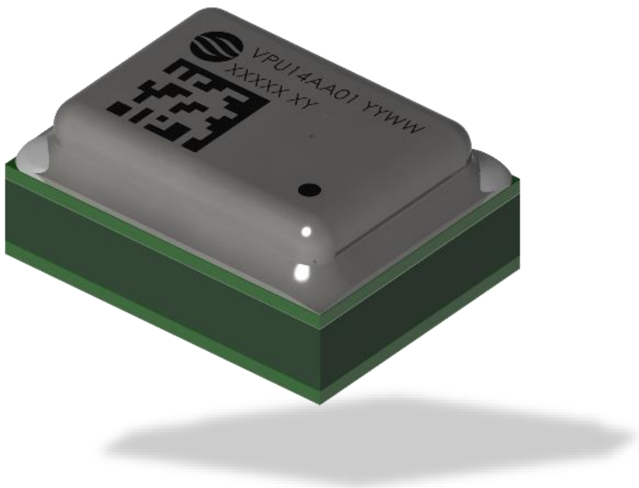


# Voice Pick Up Sensor



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Document code: VPU Bone Sensor
Version: 003
Release date: 2020-06-17

## Introduction

The Sonion Voice Pick Up Sensor is a high-performance bone conduction sensor optimized for picking up a user's own voice.
The Voice Pick Up (VPU) Sensor enhances communication in noisy/challenging types of environments. Picking up your own voice via vibrating bones in your skull, results in an intelligible voice with high SNR and without the ambient sound/background noise. This highly intelligible signal from the VPU is perfect for accurately controlling a voice operated input system. This signal can also be used for anti-occlusion purposes. For product details and specifications see the Sonion VPU Datasheet.

**Basic Features**

- Small size 3.5 mm x 2.65 mm x 1.5 mm (13.9 $mm^3$)
- High bone conduction sensitivity with ultra-low noise
- Large bandwidth up to 8 kHz
- Optimized for picking up users' own voice on different position of human head
- Ultra-low power consumption, designed to help save battery life in continuous active mode
- Halogen Free
- REACH & RoHS Compliant
- Reflow solderable (SMD)
- Full hermetic package[1], IP67 waterproof rating

**Applications**

- Hearable / wearable devices, such as True Wireless Stereo earbuds, smart glasses, head worn devices, intelligent glasses, VR glasses
- On- / Over-ear headphones
- Professional headsets, such as call center headset, pilot headset, motorcycle headset
- Communication systems
- Smartphones

This application note provides some background information and guidelines for implementation of the Sonion VPU into your wearable/hearable housing design. The tiny size of the VPU package makes it ideal for discrete and reliable communication devices.

This application note covers the following:

- Mechanical design considerations
- Electrical connections
- Application-enabling performance aspects
- Measurement set-up
- Reference design

[1] With sealed vent hole after VPU assembly.



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## Mechanical design

The Sonion VPU sensor is designed to be reflow soldered directly onto a printed circuit board. There is no need for a hole in the PCB, as the VPU is a completely sealed sensor and does not require a sound inlet. However, the VPU has a tiny vent hole that needs to remain open during reflow soldering and must be sealed afterwards (see handling of the VPU). The VPU, PCB and mechanical housing form a mechanical system that can affect the frequency response of the VPU sensor. This application note provides recommendations to ensure optimum bone conduction pick up performance and to achieve the best signal from the VPU. The following topics will be covered in the mechanical design section.

- Bone conduction transmission of own voice
- Mounting of the VPU in the housing
- Handling of the VPU
- Suggestions on glue/lacquer type
- Effect of dome hardness in closed-fit applications
- The VPU design considerations in wireless/wired applications

**Bone conduction transmission of own voice**

Publicized research has shown that human own voice transmission by bone conduction has limited speech pickup in the high frequencies above 3 kHz. Human skin behaves as a low pass filter and the higher speech frequencies of own voice pickup are attenuated by skin and soft tissue. For more information, refer to the article *Hearing one's own voice during phoneme vocalization-Transmission by air and bone conduction, Reinfeldt et al, J. Acoust. Soc. Am. 128(2), August 2010*.

**Mounting of the VPU into the housing**

The VPU should be mounted in a location inside the housing/shell where it is easy to pick up bone vibration and the VPU should be secured using some type of permanent adhesive/glue.

