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(54) **EAR-WEARABLE ELECTRONIC DEVICE INCLUDING ACOUSTIC FILTER**

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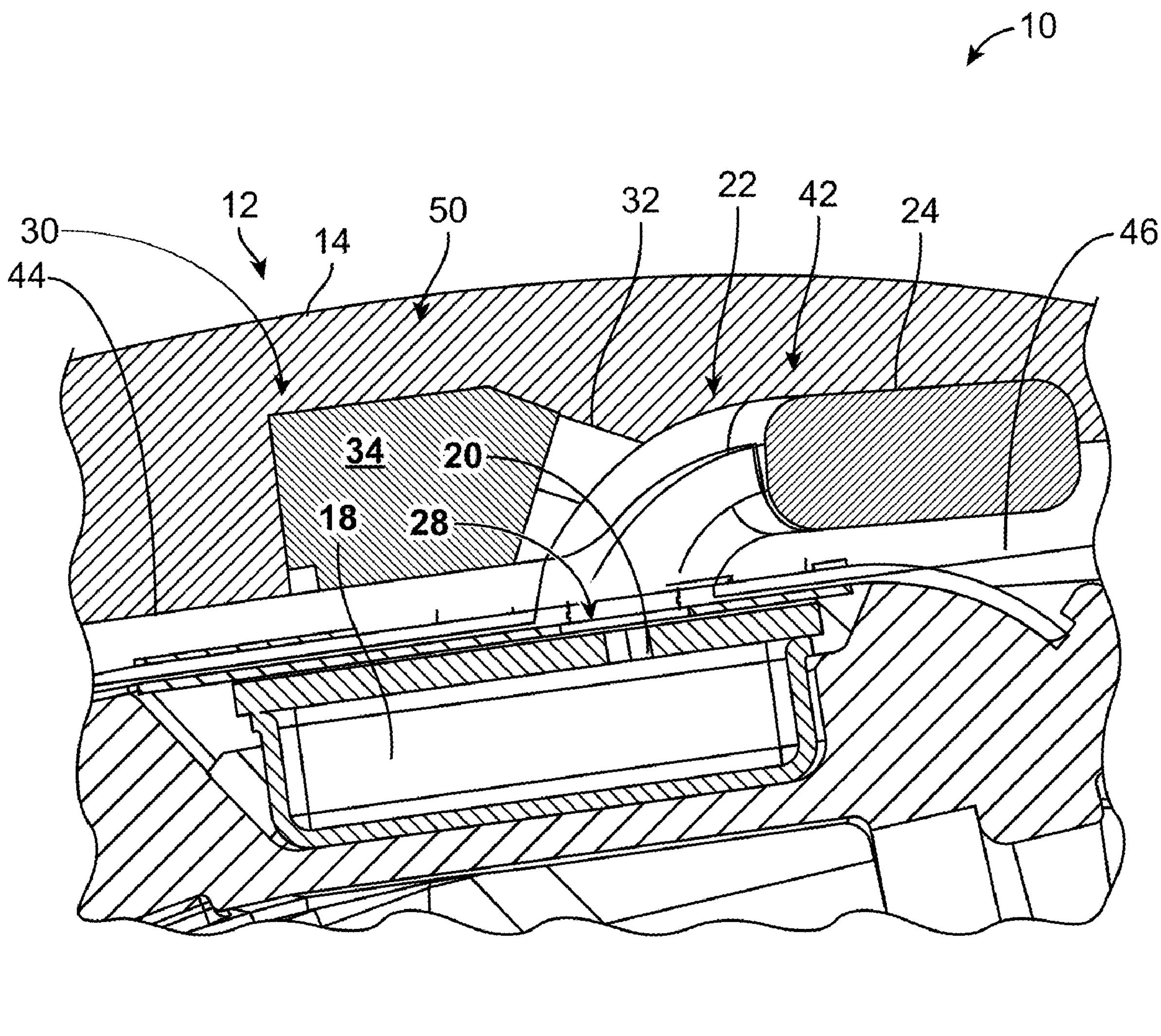
(52) **U.S. Cl.**

CPC ***H04R 1/222*** (2013.01); ***H04R 1/08*** (2013.01); ***H04R 25/48*** (2013.01)

(57) **ABSTRACT**

Various embodiments of an ear-wearable electronic device are disclosed. The device includes a housing having a top shell and a bottom shell, a microphone disposed within the housing, and an acoustic path disposed at least partially within the housing and extending between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to an inlet of the microphone. The device further includes an acoustic filter disposed at least partially within an inner surface of the top shell and includes a neck and a resonance cavity acoustically coupled to the neck. The acoustic filter is acoustically coupled to the acoustic path via the neck. Further, the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.



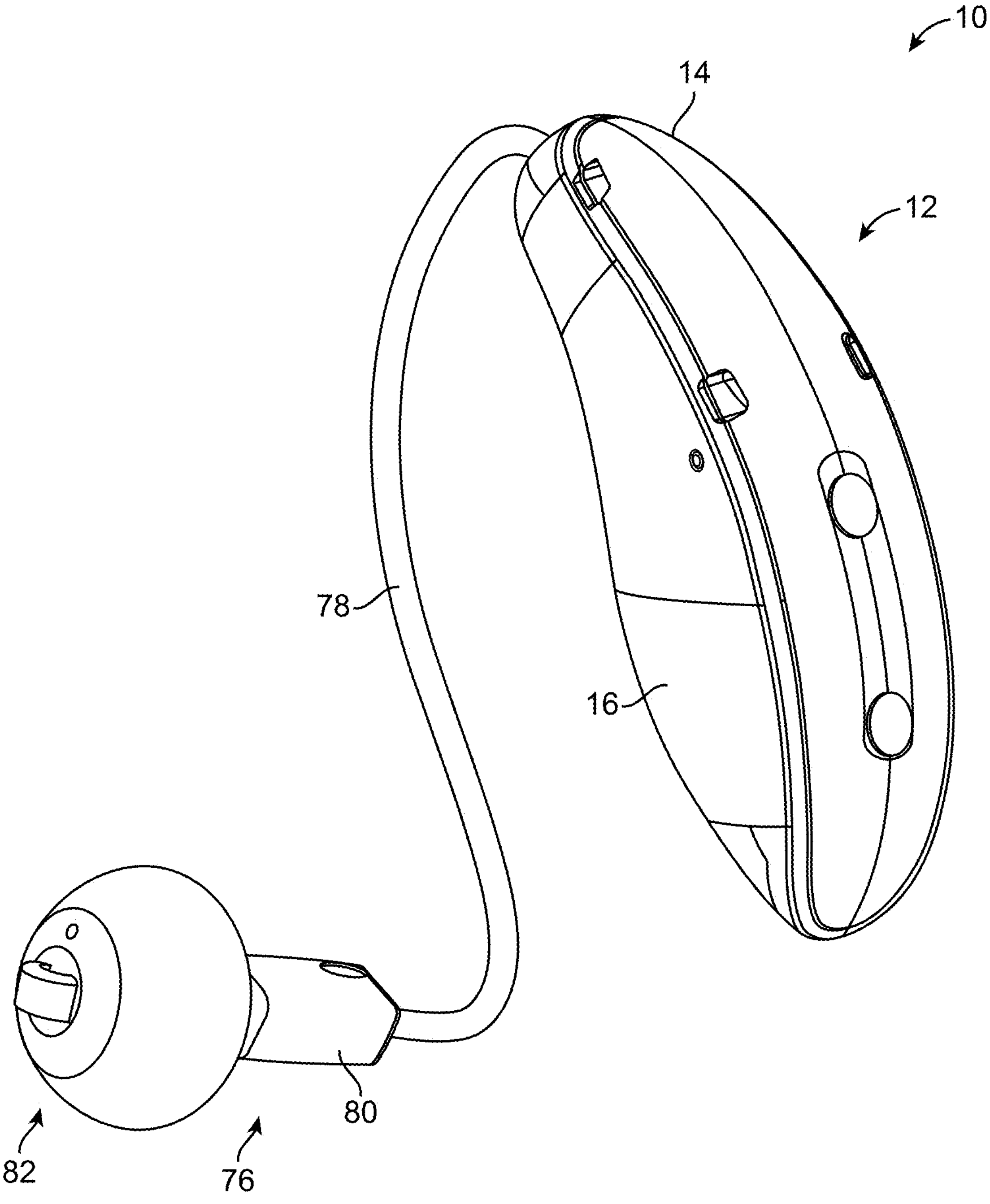
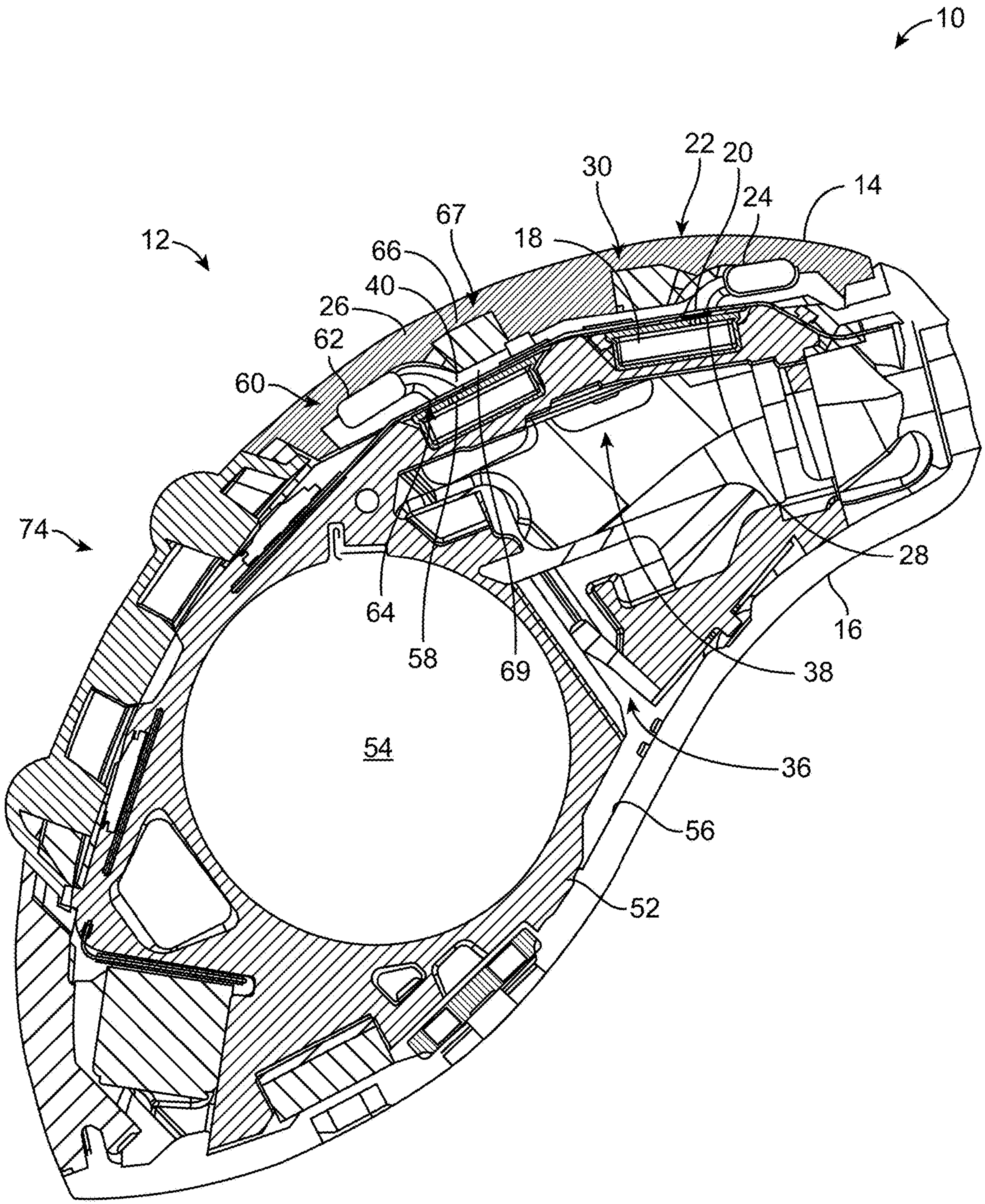


FIG. 1


10
12
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18
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69
74

