled to the lower flexible PCB strip; and
e) the array of MEMS microphones being arranged such that the bottom ports receive acoustic signals through the corresponding vents.

18. The eyewear device of claim 17, further including a membrane sandwiched between the eyeglasses frame and the microphone.

19. The eyewear device of claim 18, wherein the membrane is a wind-screen membrane and a water-proofing membrane.

20. 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 providing a first and second audio channel output from the first and second microphones, respectively.

21. 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.

22. The eyewear device of claim 21, wherein at least one of the beam-former, the voice activity detector, the adaptive noise canceller and the noise reducer are integrated into at least one of the front frame and the at least one side frame member.

23. The eyewear device of claim 1, further including a sound channel member attached to said at least one side frame member for directing sound from the speaker into said user's ear.

24. The eyewear of claim 23 in which the sound channel member includes a sound deflecting surface that extends from an outer surface of said at least one side frame member over a portion of said user's ear for channeling sound from the speaker into said user's ear while also allowing ambient sound to be heard.

25. The eyewear of claim 23 in which the sound channel member includes a sound tube mounted to the at least one side frame member, and having an inlet opening for receiving sound from the speaker and an outlet opening facing said user's ear for directing the sound from the speaker to said user's ear.

26. A method of hearing audio, comprising the steps of:
a) providing audio eyewear frame having a front frame and at least one side frame member secured to the front frame for engaging a user's ear, the at least one side frame member having a speaker therein; and
b) orienting the speaker such that an audio port of the speaker faces downwardly rearwardly at an angle away from said at least one side frame member for directing sound downwardly rearwardly into said user's ear generally along a vertical plane.

27. The method of claim 26, further including the steps of:
a) providing said at least one side frame member with a thick forward portion containing the speaker, and a thin rearward portion extending rearwardly from the thick forward portion for engaging said user's ear; and
b) positioning the speaker at a downward facing lower transition surface that narrows from the thick forward portion to the thin rearward portion along a rearwardly extending upward angle, and angling the audio port of the speaker downwardly rearwardly.

28. The method of claim 27, further including positioning the speaker within a cavity formed within said at least one side frame member.

29. The method of claim 28, further including mounting the speaker against an inner side of the lower transition surface with a sealing arrangement, the lower transition surface having audio openings for allowing sound from the speaker to pass through.

30. The method of claim 27, further including angling a speaker plane of the speaker downwardly at least about 20 degrees relative to a longitudinal plane of said at least one side frame member.

31. The method of claim 26, further including providing right and left side frame members secured to opposite sides of the front frame, each side frame member having a respective speaker therein.

32. The method of claim 31, further including containing within at least one of the right and left side frame members and front frame, and at least one of electronics, at least one microphone and at least one battery.

33. The method of claim 32, further including linking electrical signals from at least one of the speakers and the at least one microphone to a cell phone, and with at least one of the electronics and software in at least one of the eyewear and cell phone, automatically adjusting volume of the speakers according to ambient noise measured by the microphones.

34. The method of claim 26, further comprising the steps of:
a) coupling an array of microphones to the eyewear, the array of microphones including at least a first and second microphone;
b) arranging the first microphone to couple to the eyewear about a temple region, the temple region being located approximately between a top corner of a lens opening and a support arm;
c) arranging the second microphone to couple to the eyewear frame about an inner edge of the lens opening; and
d) providing a first and second audio channel output from the first and second microphones, respectively.
35. The method of claim 34, further including the steps of:
a) forming beams at a beam-former, the beam-former receiving at least the first and second 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, the 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.

36. The method of claim 35, wherein the first and second audio channels are produced digitally and the beams are formed digitally.

37. The method of claim 34, further including the steps of:
a) arranging a third microphone to couple to the eyewear about an outer lower corner of the lens opening below the first microphone;
b) arranging a fourth microphone to couple to the eyewear about a bridge support region above the second microphone; and
c) providing a third and fourth audio channel output from the third and fourth microphones, respectively.

38. The method of claim 37, wherein an array of omni-directional microphones are coupled to the eyeglasses frame.

39. The method of claim 38, wherein the coupled array of omni-directional microphones are any combination of the following: electret condenser microphones, analog micro-electromechanical systems (MEMS) microphones, or digital MEMS microphones.

40. The method of claim 37, wherein coupling the array of microphones to the eyewear uses at least one flexible printed circuit board (PCB) strip.

41. The method of claim 40, wherein coupling the array of microphones to the eyeglasses frame uses an upper flexible PCB strip including the first and fourth microphones and a lower flexible PCB strip including the second and third microphones.

42. The method of claim 41, wherein coupling the array of microphones to the eyeglasses frame further includes the steps of:
a) coupling each microphone of the array of microphones to a corresponding vent of an array of vents, the array of microphones being bottom port or top port microelectromechanical system (MEMS) microphones and the vents being located in the eyeglasses frame, wherein the first and fourth MEMS microphones are coupled to the upper flexible PCB strip and the second and third MEMS microphones are coupled to the lower flexible PCB strip; and
b) arranging the array of MEMS microphones such that the ports received acoustic signals through the corresponding vents.

43. The method of claim 42, further including coupling a membrane between the eyeglasses frame and the microphones.

44. The method of claim 43, further including wind-screening and water-proofing the array of microphones using the membrane, the membrane being made of a wind-screen and water-proofing material.

45. The method of claim 26, further including directing sound from the speaker into said user’s ear with a sound channel member attached to said at least one side frame member.

46. The method of claim 45, further including channeling sound from the speaker into said user’s ear while also allowing ambient sound to be heard with the sound channel member, the sound channel member including a sound deflecting surface that extends from an outer surface of said at least one side frame member and over a portion of said user’s ear.

47. The method of claim 45, further including directing the sound from the speaker to said user’s ear with the sound channel member, the sound channel member including a sound tube mounted to the at least one side frame member, and having an inlet opening for receiving sound from the speaker and an outlet opening facing said user’s ear through which the sound exits.

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