Figure 1 shows the VPU has a single sensitive axis (Z). When a person speaks, the whole skull vibrates. The speech induced skull vibration can be picked up on different head spots, such as ear canal, concha, behind the ear or nasal bridge. The VPU sensor should be placed in the location and in the direction where the most bone conduction is transmitted for a person's own voice.

In another word, we have a wanted (H1: speech vibration) and an unwanted (H2: environmental vibration) vibration transfer function to the VPU. An optimal VPU placement ensures that H1 is maximum and that H2 is minimum. This is very dependent on the specific design. For instance, to minimize crosstalk from moving coil speaker as H2, the sensitive axis Z of VPU is better to be orthogonal to the diaphragm of the speaker. Another example is that to minimize picking up of step signal, Z-axis of VPU facing or against ground should be avoid in the design.



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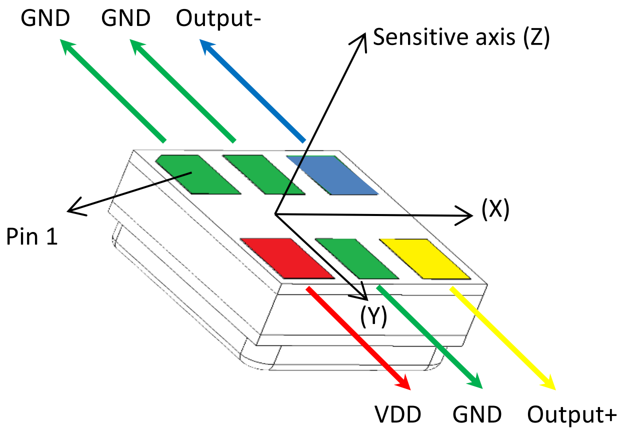


**Figure 1 Sensitive axis (Z) of VPU**

Two recommended locations inside TWS earbud housing is shown in figure 2. Position 1 is against tragus and position 2 is against concha.


**Figure 2 Recommended VPU locations inside TWS earbud**

### Handling of the VPU

Please follow Sonion's generic application note *Handling of Transducers*.

After reflow soldering, the small vent hole should be sealed by lacquer or glue. Sealing the vent hole ensures there is no acoustic leakage and makes the VPU IP67 compliant. Please **do not seal this vent hole before the reflow soldering process**, as there is a risk that the trapped air inside the VPU will expand and cause damage to the sensor. Figure 3 shows the location of the vent hole on top side of VPU.



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Please **do not blow compressed air directly into the vent** hole before sealing and curing the hole. A blow of compressed air can permanently damage the VPU sensor.

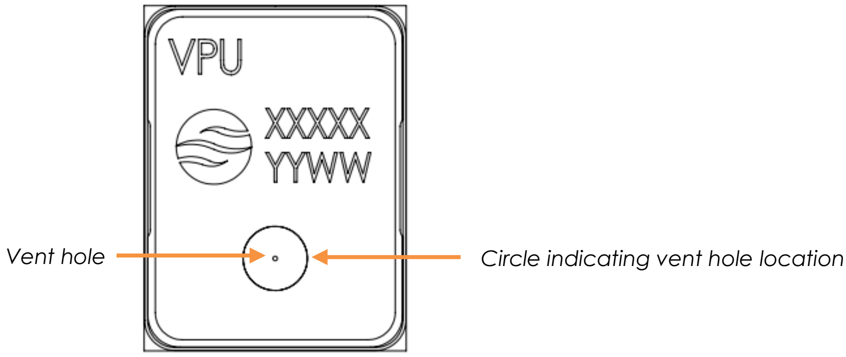


**Figure 3 Location of the vent hole**

If the VPU is mounted on the plastic wall/housing with glue/lacquer as shown in figure 4 and figure 5, it is not necessary to seal the vent hole which is covered by glue/lacquer. If the VPU is mounted on rigid PCB/FPCB, the small vent hole should be sealed by lacquer or glue after assembly into the application.