FIG. 2

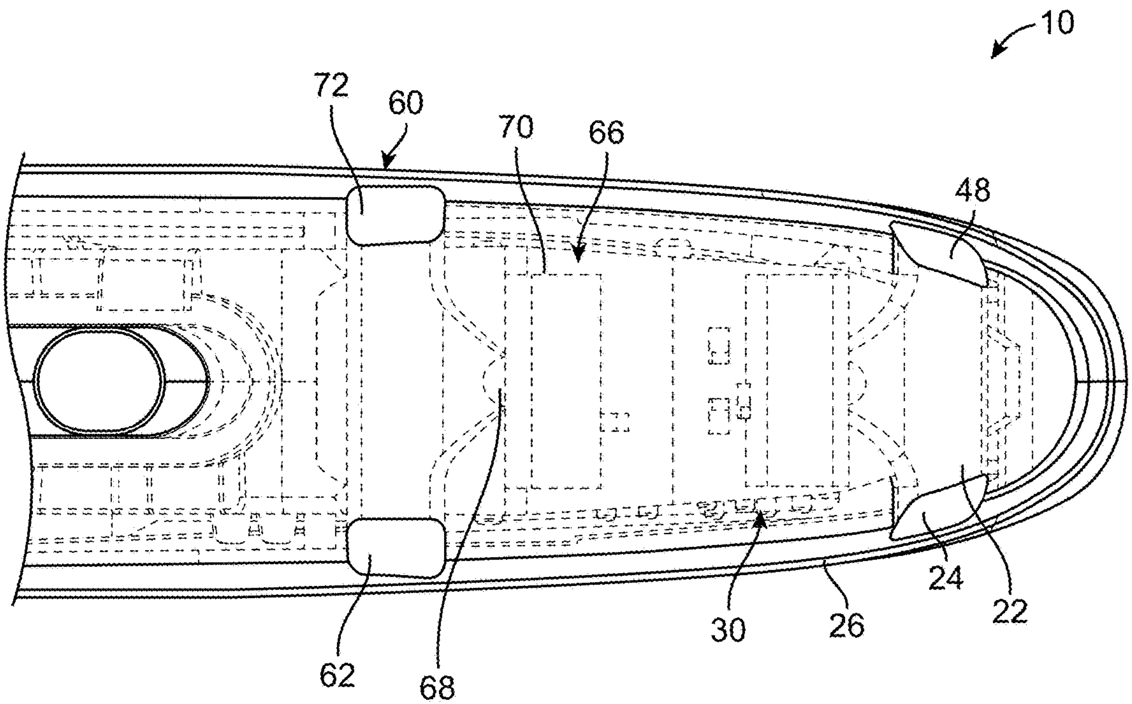

FIG. 3

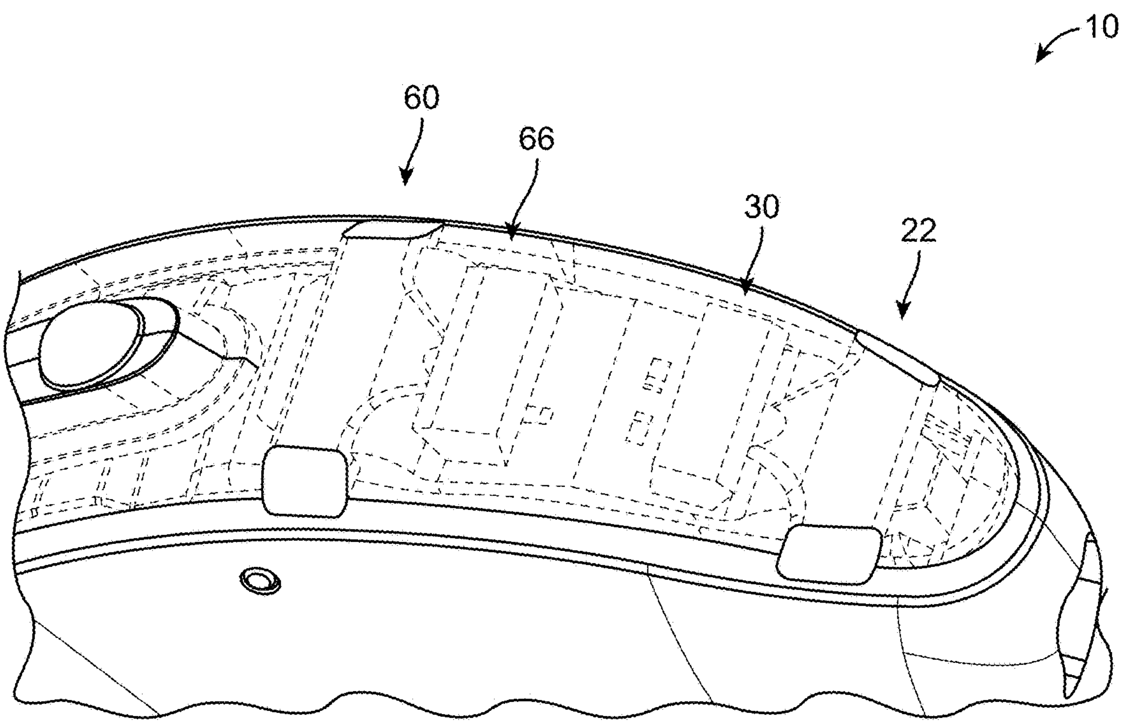

FIG. 4

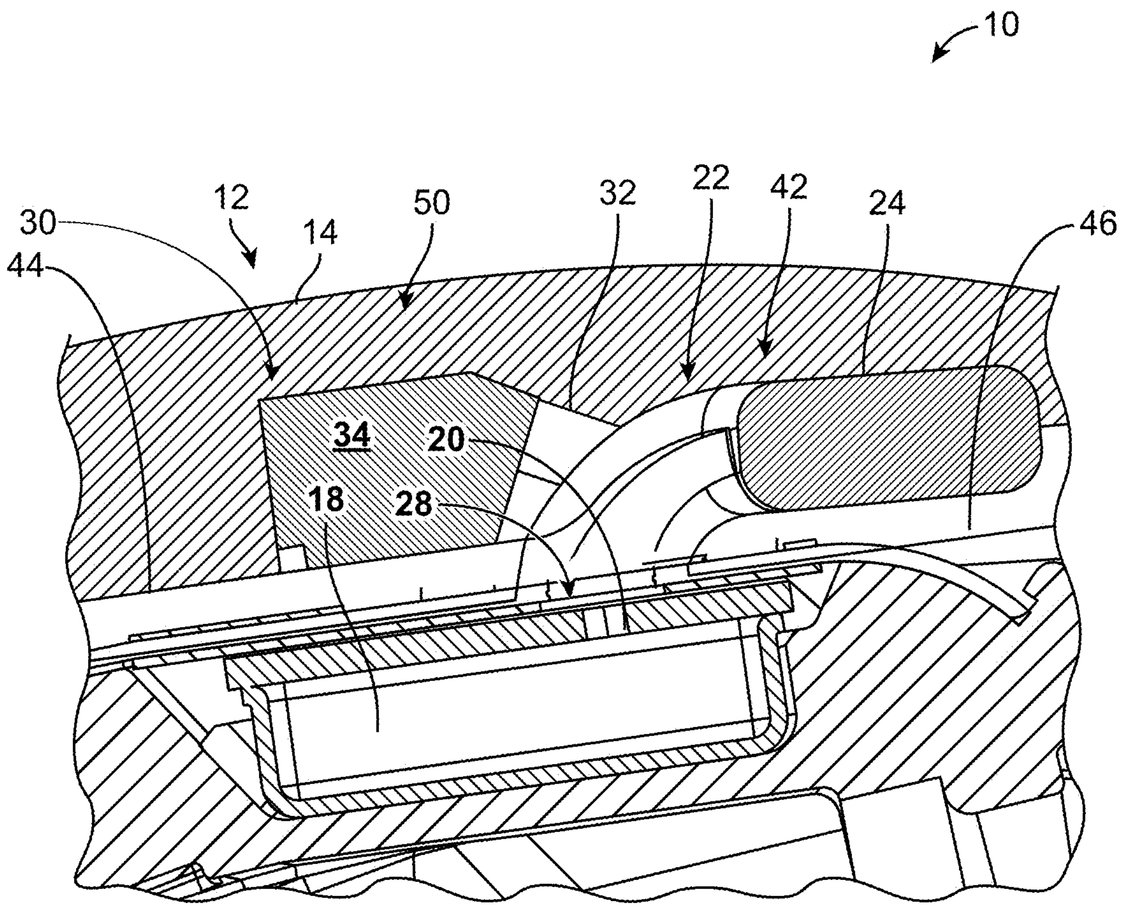

FIG. 5

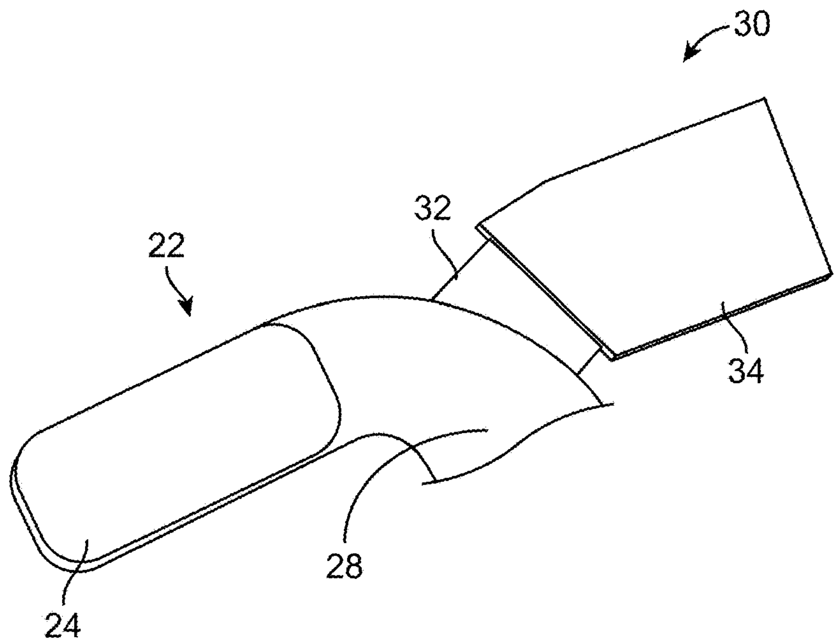

FIG. 6

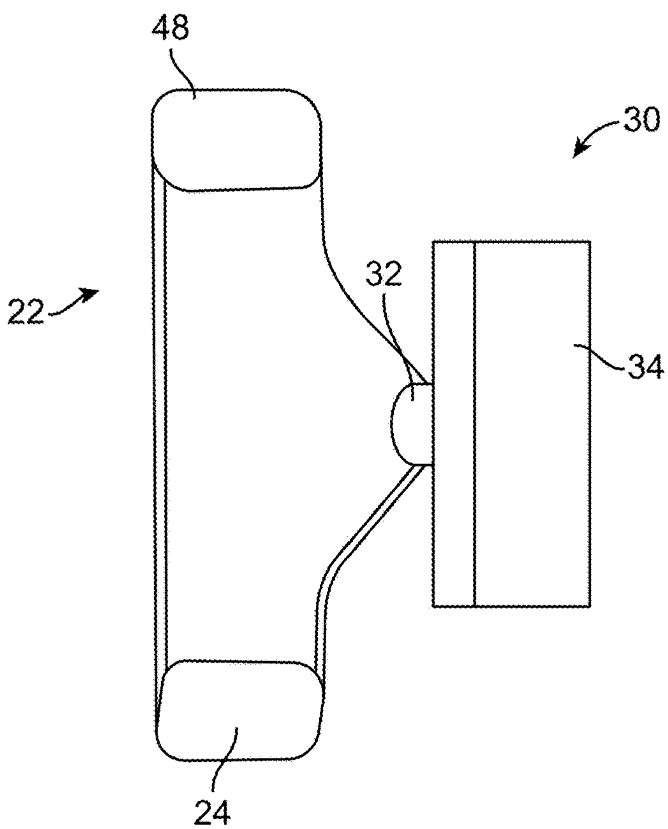

FIG. 7

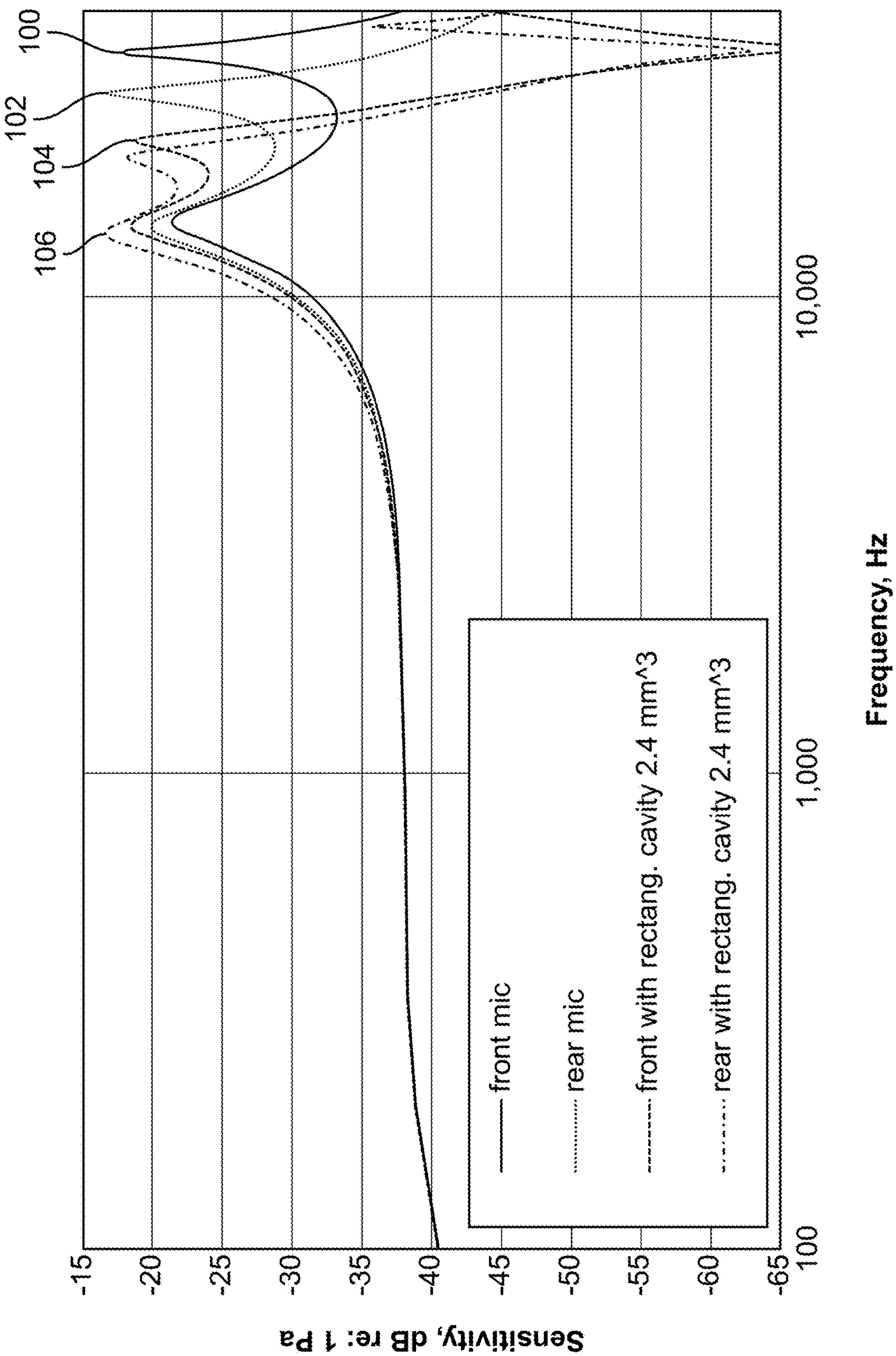
100
102
104
106
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
Sensitivity, dB re: 1 Pa
100
1,000
10,000
Frequency, Hz
front mic
rear mic
front with rectang. cavity 2.4 mm^3
rear with rectang. cavity 2.4 mm^3

FIG. 8

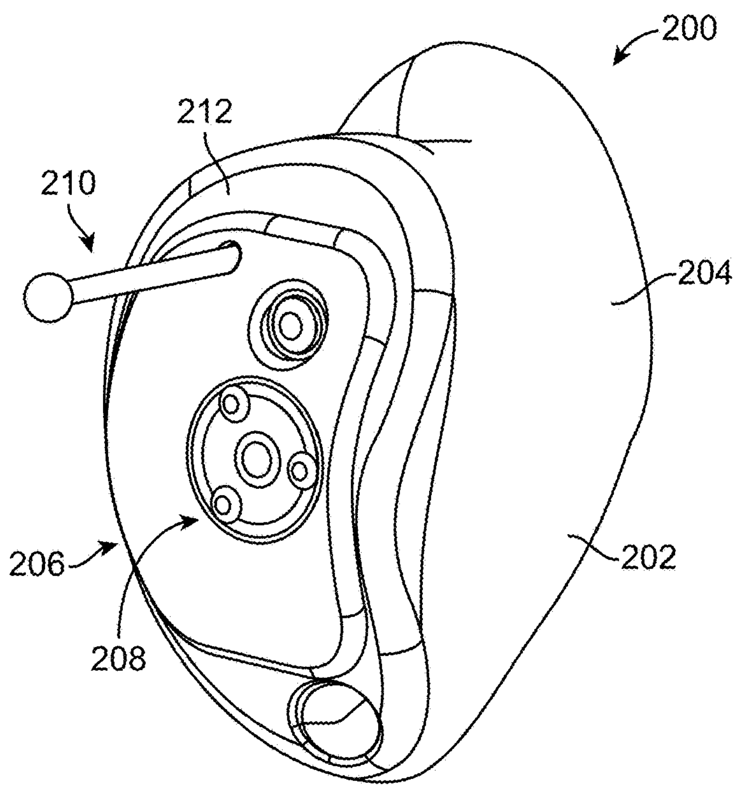

FIG. 9

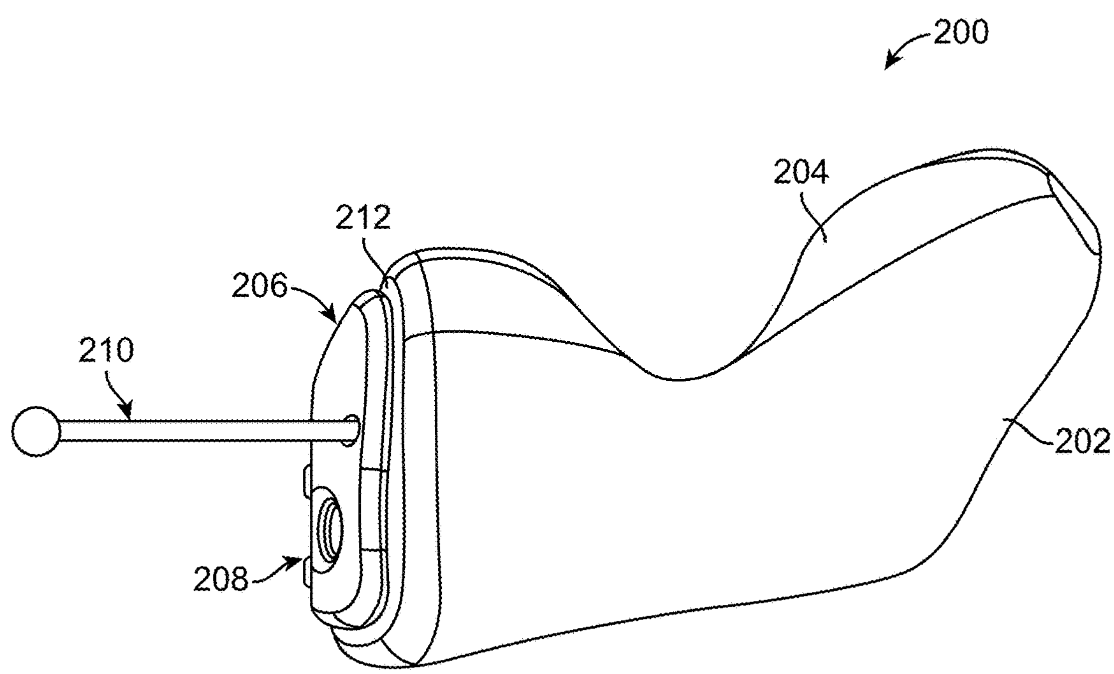

FIG. 10

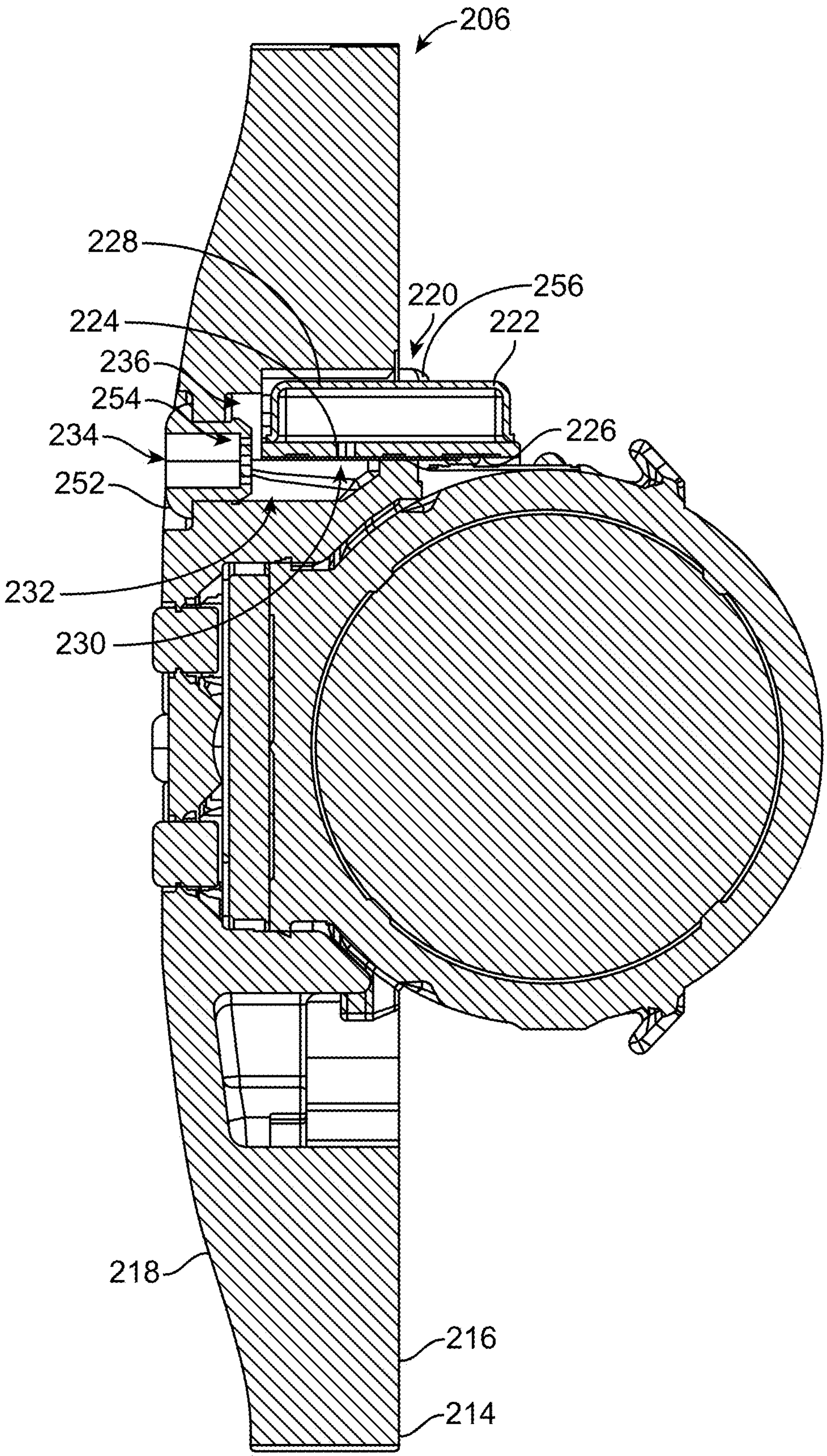

FIG. 11

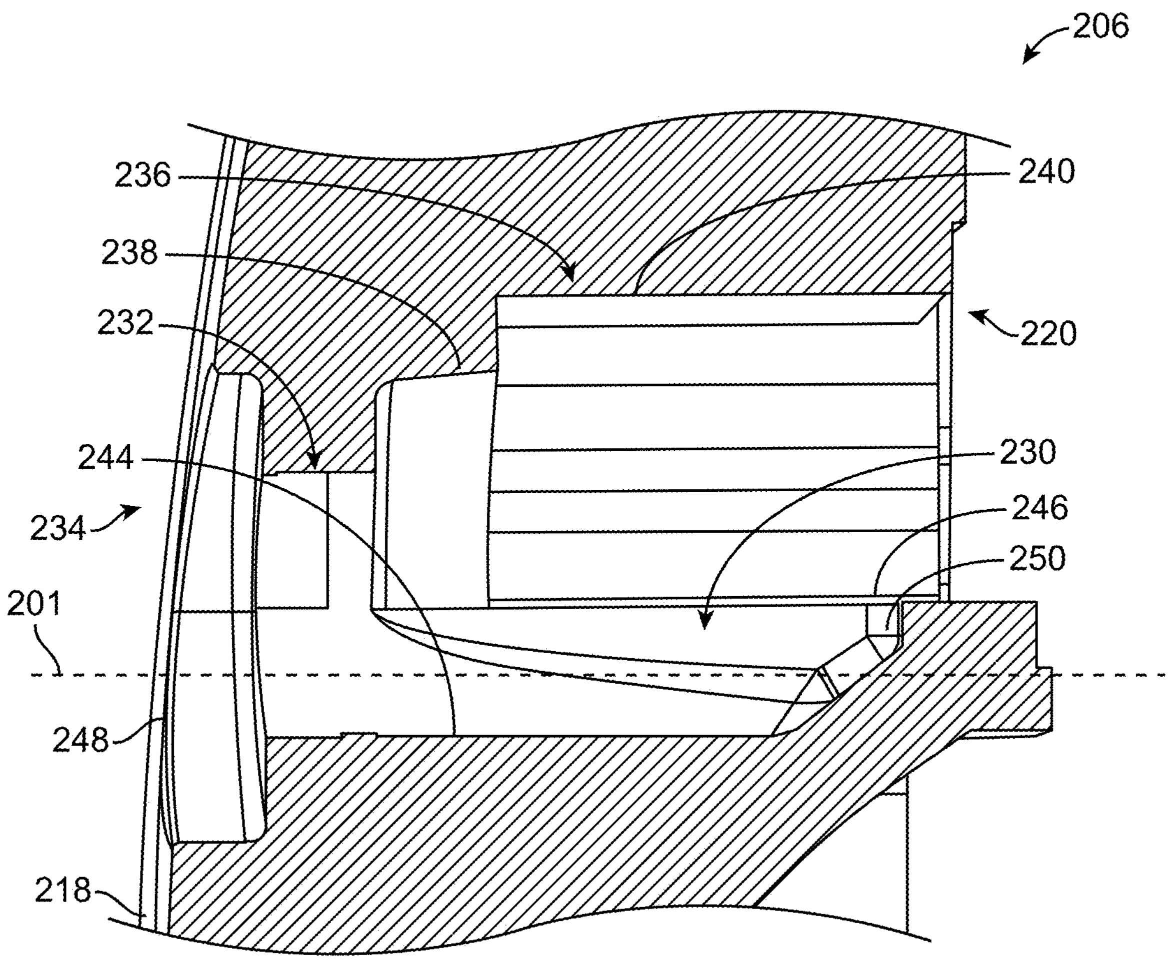

FIG. 12

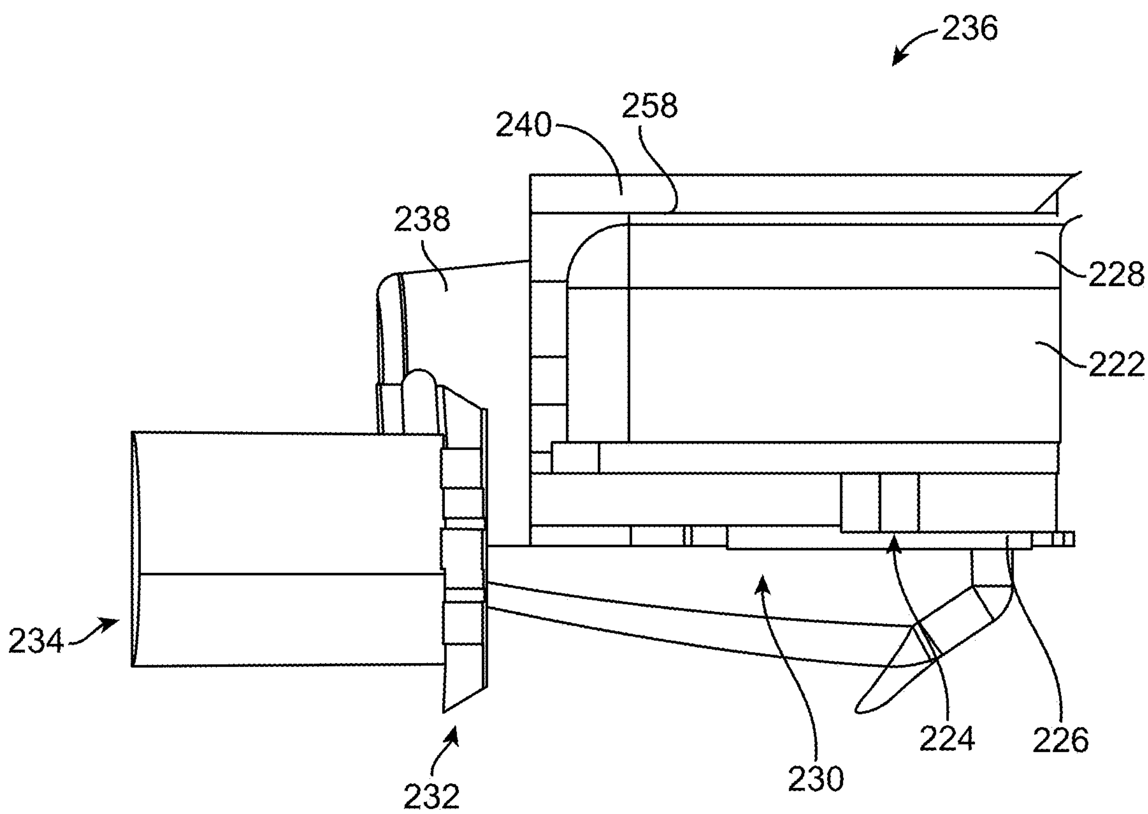

FIG. 13

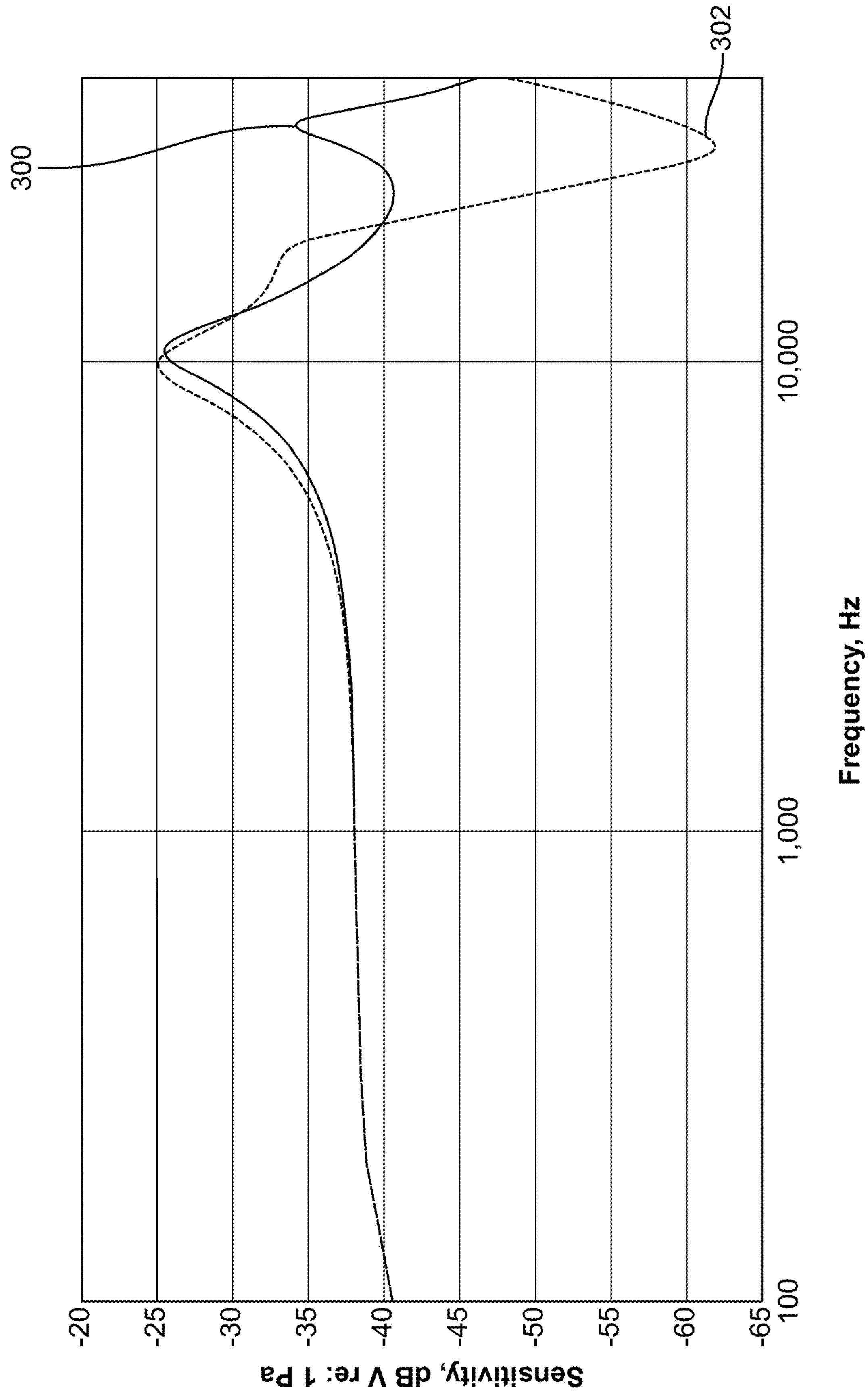
300
302
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
Sensitivity, dB V re: 1 Pa
100
1,000
10,000
Frequency, Hz