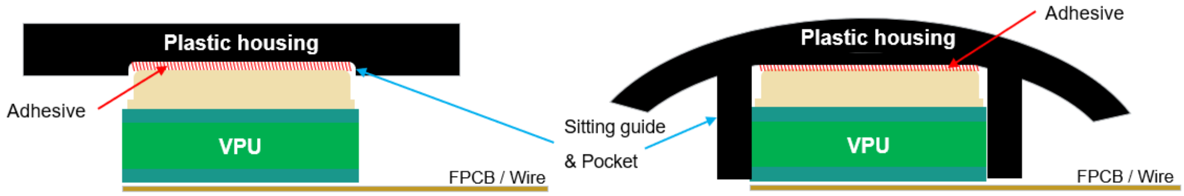


**Figure 4 VPU mounting on plastic housing**

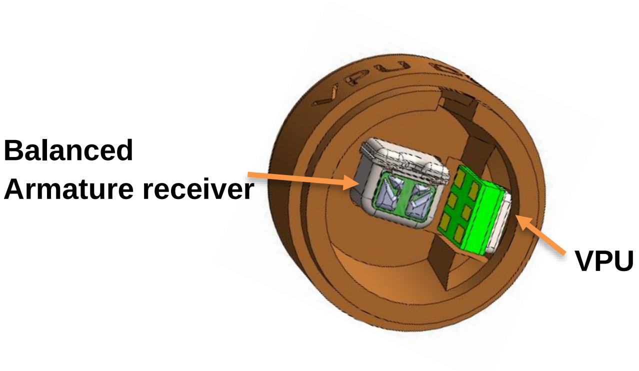


**Figure 5 VPU mounting in Sonion demo kit right earbud**

**Suggestions on glue/lacquer type**

To ensure appropriate sealing the vent hole and attach the VPU on the plastic surface, Sonion recommends glues/lacquers with viscosity > 8000m.Pa/s and room temperature curing. As indication – but not restriction, the following glues can be used:

- Loctite 3211
- Loctite 3525



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In quick tests and prototypes, tapes have also been found to be effective to seal the hole. The use of tape is not recommended for production.

**Effect of dome hardness in closed-fit applications**

At low bone conduction levels (casual conversation) the hardness of the dome does not have a big influence on bone conduction transmission. At high bone conduction levels (loud conversation) a softer dome does not provide adequate transmission of the own voice at frequencies above 1 kHz. This results in a lower sensitivity for soft domes and for optimum voice pickup we recommend using the hardest dome available for the application.

**The VPU design considerations in wireless/wired applications**

The VPU is mainly designed for wireless applications. If the VPU is used in wired applications like headphones, some extra measures to decouple vibration from wires to VPU are highly recommended. Here are some design considerations and tips in application: the cable needs to be fixated to clothing by using some sort of a cable clip. This is needed to avoid cable movement vibrations (microphonics) that would be picked up by the VPU.

For both wired and wireless applications:

- If VPU is electrically connected with wires, Litz wires which contains many very thin strands are recommended for high compliance.
- The VPU sensitive axis is recommended to be orthogonal to the main vibrating direction of speaker, i.e. diaphragm of moving coil or vibration arm of balanced armature.
- Viton tubing can be used in balanced armature applications to reduce vibration transfer to housing.
- Silicone is a poor vibration damper. Some applications are using silicone as intermedia material for vibration conduction to VPU.

For wired applications:

- The noise picked up by VPU from hard wired cable is an issue in wired applications
- Cable vibration isolation / damping measures are highly recommended, such as over the ear cable routing, a cable clip to avoid cable rubbing against cloths.



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## Electrical connections

The VPU can be connected to the analog microphone input(s) of the CODEC chipset directly or via an operational amplifier. Choice of the two options mainly depends on the requirements of signal amplification, CODEC analog I/O pin availability and circuit / PCB space budget.

**Direct connection**

The VPU14AA01 has an analog differential output signal to increase the signal output level and to guarantee the lowest electromagnetic interference. It is also possible to use single-ended output signal if needed, e.g. when number of CODEC analog I/O pin is limited. The single-ended configuration results 6 dB loss in sensitivity which can be compensated by adding 6 dB gain in CODEC. Please refer to figure 6(a) for differential mode and figure 6(b) for single-ended mode connection schematics. The VPU pins in figure 6 are from top view, i.e. terminal side down.