FIG. 14

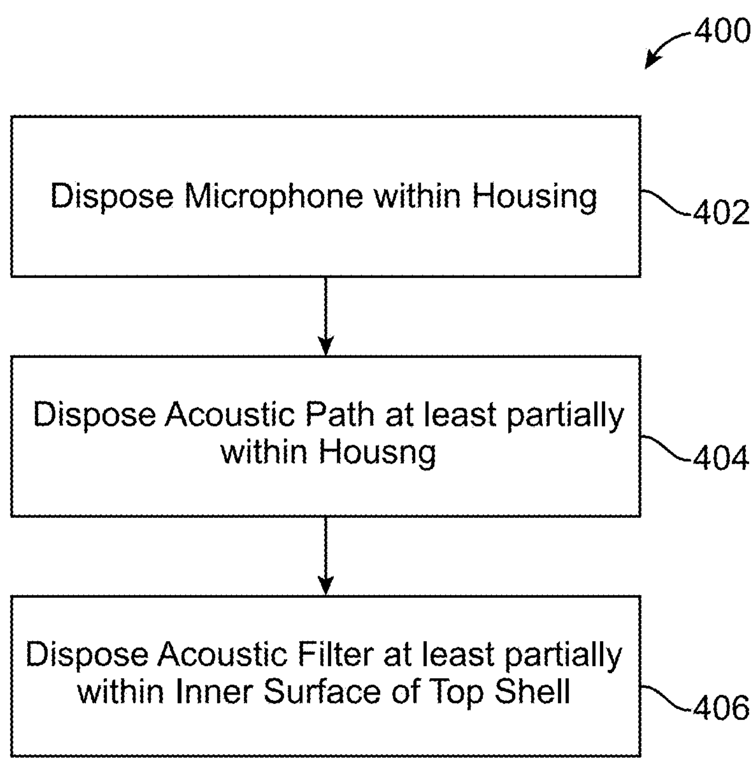
400
Dispose Microphone within Housing
402
Dispose Acoustic Path at least partially within Housng
404
Dispose Acoustic Filter at least partially within Inner Surface of Top Shell
406

FIG. 15

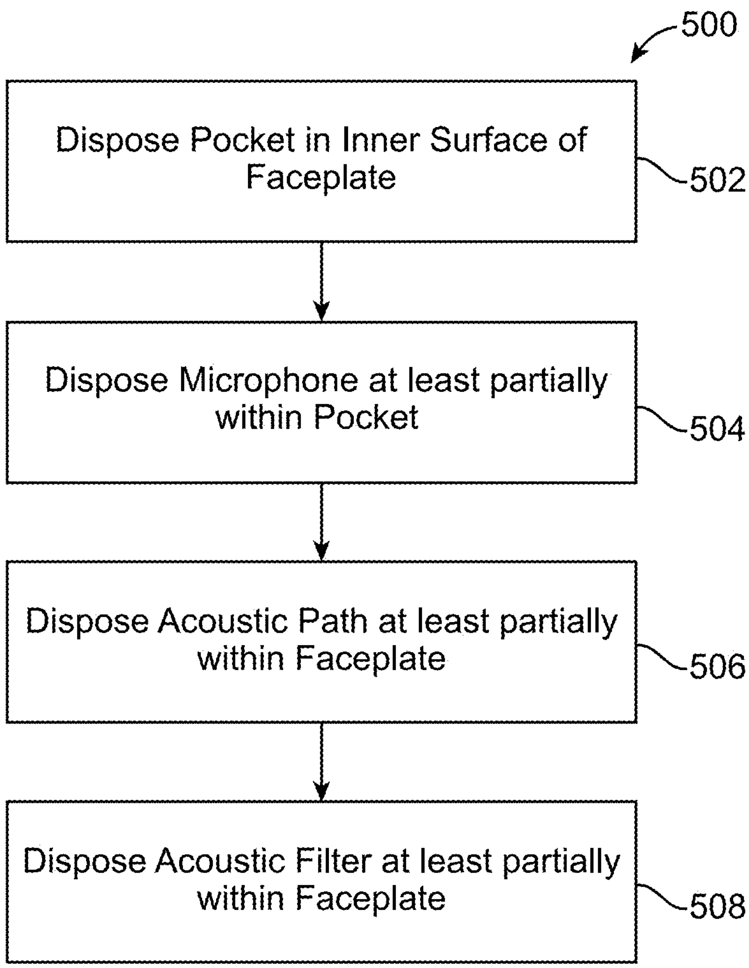
500
Dispose Pocket in Inner Surface of Faceplate
502
Dispose Microphone at least partially within Pocket
504
Dispose Acoustic Path at least partially within Faceplate
506
Dispose Acoustic Filter at least partially within Faceplate
508

FIG. 16

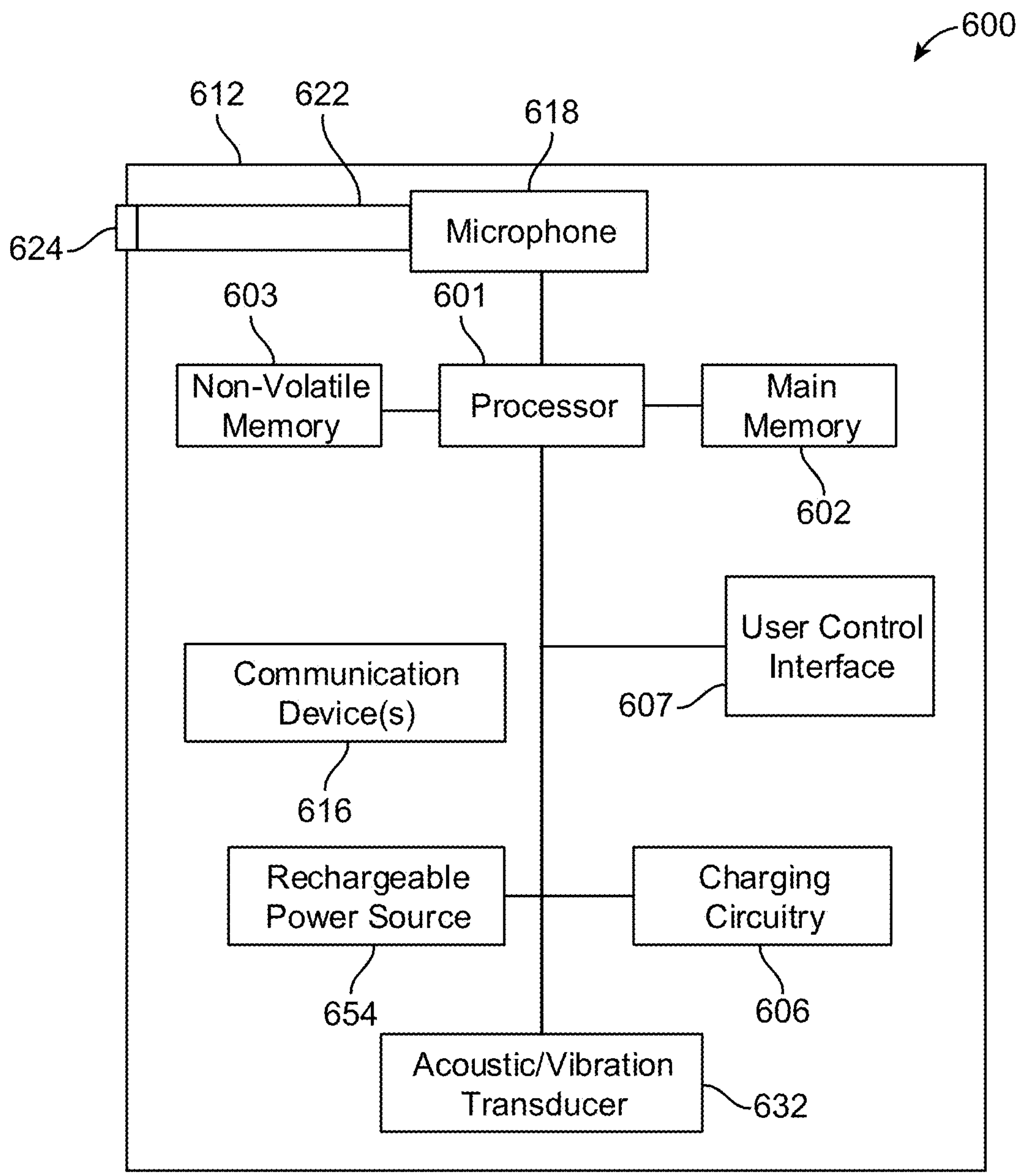
600
612
622
618
624
Microphone
603
601
Non-Volatile Memory
Processor
Main Memory
602
User Control Interface
Communication Device(s)
607
616
Rechargeable Power Source
Charging Circuitry
654
606
Acoustic/Vibration Transducer
632

FIG. 17

EAR-WEARABLE ELECTRONIC DEVICE INCLUDING ACOUSTIC FILTER

[0001] This application claims the benefit of U.S. Provisional Application No. 63/555,212, filed Feb. 19, 2024, the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] Ear-wearable electronic devices such as hearing devices are disposed in an ear of a wearer or inserted into an opening of an ear canal of the wearer and typically include a housing or shell with electronic components such as a receiver (i.e., speaker) disposed within the housing. The receiver is adapted to provide acoustic information in the form of acoustic waves to the wearer's ear canal from a controller either disposed within the housing of the hearing device or connected to the hearing device by a wired or wireless connection. This acoustic information can include music or speech from a recording or other source, e.g., ambient sounds such as speech from a person or persons that are speaking in proximity to the wearer. Such speech can be amplified so that the wearer can better hear the speaker.

[0003] Hearing assistance devices, such as hearing aids, can be used to assist wearers suffering hearing loss by amplifying sounds into one or both ear canals. Such devices typically include hearing assistance components such as a microphone for receiving ambient sound, an amplifier for amplifying the microphone signal in a manner that depends upon the frequency and amplitude of the microphone signal, a speaker or receiver for converting the amplified microphone signal to sound for the wearer, and a battery for powering the components.

SUMMARY

[0004] In general, the present disclosure provides various embodiments of an ear-wearable electronic device that includes an acoustic filter disposed at least partially within a housing of the device. The acoustic filter is acoustically coupled to an acoustic path of the device by a neck that is acoustically coupled to a resonance cavity of the filter. The acoustic filter is configured to reduce an intensity of acoustic waves sensed by a microphone of the device in a first frequency range, e.g., an ultrasonic frequency range.

[0005] In one aspect, the present disclosure provides an ear-wearable electronic device including a housing having a top shell and a bottom shell, a microphone disposed within the housing and having an inlet, and an acoustic path disposed at least partially within the housing between the top and bottom shells and extending between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to the inlet of the microphone. The device further includes an acoustic filter disposed at least partially within an inner surface of the top shell, where the acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. The acoustic filter is acoustically coupled to the acoustic path via the neck. Further, the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0006] In another aspect, the present disclosure provides an ear-wearable electronic device including a faceplate having an outer surface and an inner surface, where the faceplate defines a pocket disposed in the inner surface of the faceplate; and a microphone disposed at least partially within the pocket and including an inlet disposed within the pocket. The device also includes an acoustic path disposed at least partially within the faceplate and extending between an acoustic port disposed at the outer surface of the faceplate and an outlet disposed in the pocket, where the acoustic path is acoustically coupled to the inlet of the microphone via the outlet; and an acoustic filter disposed at least partially within the faceplate, where the acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. Further, the acoustic filter is acoustically coupled to the acoustic path via the neck. The acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0007] In another aspect, the present disclosure provides a method of forming an ear-wearable electronic device, including disposing a microphone within a housing, where the housing includes a top shell and a bottom shell; disposing an acoustic path at least partially within the housing such that it extends between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to an inlet of the microphone; and disposing an acoustic filter at least partially within an inner surface of the top shell of the housing. The acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. The acoustic filter is acoustically coupled to the acoustic path via the neck. Further, the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0008] In another aspect, the present disclosure provides a method of forming an ear-wearable electronic device, including disposing a pocket in an inner surface of a faceplate; disposing a microphone at least partially within the pocket such that an inlet of the microphone is disposed within the pocket; and disposing an acoustic path at least partially within the faceplate, where the acoustic path extends between an acoustic port disposed at an outer surface of the faceplate and an outlet disposed in the pocket. The acoustic path is acoustically coupled to the inlet of the microphone via the outlet. The method further includes disposing an acoustic filter at least partially within the faceplate. The acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. Further, the acoustic filter is acoustically coupled to the acoustic path via the neck, and the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0009] All headings provided herein are for the convenience of the reader and should not be used to limit the meaning of any text that follows the heading, unless so specified.

[0010] The terms "comprises" and variations thereof do not have a limiting meaning where these terms appear in the description and claims. Such terms will be understood to imply the inclusion of a stated step or element or group of steps or elements but not the exclusion of any other step or element or group of steps or elements. The term "consisting of" means "including," and is limited to whatever follows the phrase "consisting of." Thus, the phrase "consisting of" indicates that the listed elements are required or mandatory and that no other elements may be present. The term "consisting essentially of" means including any elements listed after the phrase and is limited to other elements that do not interfere with or contribute to the activity or action specified in the disclosure for the listed elements. Thus, the phrase "consisting essentially of" indicates that the listed elements are required or mandatory, but that other elements are optional and may or may not be present depending upon whether or not they materially affect the activity or action of the listed elements.

[0011] The words "preferred" and "preferably" refer to embodiments of the disclosure that may afford certain benefits, under certain circumstances; however, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful and is not intended to exclude other embodiments from the scope of the disclosure.

[0012] In this application, terms such as "a," "an," and "the" are not intended to refer to only a singular entity but include the general class of which a specific example may be used for illustration. The terms "a," "an," and "the" are used interchangeably with the term "at least one." The phrases "at least one of" and "comprises at least one of" followed by a list refers to any one of the items in the list and any combination of two or more items in the list.

[0013] As used herein, the term "or" is generally employed in its usual sense including "and/or" unless the content clearly dictates otherwise.

[0014] The term "and/or" means one or all of the listed elements or a combination of any two or more of the listed elements.

[0015] As used herein in connection with a measured quantity, the term "about" refers to that variation in the measured quantity as would be expected by the skilled artisan making the measurement and exercising a level of care commensurate with the objective of the measurement and the precision of the measuring equipment used. Herein, "up to" a number (e.g., up to 50) includes the number (e.g., 50).

[0016] Also herein, the recitations of numerical ranges by endpoints include all numbers subsumed within that range as well as the endpoints (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, 5, etc.).

[0017] These and other aspects of the present disclosure will be apparent from the detailed description below. In no event, however, should the above summaries be construed as limitations on the claimed subject matter, which subject matter is defined solely by the attached claims, as may be amended during prosecution.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Throughout the specification, reference is made to the appended drawings, where like reference numerals designate like elements, and wherein:

[0019] FIG. **1** is a schematic perspective view of one embodiment of an ear-wearable electronic device.

[0020] FIG. **2** is a schematic cross-section view of a housing of the electronic device of FIG. **1**.

[0021] FIG. **3** is a schematic top view of a portion of the housing of the electronic device of FIG. **1** with a top shell of the device rendered transparent for clarity.

[0022] FIG. **4** is a schematic perspective view of the portion of the housing of the electronic device shown in FIG. **3**.

[0023] FIG. **5** is a schematic cross-section view of another portion of the housing of the electronic device of FIG. **1**.

[0024] FIG. **6** is a schematic side view of an acoustic path and an acoustic filter acoustically coupled to the acoustic path of the electronic device of FIG. **1**.

[0025] FIG. **7** is a schematic top view of the acoustic path and the acoustic filter of FIG. **6**.

[0026] FIG. **8** is a plot of sensitivity versus frequency for simulated sensitivity of microphones with acoustic paths that are acoustically coupled to the microphones for the electronic device of FIG. **1**.

[0027] FIG. **9** is a schematic perspective view of another embodiment of an ear-wearable electronic device.

[0028] FIG. **10** is a schematic side view of the electronic device of FIG. **9**.

[0029] FIG. **11** is a schematic cross-section view of a faceplate and one or more electronic components of the electronic device of FIG. **9**.

[0030] FIG. **12** is a schematic cross-section view of an acoustic path, pocket, and acoustic filter of the electronic device of FIG. **9** that are disposed at least partially within the faceplate.

[0031] FIG. **13** is a schematic cross-section view of the acoustic path and acoustic filter of the electronic device of FIG. **9** in isolation with the faceplate removed.

[0032] FIG. **14** is a plot of sensitivity versus frequency for simulated sensitivity of microphones with acoustic paths that are acoustically coupled to the microphones for the electronic devices of FIG. **9**.

[0033] FIG. **15** is a flowchart of one embodiment of a method of forming the ear-wearable electronic device of FIG. **1**.

[0034] FIG. **16** is a flowchart of one embodiment of a method of forming the ear wearable electronic device of FIG. **9**.

[0035] FIG. **17** is a schematic block diagram of another embodiment of an ear-wearable electronic device.

DETAILED DESCRIPTION

[0036] In general, the present disclosure provides various embodiments of an ear-wearable electronic device that includes an acoustic filter disposed at least partially within a housing of the device. The acoustic filter is acoustically coupled to an acoustic path of the device by a neck that is acoustically coupled to a resonance cavity of the filter. The acoustic filter is configured to reduce an intensity of acoustic waves sensed by a microphone of the device in a first frequency range, e.g., an ultrasonic frequency range.

[0037] Ear-wearable electronic devices such as hearing devices can include an acoustic path that can undesirably have a natural quarter-wavelength resonance at ultrasonic frequencies of between about 20 kHz and about 40 kHz. This resonance can amplify the sensitivity of a microphone of the device that may sometimes interfere with a sampling frequency of a digital signal processing (DSP) circuit of the device. Such interference can produce an audible "crackling" artifact in acoustic waves that are directed to a wearer by a receiver or speaker of the device. As a result, it may be preferred to remove or reduce these ultrasonic resonances in the acoustic waves provided to the wearer.

[0038] Various techniques have been attempted to reduce ultrasonic resonances caused by the acoustic path. For example, a length of the acoustic path can be shortened by reducing a distance from an acoustic port at an outer surface of the device to the microphone. Such shortening of the acoustic path can increase a resonance frequency of the path beyond 32 kHz, which can be approximately equal to ⅓ of a sampling frequency of a processor (96 kHz). When an audio signal from the microphone is digitized by the processor, an ultrasonic noise can be present in the digital signal, thereby causing a crackling sound in the audio signal when the digital signal from the processor is converted back to an analog signal. Such crackling sound can be loud and unpleasant for the wearer. A similar effect can occur when the resonance frequency of the acoustic path is approximately equal to ¼ of the sampling frequency of the processor, e.g., 24 kHz, or at any other simple fraction of the sampling frequency.

[0039] One or more embodiments of ear-wearable electronic devices described herein can provide various advantages over currently-available devices. For example, one or more embodiments of devices described herein can include one or more acoustic filters that are acoustically coupled to an acoustic path of the device. Each acoustic filter can be configured to reduce an intensity of acoustic waves sensed by the microphone in one or more frequency ranges. In one or more embodiments, such frequency range can be at least 20 kHz and no greater than 50 kHz, thereby reducing or removing at least a portion of the ultrasonic frequencies that may reach the microphone. Such frequency reduction can minimize undesirable ultrasonic resonances in the acoustic waves that are directed to the wearer by a receiver of the device that are based on one or more signals provided by the microphone to digital signal processing circuitry of the device. Use of one or more acoustic filters can also enable a longer acoustic path that can enable greater design freedoms for the overall device. Further, even if the resonance of the acoustic path falls between 20 kHz and 50 kHz, the acoustic filter can be designed to compensate for such ultrasonic resonance by shifting the resonance down to a frequency where increased microphone sensitivity would not be as much of a concern.

[0040] The acoustic filter can be acoustically connected to any suitable portion or portions of the acoustic path. Further, the acoustic filter can take any suitable shape and have any suitable dimensions.

[0041] The acoustic filter can employ any suitable technique to assist in reducing the intensity of these acoustic waves that are sensed by the microphone. For example, the acoustic filter can act as an ultrasonic energy absorber by accumulating energy of the ultrasonic resonances of the acoustic path. As a result, a sound pressure level of these ultrasonic resonances at the microphone inlet can be reduced. In one or more embodiments, the acoustic filter can be configured to reduce an intensity of acoustic waves sensed by the microphone at other frequency ranges to provide a stop-band filter that can minimize noise of selected frequencies.

[0042] FIGS. **1-5** are various views of one embodiment of an ear-wearable electronic device **10**. The ear-wearable device **10** is a behind-the-ear (BTE) type device and thus includes a housing **12** that is operable to be worn on or behind an ear of a wearer. The device **10** can include any suitable electronic circuitry or components, e.g., the electronic circuitry and components of ear-wearable electronic device **600** of FIG. **17**.

[0043] The housing **12** includes a top shell **14** and a bottom shell **16**. As shown in FIG. **2**, which is a schematic cross-section view of the housing **12** of the device **10**, a microphone **18** is disposed within the housing **12** and includes an inlet **20**. An acoustic path **22** is disposed at least partially within the housing **12** between the top and bottom shells **14**, **16** and extends between an acoustic port **24** disposed at an outer surface **26** of the housing and an outlet **28** (FIG. **5**) disposed within the housing that acoustically couples the acoustic path to the inlet **20** of the microphone **18**. The device **10** further includes an acoustic filter **30** disposed at least partially within an inner surface **44** (FIG. **5**) of the top shell **14**. The acoustic filter **30** includes a neck **32** and a resonance cavity **34** acoustically coupled to the neck. As used herein, the term "acoustically coupled" means fluidically coupled or that any barrier positioned between two or more elements or components that are acoustically coupled is generally acoustically transparent for frequencies of interest, where acoustically transparent means that the element or component attenuates sound at a sound pressure level of no greater than 6 dB.

[0044] The acoustic filter **30** is acoustically coupled to the acoustic path **22** via the neck **32**. Further, the acoustic filter **30** is configured to reduce an intensity of acoustic waves sensed by the microphone **18** in a first frequency range as is further described herein.

[0045] The housing **12** of the device **10** can take any suitable shape and having any suitable dimensions. In one or more embodiments, the housing **12** is configured to rest against a wearer's outer ear in a behind-the-ear orientation. The housing **12** can be manufactured by, for example, injection-molding, 3D printing, etc. The housing **12** can also include any suitable materials, e.g., inorganic (e.g., metallic, ceramic) or polymeric materials. In one or more embodiments, the housing **12** can include at least one of silicone, urethane, acrylate, flexible epoxy, or acrylated urethane materials.

[0046] In the illustrated embodiment, the housing **12** includes the top shell **14** and the bottom shell **16**. For purposes of this disclosure, the terms "top," "bottom," "above," "below," "front," "back," etc. are not intended to indicate a required orientation of use relative to the ground or other reference point. Generally, these terms are intended to help distinguish locations relative to an arbitrary reference point and may correspond to the orientation in the drawings, but no limitation is intended by the use of these terms.

[0047] The top shell **14** can be connected to the bottom shell **16** using any suitable technique. In one or more embodiments, the top shell **14** can be removably connected to the bottom shell **16** using any suitable technique, e.g., adhering, snap fitting, press fitting, mechanically fastening, welding, etc.

[0048] The top and bottom shells **14**, **16** form an enclosure **36** that, once assembled, holds electronic components **38**. For example, the device **10** includes the microphone **18** disposed within any suitable portion of the housing **12**. In one or more embodiments, the microphone **18** can be disposed on a frame **52** that is disposed within the housing **12** between the top shell **14** and the bottom shell **16**. The frame **52** can take any suitable shape and have any suitable dimensions. Further, the frame **52** can be configured to support other electronic components such as battery **54**.

[0049] The microphone **18** includes the inlet **20**. Further, the microphone **18** can include any suitable microphone, e.g., a MEMS microphone, an electret condenser microphone, co-joined microphone sets, etc. The device **10** can include any suitable number of microphones. In one or more embodiments, the device **10** includes a second microphone

40 as is further described herein. The microphone **18** can be configured to convert acoustic waves that enter the microphone through its inlet **20** into one or more electric signals that are directed to a controller or processor (e.g., processor **601** of ear-wearable electronic device **600** of FIG. **17**) disposed within the housing **12** or remotely from the housing by a wired or wireless connection.

[0050] Disposed at least partially within the housing **12** between the top and bottom shells **14**, **16** is the acoustic path **22**. In one or more embodiments, the acoustic path **22** can be disposed entirely within the housing **12**. In one or more embodiments, the acoustic path **22** can be disposed at least partially within an inner surface **44** of the top shell **14**. In one or more embodiments, the acoustic path can be disposed at least partially within an inner surface **56** of the bottom shell **16**. In one or more embodiments, the acoustic path **22** can be formed by a concavity **42** disposed in an inner surface **44** of the top shell **14** and a gasket **46** connected to the inner surface of the top shell as is shown in FIG. **5**. The gasket **46** can take any suitable shape and have any suitable dimensions. The gasket **46** can be a single continuous piece or multiple pieces. Further, the gasket **46** can include any suitable material, e.g., at least one of an inorganic (e.g., metallic, ceramic) material or a polymeric material. Further, in one or more embodiments, the gasket **46** can be sealed to the inner surface **44** of the top shell **14** such that that acoustic path **22** is entirely enclosed by the top shell **14** and the gasket.

[0051] As can be seen in FIG. **5**, which is a schematic cross-section view of a portion of the housing **12** of the device **10**, the acoustic path **22** extends between the acoustic port **24** that is disposed at the outer surface **26** of the housing **12** (FIG. **2**) and the outlet **28** disposed within the housing. The outlet **28** acoustically couples the acoustic path **22** to the inlet **20** of the microphone **18** using any suitable technique.

[0052] The acoustic path **22** can include any suitable number of acoustic ports **24** disposed in any suitable portion or portions of the outer surface **26** of the housing **12**. For example, as shown in FIG. **3**, the acoustic path **22** includes the acoustic port **24** and a second acoustic port **48** also disposed at the outer surface **26** of the housing. In embodiments where the acoustic path **22** includes two or more acoustic ports, the acoustic port **24** can define a first acoustic port. The first and second acoustic ports **24**, **48** can take any suitable shape and have any suitable dimensions. Further, each of the first and second acoustic ports **24**, **48** can be configured to receive acoustic waves from the external environment and direct such waves into the acoustic path **22**.

[0053] The acoustic path **22** further includes the outlet **28** (FIG. **5**) disposed within the housing **12**. The outlet **28** acoustically couples the acoustic path **22** to the inlet **20** of the microphone **18** using any suitable technique. In one or more embodiments, the inlet **20** of the microphone **18** can be disposed within the outlet **28** of the acoustic path **22**. The outlet **28** can take any suitable shape and have any suitable dimensions.

[0054] Also acoustically coupled to the acoustic path **22** is the acoustic filter **30**, which is disposed at least partially within the inner surface **44** of the top shell **14**. In one or more embodiments, the acoustic filter **30** is disposed entirely within the top shell **14**. Although depicted as being disposed at least partially within the inner surface **44** of the top shell **14**, the acoustic filter **30** can be disposed at least partially within an inner surface **56** of the bottom shell **16**. In one or more embodiments, the acoustic filter **30** is formed by a concavity **50** (FIG. **5**) disposed in the inner surface **44** of the top shell **14** and the gasket **46** that is connected to the inner surface of the top shell.

[0055] The acoustic filter **30** includes the neck **32** and the resonance cavity **34** acoustically coupled to the neck. The acoustic filter **30** is acoustically coupled to the acoustic path **22** via the neck **32** as shown in FIGS. **5-7** using any suitable technique.

[0056] The neck **32** of the acoustic filter **30** can take any suitable shape and have any suitable dimensions. In one or more embodiments, the neck **32** can take any elliptical cross-sectional shape. In one or more embodiments, the neck **32** can take a rectangular cross-sectional shape. The cross-sectional area of the neck **32** can be any suitable value. In one or more embodiments, the neck **32** has a cross-sectional area of at least 0.3 mm^2 and no greater than 1 mm^2. In one or more embodiments, the neck **32** has a constant cross-sectional area. In one or more embodiments, the cross-sectional area of the neck **32** various along a length of the neck. Further, the neck **32** can have any suitable length. In one or more embodiments, the neck **32** can have a length of at least 0.15 mm and no greater than 0.35 mm.

[0057] The cavity **34** of the acoustic filter **30** can also take any suitable shape and have any suitable dimensions. In one or more embodiments, the cavity **34** comprises an ellipsoidal (e.g., spherical) shape. In one or more embodiments, the cavity **34** comprises a pyramidal or parallelpiped shape as shown in FIGS. **3-7**. Further, the cavity **34** can have any suitable volume. In one or more embodiments, the cavity **34** can have a volume of at least 1.5 mm^3 and no greater than 3.5 mm^3.

[0058] As mentioned herein, the acoustic filter **30** can be configured to reduce an intensity of acoustic waves sensed by the microphone **18** in a first frequency range. The first frequency range can include any suitable frequency values. In one or more embodiments, the first frequency range can include ultrasonic frequencies. In one or more embodiments, the first frequency range includes frequencies of at least 20 kHz and no greater than 50 kHz. Further, in one or more embodiments, the first frequency range can include frequencies of at least 25 kHz and no greater than 40 kHz.

[0059] In one or more embodiments, the acoustic filter **30** can be configured to be a Helmholtz resonator that includes any suitable resonance frequency as calculated utilizing the following ideal Helmholtz resonator equation:

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{A}{V\cdot(L+1.7\cdot R)}};$$

where c is the speed of sound, A is the cross-sectional area of the neck **32**, L is the length of the neck, R is the radius of the neck, and V is the volume of the cavity **34**. In one or more embodiments, the resonance frequency of the acoustic filter **30** can be at least 20 kHz and no greater than 50 kHz.