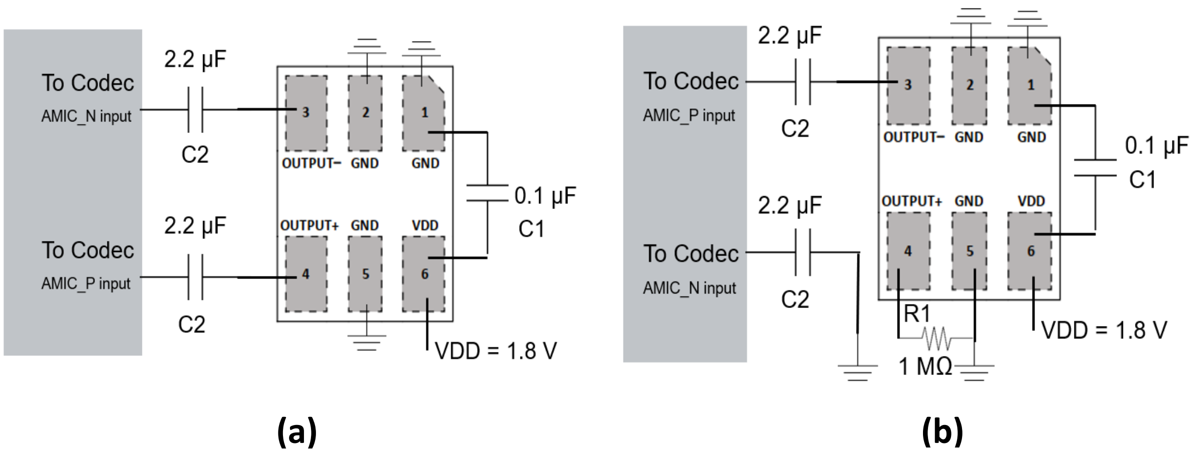


**Figure 6 Direct connection of VPU to CODEC: (a) differential, (b) single-ended.**

A DC blocking capacitor (C2) is required at each output of the VPU. This capacitor creates a high-pass filter with a corner frequency at

$$fc = 1 / (2\pi \times C2 \times R)$$

where R is the input impedance of the CODEC.

A 0.1 µF ceramic capacitor (C1) placed close to the VPU14AA01 supply pin is recommended to adequately decouple the VPU from noise on the power supply.

A clean analog voltage supply from codec, e.g. microphone supply, is recommended for the VPU VDD bias to ensure an optimal interference level at the signal line.

In signal-ended configuration, it is recommended to connect the VPU OUPUT- pin to the CODEC and to connect the VPU OUTPUT+ pin to ground via a 1 MΩ resistor.



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**Amplifier connection**

An operational amplifier can be used between VPU and CODEC. Despite adding extra components and PCB area, this configuration introduces two major benefits:

1. Because of relatively high output impedance of VPU14AA01, typ. 5.5 kΩ in differential, care must be taken to check the input impedance of the CODEC analog microphone input node where the VPU is connected directly. A too low CODEC input impedance stage following the VPU can potentially attenuate the signal level of the VPU. For instance, some CODECs have a programmable gain amplifier (PGA) before the ADC. At high gain settings, the PGA's input impedance may be as low as 10 kΩ. Thus, in high gain mode, VPU signal is attenuated by approx. 2.2 dB due to the low input impedance. An OPAMP between VPU and CODEC analog microphone input can work as an impedance converter, i.e. high-impedance to low-impedance, to solve the potential problem.

2. Because the bone conduction in human ear canal or outer ear area are rather weak, the output signal level from VPU can be very low. Using VPU14AA01 as the Industry-leading bone conduction sensor in sensitivity, the direct output level in daily conversion can be in sub-mV level. An OPAMP between VPU and CODEC analog microphone input can boost the signal before CODEC stage.

A reference schematic of OPAMP connection is depicted in figure 7.