[0060] The acoustic filter **30** can utilize any suitable technique such that it is configured to reduce the intensity of acoustic waves sensed by the microphone **18** in any selected frequency range. While not wishing to be bound by any particular theory, the acoustic filter **30** can be configured such that it redirects the ultrasonic energy from the microphone **18** to the cavity **34** of the filter. Simulations confirm that an amplitude of ultrasonic signals can be reduced at the frequencies where motion detectors operate as such motion detectors can act as ultrasonic acoustic field sources that can interfere with the acoustic signals produced by the microphone **18**. In one or more embodiments, the acoustic filter **30** can absorb acoustic energy present in the acoustic waves that propagate within the acoustic path **22** to reduce the intensity of such acoustic energy or waves sensed by the microphone **18** in the selected frequency range.

[0061] For example, FIG. **8** is a plot of simulated sensitivity of a Sonion P8 MEMS microphone (available from Sonion, Roskilde, Denmark) at audio and ultrasonic frequencies. An acoustic path utilized to obtain data shown in this plot was a split tube extending between two ports having a rectangular cross-section, where an average cross-sectional area of the acoustic path was about 0.97 mm^2. Sides of the acoustic path were about 1.05 and 1.27 mm, and a length of one branch from a microphone to a port on one side was 3.2 mm.

[0062] Curve **100** shows the simulated sensitivity of a front microphone with no acoustic filter acoustically connected to an acoustic path of the microphone, curve **102** shows the simulated sensitivity of a rear microphone with no acoustic filter acoustically connected to an acoustic path of the rear microphone. Further, curve **104** shows the simulated sensitivity of the front microphone with an acoustic filter that is acoustically connected to the acoustic path of the front microphone that has rectangular resonance cavity of 2.4 mm^3 in volume. In addition, curve **106** is a simulated sensitivity of the rear microphone with an acoustic filter acoustically coupled to the acoustic path of the rear microphone that has a rectangular cavity of 2.4 mm^3 in volume.

[0063] At audio frequencies, specifically below 10 kHz, the sensitivity of each microphone appears to be unaffected by the presence of the acoustic filter in the acoustic path. For example, a change of approximately 2 dB at 10 kHz is present for both the front and rear microphones. At 30 kHz, however, the sensitivity peaks for each microphone are replaced with a reduction of at least −60 dB, which may block any ultrasonic peak from registering with the digital signal processing circuitry connected to the microphones. This frequency reduction can be adjusted by changing the ultrasonic filter's cavity volume and shape based upon the equation for an ideal Helmholtz resonator as previously described herein. The Helmholtz resonator frequency for the acoustic filters of the simulation shown in FIG. **8** were calculated to be 27.5 kHz, while the simulated sensitivity minimum was 33 kHz. The minimum frequency changes with cavity volume and adjacent acoustic path shape. In a spherical cavity, the sharp minimum is absent, replaced by a smooth decline of the curve. This can provide additional degrees of freedom for the cavity design.

[0064] Resultant sensitivity reduction at critical frequencies is summarized in Table 1 below. The term "sensitivity" means the voltage that the microphone produces per 1 Pa of pressure, converted to dB. Further, the term "reduction" means a difference between the sensitivity with the resonance cavity of the acoustic filter present and the sensitivity without the cavity present. The cavities of the acoustic filters can also be adjusted individually with each having its own target frequency. The shape of such cavities can be changed to trapezoidal or another smooth form to broaden the ultrasonic minimum and cover a wider range of frequencies with better sensitivity reduction.

TABLE 1

Position-Frequency (kHz)	35	32	40
Front microphone (dB)	−4	−42	−4
Rear microphone (dB)	−17	−24	−2

[0065] As mentioned herein, the ear-wearable electronic device **10** can include any suitable number of microphones. For example, as shown in FIG. **2**, the device **10** includes the second microphone **40** disposed within the housing **12**. The device **10** can further include a second acoustic path **60** acoustically coupled to the second microphone **40**, and a second acoustic filter **66** acoustically coupled to the second acoustic path. All design considerations and possibilities described herein regarding the first microphone **18**, the first acoustic path **22**, and the first acoustic filter **30** apply equally to the second microphone **40** and its associated second acoustic path **60** and second acoustic filter **66**.

[0066] The second microphone **40** includes an inlet **58**. Further, the device **10** includes the second acoustic path **60** disposed at least partially within the housing **12** between the top and bottom shells **14**, **16** and extending between an acoustic port **62** disposed at the outer surface **26** of the housing and an outlet **64** disposed within the housing that acoustically couples the second acoustic path **60** to the inlet **58** of the second microphone **40**. In one or more embodiments, the second acoustic path **60** can include a second acoustic port **72** (FIG. **3**) disposed at the outer surface **26** of the housing **12**.

[0067] The device **10** can also include the second acoustic filter **66** disposed at least partially within the top shell **14**. As shown in FIGS. **3** and **4**, the second acoustic filter **66** includes a neck **68** and a resonance cavity **70** acoustically coupled to the neck. Further, the second acoustic filter **66** is acoustically coupled to the second acoustic path **60** via the neck **68**. The second acoustic filter **66** is configured to reduce an intensity of acoustic waves sensed by the second microphone **40** in the first frequency range. In one or more embodiments, the second acoustic filter **66** can be configured to reduce an intensity of the acoustic waves sensed by the second microphone **40** in a second frequency range, where the second frequency range is different from the first frequency range.

[0068] The second acoustic filter **66** can be formed using any suitable technique. In one or more embodiments, the second acoustic filter **66** can be formed by a second concavity **67** disposed in the top shell **14** and a second gasket **69** connected to the inner surface **44** of the top shell. In one or more embodiments, the second gasket **69** can be a portion of the first gasket **46** or a separate gasket.

[0069] Although the embodiment of device **10** of FIGS. **1-5** includes a single acoustic filter **30**, **66** acoustically coupled to each acoustic path **22**, **60**, in one or more embodiments, each acoustic path can include two or more acoustic filters that are acoustically coupled to the respective acoustic path using any suitable technique. In such embodiments, each acoustic filter acoustically coupled to an acoustic path can be configured to reduce an intensity of acoustic waves sensed by the associated microphone in a selected frequency range. For example, a first acoustic filter connected to the acoustic path can be configured to reduce an intensity of acoustic waves sensed by the associate microphone in a first frequency range, and a second acoustic filter acoustically connected to the acoustic path can be configured to reduce an intensity of acoustic waves sensed by the associated microphone in a second frequency range that is different from the first frequency range. In such embodiments, each acoustic filter can be configured to be a stop band filter that is configured to reduce the intensity of the acoustic waves sensed by the associated microphone in any desirable frequency range.

[0070] Returning to FIGS. **1** and **2**, the ear-wearable device **10** can include one or more user input devices **74**. In the illustrated embodiment, the user input devices **74** are disposed on the top shell **14** of the housing **12**, but other placements of the user input devices are possible. The user input devices **74** may include buttons, switches, or the like, such as a first button and a second button. The user can interact with the user input devices **74** (e.g., by pressing one or more buttons) to adjust the volume, change one or more settings, or turn the ear-wearable electronic device **10** on or off.

[0071] As shown in FIG. **1**, an earpiece **76** is coupled to the housing **12** by a cable **78**. The earpiece **76** can include an earpiece housing **80** and a receiver (e.g., acoustic/vibration transducer **632** of FIG. **17**) disposed at least partially within the earpiece housing. The receiver is configured to direct acoustic waves into the wearer's ear through a receiver path that extends between an outlet **82** disposed at an outer surface of the earpiece housing **80** and an inlet (not shown) disposed within the earpiece housing that is acoustically coupled to the receiver. This configuration is referred to as receiver-in-canal (RIC). Note that the features described herein, while shown implemented in a RIC device, are applicable to other configurations, such as in-the-canal (ITC) types of devices, in which the receiver is integrated into a housing that fits in the ear canal. In such device, the housing (which holds at least one externally-facing microphone) may be hidden in the canal or housing or have a visible part in the outer ear extending from the ear canal.

[0072] The ear-wearable electronic device **10** can be manufactured using any suitable technique. For example, FIG. **15** is a flowchart of one embodiment of a method **400** of forming the ear-wearable electronic device **10**. Although described regarding the device **10** of FIGS. **1-5**, the method **400** can be utilized to form any suitable ear-wearable electronic device. At **402**, the microphone **18** is disposed within the housing **12** using any suitable technique. The acoustic path **22** can be disposed at least partially within the housing **12** using any suitable technique at **404** such that the acoustic path extends between the acoustic port **24** disposed at the outer surface **26** of the housing **12** and the outlet **28** disposed within the housing, where the outlet acoustically couples the acoustic path to the inlet **20** of the microphone **18**. At **406**, the acoustic filter **30** is disposed at least partially within the inner surface **44** of the top shell **14** of the housing **12** using any suitable technique. In one or more embodiments, the acoustic filter **30** can be disposed at least partially within the inner surface **44** of the top shell **14** by disposing the concavity **42** in the inner surface of the top shell that defines at least a portion of the neck **32** and the cavity **34** of the acoustic filter. In one or more embodiments, the acoustic filter **30** can be formed by the concavity **42** disposed in the inner surface **44** of the top shell **14** and the gasket **46** that is connected to the inner surface of the top shell. The concavity **42** can define at least a portion of the neck **32** and the cavity **34** of the acoustic filter **30**.

[0073] As mentioned herein, the various embodiments of ear-wearable electronic devices can include any suitable type of device. Although the device **10** of FIGS. **1-5** is configured to be disposed behind the ear of the wearer, in one or more embodiments, the device can be configured to be disposed at least partially within an ear canal of the wearer. For example, FIGS. **9** and **10** are various views of another embodiment of an ear-wearable electronic device **200**. All design considerations and possibilities described herein regarding device **10** of FIGS. **1-5** apply equally to device **200** of FIGS. **9-10**. The device **200** can represent a variety of different custom hearing devices and can be configured as an in-the-ear (ITE), in-the-canal (ITC), completely-in-canal (CIC) or invisible-in-canal (IIC) type hearing device, for example. Further, the device **200** can include any suitable ear-wearable electronic device **200**, e.g., one or more embodiments of ear-wearable devices described in in U.S. Patent Application No. 63/555,206, filed Feb. 19, 2024, and entitled EAR-WEARABLE ELECTRONIC DEVICE INCLUDING FACEPLATE. The device **200** can further include any suitable electronic circuitry or components, e.g., the electronic circuitry or components of ear-wearable device **600** of FIG. **17**.

[0074] The device **200** includes a shell **202**, which, in one or more embodiments, can have a uniquely shaped outer surface **204** that corresponds uniquely to an ear geometry of a wearer of the device. For example, the shell **202** can be developed based on a mold taken from the wearer's ear. As such, the device **200** can be considered a custom ear-wearable electronic device. The shell **202** is configured to be disposed at least partially within an ear canal of the wearer.

[0075] The device **200** also includes a faceplate **206**, which is shown connected to the shell **202** in FIGS. **9** and **10**. The faceplate **206** can include a number of features, such as charge contacts **208** and a removal handle **210**. The charge contacts **208** are configured to engage charge contacts of a charging unit when charging a battery (e.g., rechargeable power source **654** of FIG. **17**) of the device **200**. The faceplate **206** can be connected to the shell **202** using any suitable technique, e.g., adhering, mechanically fastening, friction or press fitting, bonding, welding, etc.

[0076] The shell **202** includes an end surface **212** having a predefined configuration that can be standardized across a family or families of devices **200**. The end surface **212** is configured to matingly engage a mating surface **214** (FIG. **11**) of the faceplate **206** to form an enclosure of the electronic device **200**. Any suitable technique can be utilized to matingly engage the end surface **212** of the shell **202** with the mating surface **214** of the faceplate **206**, e.g., one or more of the techniques described in U.S. Patent Publication No. 2023/0336928 A1, entitled COMPACT ELECTRO-MECHANICAL PACKAGING FOR A CUSTOM HEARING DEVICE.

[0077] Connected to the shell **202** of the device **200** is the faceplate **206**. As shown in FIG. **11**, the faceplate **206** includes an outer surface **218** and the inner surface **216**. The faceplate **206** defines a cavity or pocket **220** disposed in the inner surface **216** of the faceplate. Disposed at least partially within the pocket **220** is a microphone **222**. The microphone **222** includes an inlet **224**. In one or more embodiments, the inlet **224** can be disposed in an outer major surface **226** of a housing **228** of the microphone **222**. In one or more embodiments, the outer major surface **226** of the microphone **222** can partially occlude an outlet **230** of an acoustic path **232** of the device **200** as is further described herein.

[0078] The device **200** also includes the acoustic path **232** disposed at least partially within the faceplate **206** and extending between an acoustic port **234** disposed at the outer surface **218** of the faceplate and the outlet **230** disposed in the pocket **220** of the faceplate. The acoustic path **232** is acoustically coupled to the inlet **224** of the microphone **222** via the outlet **230**. In one or more embodiments, the inlet **224** can be disposed in the pocket **220**. In one or more embodiments, the inlet **224** can be disposed in the outlet **230** of the acoustic path **232**. Further, in one or more embodiments, the acoustic path **232** is configured such that all acoustic waves propagating within the acoustic path pass directly from the acoustic path to the inlet **224** of the microphone **222**.

[0079] The ear-wearable electronic device **200** also includes an acoustic filter **236** disposed at least partially within the faceplate **206**. As shown in FIG. **12**, the acoustic filter **236** includes a neck **238** and a resonance cavity **240** acoustically coupled to the neck. The acoustic filter **236** is acoustically coupled to the acoustic path **232** via the neck **238** using any suitable technique. Further, in one or more embodiments, the acoustic filter **236** is configured to reduce an intensity of acoustic waves sensed by the microphone **222** (FIG. **13**) in a first frequency range as is further described herein.

[0080] The faceplate **206** can take any suitable shape and have any suitable dimensions. Further, the faceplate **206** can include any suitable materials, e.g., at least one of an inorganic (e.g., metallic, ceramic) or polymeric material. In one or more embodiments, the faceplate **206** includes a nylon-based polyamide thermoplastic material. The faceplate **206** can be manufactured using any suitable technique, e.g., molding, injection molding, 3D printing, etc.

[0081] Defined by the faceplate **206** is the pocket **220**, which can be disposed in the inner surface **216** of the faceplate using any suitable technique, e.g., etching, molding, etc. The pocket **220** can take any suitable shape and have any suitable dimensions. In one or more embodiments, the pocket **220** is configured to receive at least a portion of the microphone **222**.

[0082] Any suitable portion or portions of the microphone **222** can be disposed within the pocket **220**. In one or more embodiments, the microphone **222** is disposed completely or entirely within the pocket **220**. The microphone **222** can include any suitable microphone, e.g., a MEMS microphone, an electret condenser microphone, co-joined microphone sets, etc. Although depicted as including one microphone **222**, the device **200** can include any suitable number of microphones disposed in any suitable location on the device or disposed within the device. The microphone **222** can be electrically connected to a printed circuit board assembly (PCBA) (not shown) using any suitable technique, e.g., one or more of the techniques described in U.S. Patent Publication No. 2023/0336928 A1. In one or more embodiments, the microphone **222** is configured to convert acoustic waves that are directed into the microphone housing **228** through the inlet **224** of the microphone by the acoustic path **232**. In one or more embodiments, the microphone **222** does not include a manifold that would, in currently-available products, form a portion of the acoustic path **232** but would be separate from the acoustic path. Instead, the acoustic path **232** solely directs acoustic waves to the microphone **222** without the assistance of a microphone manifold.

[0083] The microphone **222** includes the housing **228** that can take any suitable shape and have any suitable dimensions. The housing **228** includes the outer major surface **226** that can be disposed on a surface or surfaces of the pocket **220**. The inlet **224** of the microphone **222** is disposed in any suitable portion of the outer major surface **226**. In one or more embodiments, the outer major surface **226** can at least partially occlude the outlet **230** of the acoustic path **232** as is further described, e.g., in U.S. Patent Application No. ______ (Atty Docket No. ST1068PRV), entitled EAR-WEARABLE ELECTRONIC DEVICE INCLUDING FACEPLATE.

[0084] The acoustic path **232** is disposed at least partially within the faceplate **206**. In one or more embodiments, the acoustic path **232** can be disposed completely or entirely within the faceplate **206**. As shown in FIG. **12**, which is a schematic cross view of a portion of the faceplate **206**, where the microphone **222** is removed for clarity, the acoustic path **232** extends between the acoustic port **234** disposed at the outer surface **218** of the faceplate and the outlet **230** disposed in the pocket **220**. The acoustic path **232** can take any suitable shape and have any suitable dimensions. In one or more embodiments, the acoustic path **232** has a cross-sectional area in a plane substantially orthogonal to an acoustic axis **201** that decreases in a direction from the acoustic port **234** to the outlet **230** of the acoustic path, where the acoustic path extends along the acoustic axis as shown in FIG. **12**. In one or more embodiments, the acoustic path **232** has a constant cross-sectional area in the substantially orthogonal plane. Further, in one or more embodiments, the acoustic path **232** has a cross-sectional area in the substantially orthogonal plane that increases in the direction from the acoustic port **234** to the outlet **230**.

[0085] In one or more embodiments, the acoustic path **232** is configured to direct acoustic waves incident on the acoustic port **234** to the inlet **224** of the microphone **222** (FIG. **11**).

[0086] The acoustic path **232** can be defined by the faceplate **206**. For example, the acoustic path **232** can be formed by disposing a channel in the faceplate **206** that extends from the acoustic port **234** to the outlet **230**. In such embodiments, an inner surface **244** of the acoustic path **232** is formed by the material of the faceplate **206** and does not include any additional elements or components disposed in the acoustic path such as a microphone manifold. In one or more embodiments, the acoustic path **232** can be manufactured separately from the faceplate **206** and inserted into an opening in the faceplate using any suitable technique.

[0087] The acoustic port **234** disposed at the outer surface **218** of the faceplate **206** can take any suitable shape and have any suitable dimensions. In one or more embodiments, the acoustic port **234** can take an elliptical shape in a plane of the outer surface **218** of the faceplate **206**.

[0088] Further, the outlet **230** of the acoustic path **232** can take any suitable shape and have any suitable dimensions. In one or more embodiments, the outlet **230** can take an elongated shape that is disposed in an inner surface **246** of the pocket **220** and the inner surface **244** of the acoustic path **232** such that the acoustic path is acoustically connected to the cavity via the outlet.

[0089] The outlet **230** can be disposed in any suitable portion or portions of the acoustic path **232**. As shown in FIG. **12**, the acoustic path **232** can extend between a first end **248** and a second end **250**, where the first end is defined by the acoustic port **234** and the second end can be disposed within the faceplate **206**. In one or more embodiments, the outlet **230** of the acoustic path **232** can be disposed at the second end **250** of the acoustic path. Further, in one or more embodiments, the outlet **230** can be disposed along the acoustic path **232** between its first end **248** and second end **250**.

[0090] In one or more embodiments, the device **10** can also include a basket or filter **252** disposed at least partially within the acoustic port **234** as shown in FIG. **11**. The basket **252** can be configured to collect debris entering the acoustic path **232** through acoustic port **234**. The basket **252** can take any suitable shape and have any suitable dimensions. In one or more embodiments, the basket **252** can include one or more openings **254** configured to transmit acoustic waves that enter the acoustic port **234** into the acoustic path **232**.

[0091] Acoustically coupled to the acoustic path **232** is the acoustic filter **236**, which can include any suitable acoustic filter, e.g., acoustic filter **30** of FIGS. **2-7**. All design considerations and possibilities described herein regarding the acoustic filter **30** of FIGS. **2-7** apply equally to acoustic filter **236** of FIGS. **11-13**. As illustrated in FIG. **12**, the acoustic filter **236** includes the neck **238** and the resonance cavity **240** acoustically coupled to the neck.

[0092] The acoustic filter **236** can be formed separately from the pocket **220** and acoustic path **232** and inserted into at least one of the pocket or the acoustic path using any suitable technique. In one or more embodiments, one or more portions of the pocket **220** and/or the acoustic path **232** can provide one or more portions of the neck **238** and/or cavity **240** of the acoustic filter **236**. For example, as shown in FIG. **12**, the pocket **220** can define at least a portion of the neck **238** disposed within the faceplate **206** of the device **200**. The outlet **230** of the acoustic path **232** can be acoustically connected to the neck **238**. Further, the pocket **220** can also define at least a portion of the cavity **240** of the acoustic filter **236** such that the cavity is disposed within the faceplate **206** of the device **200**. In one or more embodiments, the cavity **240** of the acoustic filter **236** can be acoustically connected to the acoustic path **232** by the outlet **230** of the acoustic path. The cavity **240** of the acoustic filter **236** can be enclosed by the pocket **220** and the microphone **222**. In one or more embodiments the cavity **240** can be acoustically sealed by a gasket **256** (FIG. **11**) disposed between the housing **228** of the microphone **222** and the inner surface **216** of the faceplate **206** to acoustically seal the cavity of the acoustic filter.

[0093] The neck **238** and cavity **240** of the acoustic filter **236** can take any suitable shape, e.g., one or more of the shapes described herein regarding the neck **32** and cavity **34** of the acoustic filter **30** of FIGS. **2-7**. Further, the neck **238** and the cavity **240** of the acoustic filter **236** can have any suitable dimensions, e.g., the same dimensions described herein regarding the neck **32** and cavity **34** of the acoustic filter **30**. In one or more embodiments, the cavity **240** of the acoustic filter **236** can have a volume of at least about 1.5 mm^3 and no greater than about 3.5 mm^3. Further, the neck **238** of the acoustic filter **236** can have a length of at least about 0.15 mm and no greater than about 0.35 mm. The neck **238** can also include a cross-sectional area of at least about 0.3 mm^2 and no greater than about 1 mm^2.

[0094] Further, the acoustic filter **236** can be configured to reduce an intensity of acoustic waves sensed by the microphone **222** in any suitable first frequency range. In one or more embodiments, the first frequency range includes frequencies of at least about 20 kHz and no greater than about 50 kHz. In one or more embodiments, the first frequency range includes frequencies of at least about 20 kHz and no greater than about 40 kHz. The acoustic filter **236** can include a Helmholtz resonator that includes a resonance frequency of at least about 20 kHz and no greater than about 50 kHz.

[0095] The acoustic filter **236** can be disposed in any suitable portion or portions of the faceplate **206** and any suitable position relative to the microphone **222**. In one or more embodiments, the microphone **222** can be disposed within the pocket **220** and the cavity **240** of the acoustic filter **236** such that the cavity is disposed at least partially around the microphone. For example, FIG. **13** is a schematic cross-section view of the microphone **222**, the acoustic path **232**, and the acoustic filter **236** in isolation from the faceplate **206**. As can be seen in FIG. **13**, the cavity **240** of the acoustic filter **236** is disposed at least partially around the microphone **222**. In one or more embodiments, the microphone **222** is disposed within the cavity **240** of the acoustic filter **236**. The microphone **222** can take any suitable volume of the cavity **240**. In other words, the cavity **240** can be selected to have a desired volume such that the remaining space between the microphone **222** and an inner surface **258** of the cavity provides the desired acoustic properties of the acoustic filter **236**.

[0096] FIG. **14** is a plot of simulated sensitivity of the Sonion P8 MEMS microphone at various audio and ultrasonic frequencies as disposed in device **200**. Curve **300** shows the simulated sensitivity of a front microphone with no acoustic filter acoustically connected to an acoustic path of the microphone. The acoustic path included a circular cylinder followed by a half-circular, slightly conical cylinder. The circular portion had a length of 0.97 mm and a diameter of 0.73 mm, while the half-circular cylindrical portion had a length of 1.73 mm and a width of 1 mm at its widest side. Further, curve **302** shows the simulated sensitivity of the microphone with an acoustic filter acoustically coupled to the acoustic path of the microphone. The cavity of the acoustic filter **236** has a volume of approximately 1 mm^3.

[0097] At audio frequencies, specifically below 10 kHz, the sensitivity of the microphone appears to be unaffected by the presence of an acoustic filter coupled to the acoustic path. At approximately 30 kHz, however, the sensitivity for the microphone peak is replaced with a depth of at least 20 dB, which may block any ultrasonic peak from registering with the digital signal processing circuitry connected to the microphone. This frequency depth can be adjusted by changing the acoustic filter's cavity volume and shape based upon the equation for an ideal Helmholtz resonator as previously described herein. The Helmholtz resonator frequency for the acoustic filters of the simulation shown in FIG. **14** is calculated be approximately 31 kHz, while the simulated sensitivity minimum is at 28.9 kHz. The minimum frequency changes with cavity volume and adjacent acoustic path shape. In a spherical cavity, the sharp minimum is absent, replaced by smooth decline of the curve. This can provide additional degrees of freedom for the cavity design.

[0098] The ear-wearable electronic device **200** of FIGS. **9-13** can be manufactured using any suitable technique. For example, FIG. **16** is a flowchart of one embodiment of a method **500** that can be utilized to form the ear-wearable electronic device **200** of FIGS. **9-13**. Although described regarding ear-wearable electronic device **200** of FIGS. **9-13**, the method **500** can be utilized to form any suitable ear-wearable electronic device. At **502**, the method **500** includes disposing the pocket **220** in the inner surface **216** of the faceplate **206** using any suitable technique. The microphone **222** can be disposed at least partially within the pocket **220** at **504** such that the inlet **224** of the microphone is disposed within the pocket using any suitable technique. Further, at **506**, the acoustic path **232** can be disposed at least partially within the faceplate **206** using any suitable technique such that the acoustic path extends between the acoustic port **234** disposed at the outer surface **218** of the faceplate **206** and the outlet **230** disposed in the pocket **220**. The acoustic path **232** is acoustically coupled to the inlet **224** of the microphone **222** via the outlet **230** of the acoustic path. At **508**, the acoustic filter **236** can be disposed at least partially within the faceplate **206** using any suitable technique. In one or more embodiments, the acoustic filter **236** can be disposed in the faceplate **206** such that the cavity **240** of the filter is disposed at least partially around the microphone **222**.

[0099] In one or more embodiments, the acoustic filter **236** can be disposed in the faceplate **206** when the pocket **220** is also disposed in the faceplate. In one or more embodiments, the pocket **220** forms at least a portion of the cavity **240** of the acoustic filter **236**. In one or more embodiments, the pocket **220** forms at least a portion of the neck **238** of the acoustic filter **236**. Further, the acoustic path **232** can form at least a portion of the neck **238** of the acoustic filter **236**. In one or more embodiments, the pocket **220**, the acoustic path **232**, and the acoustic filter **236** can be formed at the same time and be interconnected. For example, the faceplate **206** can be molded, machined, or printed such that the pocket **220**, the acoustic path **232**, and the acoustic filter **236** are formed during processing as a continuous passageway through the faceplate. Similarly, the faceplate **206** can be 3D printed such that the pocket **220**, the acoustic path **232**, and the acoustic filter **236** are formed as a continuous passageway.

[0100] The various embodiments of ear-wearable devices described herein can include any suitable electronic components or circuitry. For example, FIG. **17** is a block diagram that illustrates one embodiment of a system and ear-wearable electronic device **600** in accordance with any of the embodiments disclosed herein. The device **600** includes a housing **612** configured to be worn in, on, or about an ear of a wearer. The device **600** shown in FIG. **17** can represent a single hearing device configured for monaural or single-ear operation or one of a pair of hearing devices configured for binaural or dual-ear operation. Various components are situated or supported within or on the housing **612**. The housing **612** can be configured for deployment on a wearer's ear (e.g., a behind-the-ear device housing), within an ear canal of the wearer's ear (e.g., an in-the-ear, in-the-canal, invisible-in-canal, or completely-in-the-canal device housing) or both on and in a wearer's ear (e.g., a receiver-in-canal or receiver-in-the-ear device housing).

[0101] The device **600** includes a processor **601** operatively coupled to a main memory **602** and a non-volatile memory **603**. The processor **601** can be implemented as one or more of a multi-core processor, a digital signal processor (DSP), a microprocessor, a programmable controller, a general-purpose computer, a special-purpose computer, a hardware controller, a software controller, a combined hardware and software device, such as a programmable logic controller, and a programmable logic device (e.g., FPGA, ASIC). The processor **601** can include or be operatively coupled to main memory **602**, such as RAM (e.g., DRAM, SRAM). The processor **601** can include or be operatively coupled to non-volatile (persistent) memory **603**, such as ROM, EPROM, EEPROM or flash memory.

[0102] The device **600** includes an audio processing facility operably coupled to, or incorporating, the processor **601**. The audio processing facility includes audio signal processing circuitry (e.g., analog front-end, analog-to-digital converter, digital-to-analog converter, DSP, and various analog and digital filters), a microphone arrangement **618**, and an acoustic/vibration transducer **632** (e.g., loudspeaker, receiver, bone conduction transducer, motor actuator). The acoustic transducer **632** produces amplified sound inside of the ear canal. The microphone arrangement **618** can include one or more discrete microphones or a microphone array(s) (e.g., configured for microphone array beamforming). Each of the microphones of the microphone arrangement **618** can be situated at different locations of the housing **612**. It is understood that the term microphone used herein can refer to a single microphone or multiple microphones unless specified otherwise. The microphone **618** is operatively coupled to the processor **601** and is configured to direct a microphone signal to the processor, which in turn directs a receiver signal to the transducer **632** that is based at least in part on the microphone signal.

[0103] At least one of the microphones **618** may be configured as a reference microphone producing a reference signal in response to external sound outside an ear canal of a user. Generally, at least one the reference microphones **618** (also referred to as an externally facing microphones) is acoustically coupled to ambient air outside the housing **612** via an acoustic pathway or acoustic path **622** and an acoustic port **624**. The acoustic port **624** allows air to pass between two parts of the housing **612** or may be formed within one part of the housing.

[0104] The device **600** may also include a user control interface **607** operatively coupled to the processor **601**. The user control interface **607** is configured to receive an input from the wearer of the device **600**. The input from the wearer can be any type of user input, such as a touch input, a gesture input, or a voice input. The user control interface **607** may be configured to receive an input from the wearer of the device **600**.

[0105] The device **600** can include one or more communication devices **616**. For example, the one or more communication devices **616** can include one or more radios coupled to one or more antenna arrangements that conform to an IEEE 802.13 (e.g., Wi-Fi®) or Bluetooth® (e.g., BLE, Bluetooth® 4.2, 5.0, 5.1, 5.2 or later) specification, for example. In addition, or alternatively, the device **600** can include a near-field magnetic induction (NFMI) sensor (e.g., an NFMI transceiver coupled to a magnetic antenna) for effecting short-range communications (e.g., ear-to-ear communications, ear-to-kiosk communications). The communications device **616** may also include wired communications, e.g., universal serial bus (USB) and the like.