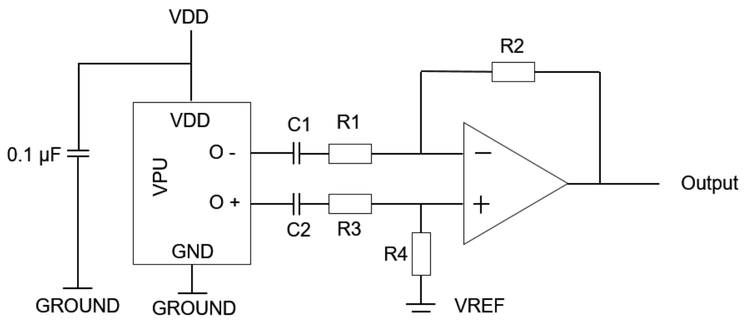


**Figure 7 Reference schematic of VPU to OPAMP connection**

Typical values in the schematic are as below:

- VDD = 1.8 $V_{DC}$ (both for VPU and OPAMP)
- VREF = 0.9 $V_{DC}$
- C1, C2 = 2.2 µF
- R1, R3 = 100 kΩ and R2, R4 = 100 kΩ
- Increasing values of R2 and R4 increases the gain

The gain of OPAMP can be tuned by varying the resistance ratio of R2/R1 and R4/R3. A pre-filtering of the VPU signal can be applied by adding capacitors in parallel to R1...R4. A decoupling capacitor of e.g. 2.2 µF should be placed between the output of the OPAMP and the CODEC analog microphone input.



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## Performance

**Ultra-low acoustic sensitivity**

The VPU sensor has an ultra-low sensitivity to acoustic signals when the vent hole is properly sealed. On component level, the VPU shows virtually no sensitivity to acoustics. Note that on application level, high acoustic level may convert into vibration that will be picked-up by the VPU. A control of the seal can be performed by exposing the VPU component to acoustic signals – hearing them as a microphone would indicates an inappropriate seal.

## Measurement set-up

The measurement setup in figure 8 is used for frequency response measurement of the VPU. The VPU is connected using a custom test fixture with pogo pins that connect power and signal to the VPU. The VPU is supplied using 1.8 $V_{DC}$. The VPU fixture is attached to a reference accelerometer (B&K type 4533-B-001) and the accelerometer is connected to a B&K shaker (type 4810). The accelerometer output is connected to the input channel of the audio analyzer. Flexible cables are used to connect the fixture to other equipment in the test setup. The differential output of the VPU is connected to the inputs of a single-ended amplifier, which is connected to the audio analyzer input channel. The shaker is connected to the audio analyzer generator via a Power Buffer, which is driven with a white noise level of 100 mVrms. The frequency response of the VPU is measured by the audio analyzer from 100 Hz-10 kHz. We recommend an accelerometer, or Laser Doppler Vibrometer (LDV) as a reference sensor.

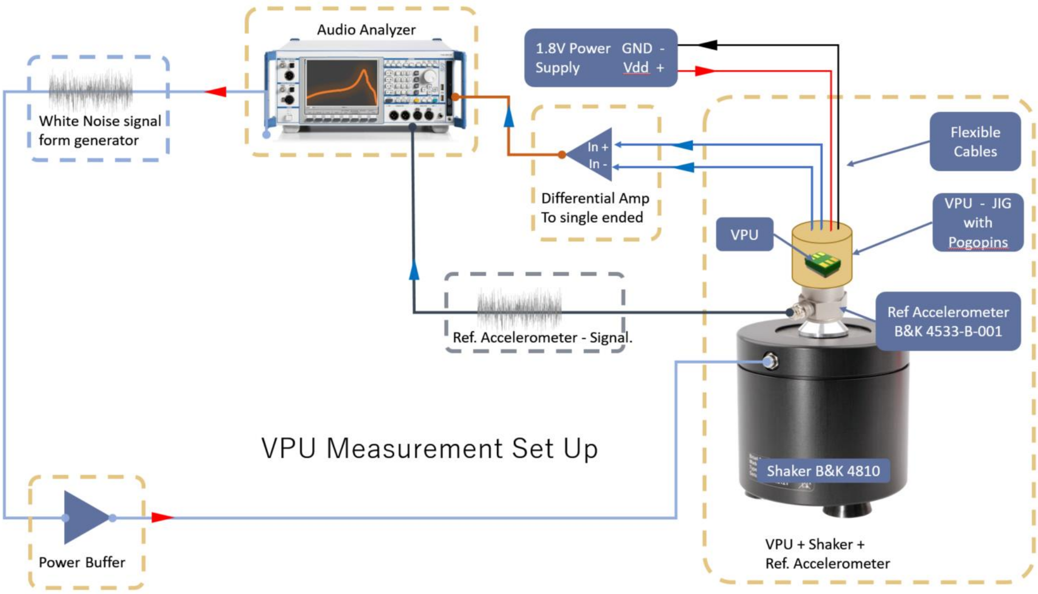


**Figure 8 The Sonion VPU frequency response measurement set up**



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# VPU reference design

**Wired earbuds demo kit for generic function demonstration / test**

Sonion has developed a VPU reference demo kit earbuds equipped with acoustic components and a VPU and an associated functional circuit board. The full pack of VPU demo kit is shown in figure 9. The reference design is used to demonstrate the performance of the VPU versus a microphone in noisy background environment. Please refer to VPU demo kit quick start guide for detailed use of it.

**The VPU demo kit package includes**

- 1x 3.5mm TRRS audio connector cable
- 1x VPU demo board v2.9 with wired earbuds
  - Left earbud
    - 1x Balanced Armature driver
  - Right earbud
    - 1x VPU14AA01 Voice Pickup sensor
    - 1x MEMS microphone
    - 1x Balanced Armature driver
- 1x CR2032 lithium battery

**Figure 9 Sonion VPU demo kit set**

The demo kit circuit board enables voice pick up device switching between microphone (direct output to phone or recorder) and VPU (differential output amplified by 3.5 dB through OPAMP to phone or recorder). The reference schematic of demo kit circuit board and OPAMP frequency response curve are depicted in figure 10 and figure 11, respectively.

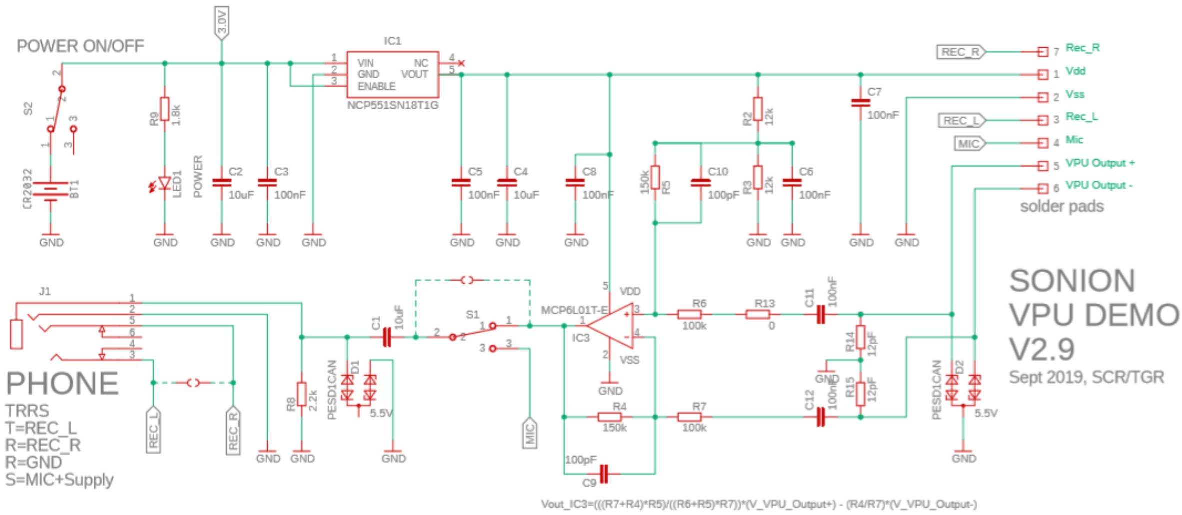


**Figure 10 Reference schematic of demo kit circuit board**



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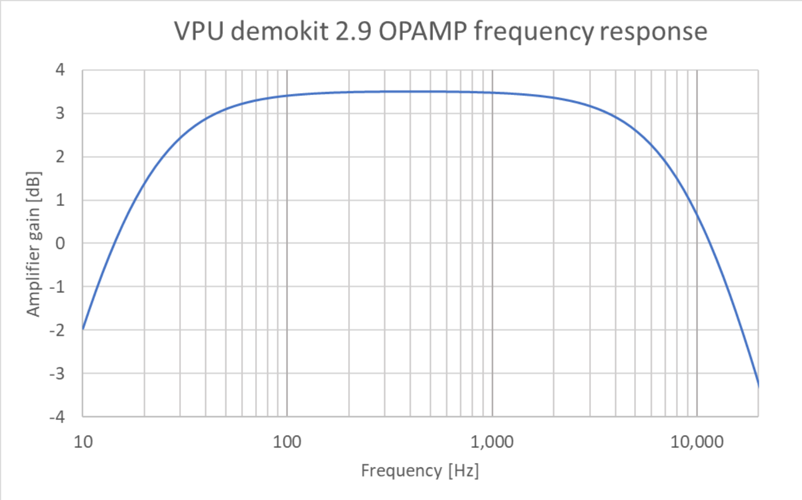