[0106] The device **600** also includes a power source, which can be a conventional battery, a rechargeable battery (e.g., a lithium-ion battery), or a power source including a supercapacitor. In the embodiment shown in FIG. **17**, the device **600** includes a rechargeable power source **654** that is operably coupled to power management circuitry for supplying power to various components of the device **600**. The rechargeable power source **654** is coupled to charging circuity **606**. The charging circuitry **606** is, for example, electrically coupled to charging contacts on the housing **612** that are configured to electrically couple to corresponding charging contacts of a charging unit when the device **600** is placed in the charging unit.

[0107] Embodiments of the disclosure are defined in the claims; however, herein there is provided a non-exhaustive listing of non-limiting examples. Any one or more of the features of these examples may be combined with any one or more features of another example, embodiment, or aspect described herein.

[0108] Example Ex1. An ear-wearable electronic device including a housing having a top shell and a bottom shell, a microphone disposed within the housing and having an inlet, and an acoustic path disposed at least partially within the housing between the top and bottom shells and extending between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to the inlet of the microphone. The device further includes an acoustic filter disposed at least partially within an inner surface of the top shell, where the acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. The acoustic filter is acoustically coupled to the acoustic path via the neck. Further, the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0109] Example Ex2. The device of Ex1, where the acoustic path includes a second acoustic port disposed at the outer surface of the housing.

[0110] Example Ex3. The device of any one of Ex1-Ex2, where the first frequency range includes frequencies of at least about 20 kHz and no greater than about 50 kHz.

[0111] Example Ex4. The device of Ex3, where the first frequency range includes frequencies of at least about 20 kHz and no greater than about 40 kHz.

[0112] Example Ex5. The device of any one of Ex1-Ex4, where the cavity of the acoustic filter includes a volume of at least about 1.5 mm^3 and no greater than about 3.5 mm^3.

[0113] Example Ex6. The device of any one of Ex1-Ex5, where the neck of the acoustic filter includes a length of at least about 0.15 mm and no greater than about 0.35 mm.

[0114] Example Ex7. The device of any one of Ex1-Ex6, where the neck of the acoustic filter includes a cross-sectional area of at least about 0.3 mm^2 and no greater than about 1 mm^2.

[0115] Example Ex8. The device of any one of Ex1-Ex7, where the neck includes an elliptical cross-sectional shape.

[0116] Example Ex9. The device of any one of Ex1-Ex8, where the acoustic filter is formed by a concavity disposed in the inner surface of the top shell and a gasket connected to the inner surface of the top shell.

[0117] Example Ex10. The device of any one of Ex1-Ex9, where the cavity of the acoustic filter includes a spherical shape.

[0118] Example Ex11. The device of any one of Ex1-Ex10, where the acoustic filter includes a Helmholtz resonator having a resonance frequency of at least about 20 kHz and no greater than about 50 kHz.

[0119] Example Ex12. The device of any one of Ex1-Ex11, where the microphone defines a first microphone, the acoustic path defines a first acoustic path, and the acoustic filter defines a first acoustic filter. The device further includes a second microphone disposed within the housing and having an inlet, a second acoustic path disposed at least partially within the housing between the top and bottom shells and extending between an acoustic port disposed at the outer surface of the housing and an outlet disposed within the housing that acoustically couples the second acoustic path to the inlet of the second microphone, and a second acoustic filter disposed at least partially within the top shell and including a neck and a resonance cavity acoustically coupled to the neck. Further, the second acoustic filter is acoustically coupled to the second acoustic path via the neck, and the second acoustic filter is configured to reduce an intensity of acoustic waves sensed by the second microphone in a first frequency range.

[0120] Example Ex13. The device of Ex12, where the second acoustic path includes a second acoustic port disposed at the outer surface of the housing.

[0121] Example Ex14. The device of any one of Ex12-Ex13, where the second frequency range includes frequencies of at least about 20 kHz and no greater than about 50 kHz.

[0122] Example Ex15. The device of Ex14, where the second frequency range includes frequencies of at least about 20 kHz and no greater than about 40 kHz.

[0123] Example Ex16. The device of any one of Ex12-Ex15, where the cavity of the second acoustic filter includes a volume of at least about 1.5 mm^3 and no greater than about 3.5 mm^3.

[0124] Example Ex17. The device of any one of Ex12-Ex16, where the neck of the second acoustic filter includes a length of at least about 0.15 mm and no greater than about 0.35 mm.

[0125] Example Ex18. The device of any one of Ex12-Ex17, where the neck of the second acoustic filter includes a cross-sectional area of at least about 0.3 mm^2 and no greater than about 1 mm^2.

[0126] Example Ex19. The device of any one of Ex12-Ex18, where the neck of the second acoustic filter includes an elliptical cross-sectional shape.

[0127] Example Ex20. The device of any one of Ex12-Ex18, where the second acoustic filter is formed by a second concavity disposed in the top shell and a second gasket connected to the inner surface of the top shell.

[0128] Example Ex21. The device of any one of Ex12-Ex20, where the cavity of the second acoustic filter includes a spherical shape.

[0129] Example Ex22. The device of any one of Ex12-Ex21, where the second acoustic filter includes a Helmholtz resonator having a resonance frequency of at least about 20 kHz and no greater than about 50 kHz.

[0130] Example Ex23. The device of any one of Ex1-Ex22, further including an earpiece that is coupled to the housing by a cable. The earpiece includes an earpiece housing and a receiver disposed at least partially within the earpiece housing. The receiver is configured to direct acoustic waves into a wearer's ear through a receiver path that extends between an outlet disposed at an outer surface of the earpiece housing and an inlet disposed within the earpiece housing that is acoustically coupled to the receiver.

[0131] Example Ex24. An ear-wearable electronic device including a faceplate having an outer surface and an inner surface, where the faceplate defines a pocket disposed in the inner surface of the faceplate; and a microphone disposed at least partially within the pocket and including an inlet disposed within the pocket. The device also includes an acoustic path disposed at least partially within the faceplate and extending between an acoustic port disposed at the outer surface of the faceplate and an outlet disposed in the pocket, where the acoustic path is acoustically coupled to the inlet of the microphone via the outlet; and an acoustic filter disposed at least partially within the faceplate and having a neck and a resonance cavity acoustically coupled to the neck. Further, the acoustic filter is acoustically coupled to the acoustic path via the neck, and the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0132] Example Ex25. The device of Ex24, where the cavity of the acoustic filter is disposed at least partially around the microphone.

[0133] Example Ex26. The device of any one of Ex24-Ex25, where the pocket forms at least a portion of the cavity of the acoustic filter.

[0134] Example Ex27. The device of any one of Ex24-Ex26, where the first frequency range includes frequencies of at least about 20 kHz and no greater than about 50 kHz.

[0135] Example Ex28. The device of Ex27, where the first frequency range includes frequencies of at least about 20 kHz and no greater than about 40 kHz.

[0136] Example Ex29. The device of any one of Ex24-Ex28, where the cavity of the acoustic filter includes a volume of at least about 1.5 mm^3 and no greater than about 3.5 mm^3.

[0137] Example Ex30. The device of any one of Ex24-Ex29, where the neck of the acoustic filter includes a length of at least at least about 0.15 mm and no greater than about 0.35 mm.

[0138] Example Ex31. The device of any one of Ex24-Ex30, where the neck of the acoustic filter includes a cross-sectional area of at least about 0.3 mm^2 and no greater than about 1 mm^2.

[0139] Example Ex32. The device of any one of Ex24-Ex31, where the neck includes an elliptical cross-sectional shape.

[0140] Example Ex33. The device of any one of Ex24-Ex32, further including a gasket disposed on the inner surface of the faceplate and that is configured to seal the cavity of the acoustic filter.

[0141] Example Ex34. The device of any one of Ex24-Ex33, where the cavity includes a spherical shape.

[0142] Example Ex35. The device of any one of Ex24-Ex34, where the acoustic filter includes a Helmholtz resonator including a resonance frequency of at least at least about 20 kHz and no greater than about 50 kHz.

[0143] Example Ex36. The device of any one of Ex24-Ex35, further including a shell configured to be disposed at least partially within an ear canal of a wearer. The shell includes an end surface that is configured to matingly engage a mating surface of the faceplate to form an enclosure of the device.

[0144] Example Ex37. A method of forming an ear-wearable electronic device, including disposing a microphone within a housing, where the housing includes a top shell and a bottom shell; disposing an acoustic path at least partially within the housing such that it extends between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to an inlet of the microphone; and disposing an acoustic filter at least partially within an inner surface of the top shell of the housing. The acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. The acoustic filter is acoustically coupled to the acoustic path via the neck. Further, the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0145] Example Ex38. The method of Ex37, where disposing the acoustic filter includes disposing a concavity in the inner surface of the top shell that defines at least a portion of the neck and the cavity of the acoustic filter.

[0146] Example Ex39. The method of Ex38, where disposing the acoustic filter further includes disposing a gasket on the inner surface of the top shell, where the concavity and the gasket define the neck and cavity of the acoustic filter.

[0147] Example Ex40. A method of forming an ear-wearable electronic device, including disposing a pocket in an inner surface of a faceplate; disposing a microphone at least partially within the pocket such that an inlet of the microphone is disposed within the pocket; and disposing an acoustic path at least partially within the faceplate, where the acoustic path extends between an acoustic port disposed at an outer surface of the faceplate and an outlet disposed in the pocket. The acoustic path is acoustically coupled to the inlet of the microphone via the outlet. The method further includes disposing an acoustic filter at least partially within the faceplate. The acoustic filter includes a neck and a resonance cavity acoustically coupled to the neck. Further, the acoustic filter is acoustically coupled to the acoustic path via the neck, and the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

[0148] Example Ex41. The method of Ex40, where the cavity of the acoustic filter is disposed at least partially around the microphone.

[0149] Example Ex42. The method of Ex41, where the pocket disposed in the faceplate forms at least a portion of the cavity of the acoustic filter.

[0150] All references and publications cited herein are expressly incorporated herein by reference in their entirety into this disclosure, except to the extent they may directly contradict this disclosure. Illustrative embodiments of this disclosure are discussed and reference has been made to possible variations within the scope of this disclosure. These and other variations and modifications in the disclosure will be apparent to those skilled in the art without departing from the scope of the disclosure, and it should be understood that this disclosure is not limited to the illustrative embodiments set forth herein. Accordingly, the disclosure is to be limited only by the claims provided below.

What is claimed is:

1. An ear-wearable electronic device comprising:

a housing comprising a top shell and a bottom shell;

a microphone disposed within the housing and comprising an inlet;

an acoustic path disposed at least partially within the housing between the top and bottom shells and extending between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to the inlet of the microphone; and

an acoustic filter disposed at least partially within an inner surface of the top shell and comprising a neck and a resonance cavity acoustically coupled to the neck, wherein the acoustic filter is acoustically coupled to the acoustic path via the neck, and further wherein the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

2. The device of claim **1**, wherein the acoustic path comprises a second acoustic port disposed at the outer surface of the housing.

3. The device of claim **1**, wherein the first frequency range comprises frequencies of at least about 20 kHz and no greater than about 50 kHz.

4. The device of claim **1**, wherein the cavity of the acoustic filter comprises a volume of at least about 1.5 mmˆ3 and no greater than about 3.5 mmˆ3.

5. The device of claim **1**, wherein the neck of the acoustic filter comprises a length of at least about 0.15 mm and no greater than about 0.35 mm.

6. The device of claim **1**, wherein the microphone defines a first microphone, the acoustic path defines a first acoustic path, and the acoustic filter defines a first acoustic filter, wherein the device further comprises:

a second microphone disposed within the housing and comprising an inlet;

a second acoustic path disposed at least partially within the housing between the top and bottom shells and extending between an acoustic port disposed at the outer surface of the housing and an outlet disposed within the housing that acoustically couples the second acoustic path to the inlet of the second microphone; and

a second acoustic filter disposed at least partially within the top shell and comprising a neck and a resonance cavity acoustically coupled to the neck, wherein the second acoustic filter is acoustically coupled to the second acoustic path via the neck, and further wherein the second acoustic filter is configured to reduce an intensity of acoustic waves sensed by the second microphone in a second frequency range.

7. The device of claim **6**, wherein the second frequency range comprises frequencies of at least about 20 kHz and no greater than about 50 kHz.

8. The device of claim **6**, wherein the cavity of the second acoustic filter comprises a volume of at least about 1.5 mmˆ3 and no greater than about 3.5 mmˆ3.

9. The device of claim **6**, wherein the neck of the second acoustic filter comprises a length of at least about 0.15 mm and no greater than about 0.35 mm.

10. An ear-wearable electronic device comprising:

a faceplate comprising an outer surface and an inner surface, wherein the faceplate defines a pocket disposed in the inner surface of the faceplate;

a microphone disposed at least partially within the pocket and comprising an inlet disposed within the pocket;

an acoustic path disposed at least partially within the faceplate and extending between an acoustic port disposed at the outer surface of the faceplate and an outlet disposed in the pocket, wherein the acoustic path is acoustically coupled to the inlet of the microphone via the outlet; and

an acoustic filter disposed at least partially within the faceplate and comprising a neck and a resonance cavity acoustically coupled to the neck, wherein the acoustic filter is acoustically coupled to the acoustic path via the neck, and further wherein the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

11. The device of claim **10**, wherein the cavity of the acoustic filter is disposed at least partially around the microphone.

12. The device of claim **10**, wherein the pocket forms at least a portion of the cavity of the acoustic filter.

13. The device of claim **10**, wherein the first frequency range comprises frequencies of at least about 20 kHz and no greater than about 50 kHz.

14. The device of claim **10**, wherein the cavity of the acoustic filter comprises a volume of at least about 1.5 mmˆ3 and no greater than about 3.5 mmˆ3.

15. The device of claim **10**, wherein the neck of the acoustic filter comprises a length of at least at least about 0.15 mm and no greater than about 0.35 mm.

16. The device of claim **10**, further comprising a shell configured to be disposed at least partially within an ear canal of a wearer, the shell comprising an end surface that is configured to matingly engage a mating surface of the faceplate to form an enclosure of the device.

17. The device of claim **10**, wherein the cavity comprises a spherical shape.

18. A method of forming an ear-wearable electronic device, comprising:

disposing a microphone within a housing, wherein the housing comprises a top shell and a bottom shell;

disposing an acoustic path at least partially within the housing such that it extends between an acoustic port disposed at an outer surface of the housing and an outlet disposed within the housing that acoustically couples the acoustic path to an inlet of the microphone; and

disposing an acoustic filter at least partially within an inner surface of the top shell of the housing, wherein the acoustic filter comprises a neck and a resonance cavity acoustically coupled to the neck, wherein the acoustic filter is acoustically coupled to the acoustic path via the neck, and further wherein the acoustic filter is configured to reduce an intensity of acoustic waves sensed by the microphone in a first frequency range.

19. The method of claim **17**, wherein disposing the acoustic filter comprises disposing a concavity in the inner surface of the top shell that defines at least a portion of the neck and the cavity of the acoustic filter.

20. The method of claim **17**, wherein disposing the acoustic filter further comprises disposing a gasket on the inner surface of the top shell, wherein the concavity and the gasket define the neck and cavity of the acoustic filter.

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