**Figure 11 Frequency response of OPAMP used for VPU output**

**TWS earbuds demo kit for advanced dynamic mixing function demonstration / test**
Together with software partner Absolute Audio Labs[2], Sonion is developing a VPU reference design in TWS earbuds based on Qualcomm platform introducing advanced dynamic mixing feature to provide best in class speech intelligibility and quality in noisy / windy environment.

The PYOUR audio firmware measures the surrounding noise to the headset and creates the optimal mix of signals from the microphone and VPU bone sensor dynamically. For instance, when a user is talking through earbuds in a quiet room, 100% of outer microphone(s) signal is used for the best voice quality. When the user steps out the quiet room into a noisy canteen, the firmware combines user voice signal picked up by VPU and microphone(s) with a proper weight according to the ambient noise level. In this way, both speech intelligibility and quality are ensured in all possible conditions.

[2] https://www.absoluteaudiolabs.com/



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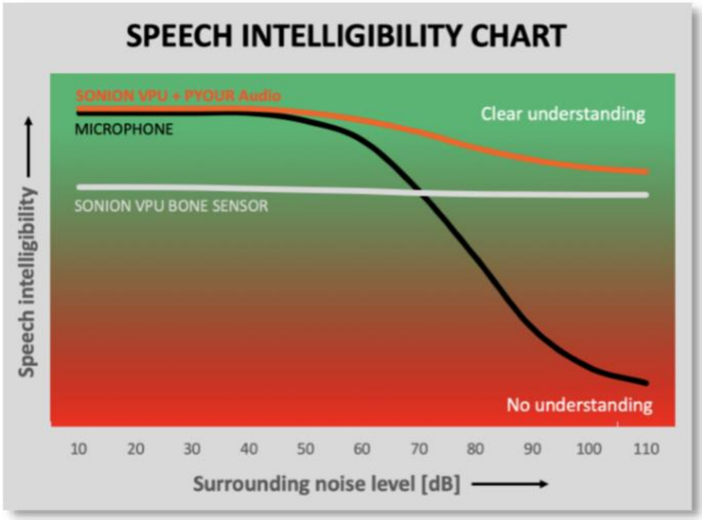


**Figure 12 Speech intelligibility in noise comparison between dynamic mixing of VPU and microphone(s)**

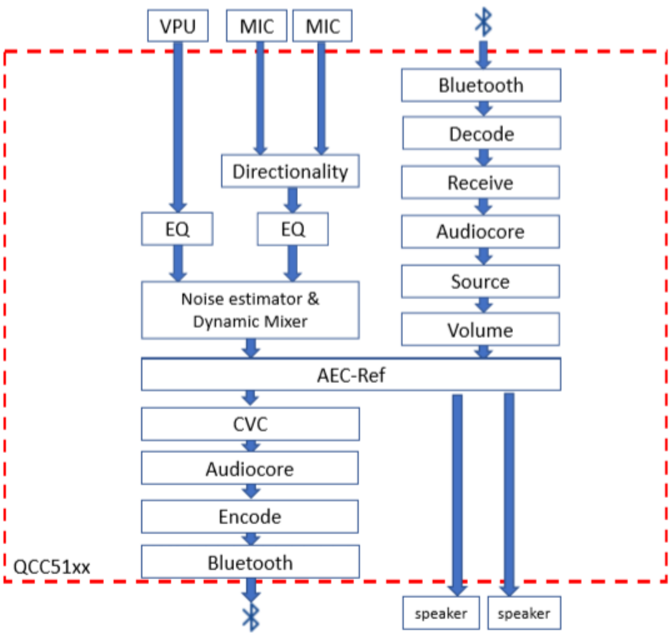


**Figure 13 Flow diagram of VPU dynamic mixing implementation in latest QCC51xx platform**



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