Keysight Technologies
Testing Hearable Designs with the U8903B Performance Audio Analyzer

Application Note

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights

Introduction

Smart headphones, popularly known as hearables are electronic in-ear-devices designed to enhance the listening experience. Their application includes phone calls, music, noise cancellation, GPS navigation, medical monitoring, and fitness tracking as well as many other applications. In the future, Siri, Google Now, and virtual-reality applications will use hearables.

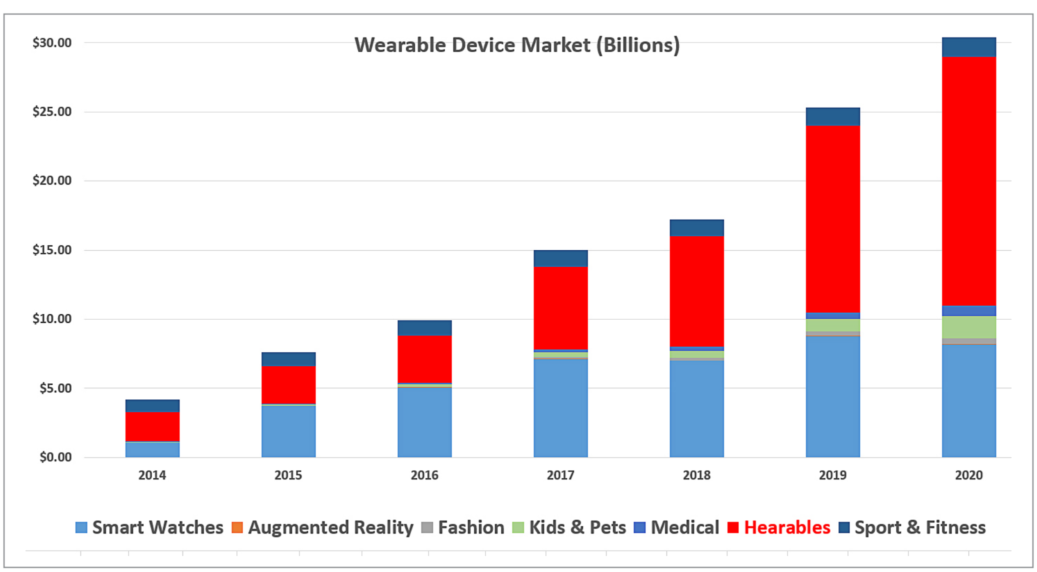
The term hearable was first introduced in April 2014 as a combination of the terms headphones and wearable. A hearable combines wearable technology with the basic principles of audio-based information services.

Hearables are the fastest growing segment in the wearable technology market. Hearables use wireless technology, enabling us to make personal and business calls, record medical data and provide feedback on our training programs at the gym. They also help us navigate via GPS and remind us of important appointments. Currently, there are several designs that use hearables for real-time translation.

This application note highlights how R&D engineers, test engineers and test lab personnel can test and evaluate hearables as well as other *Bluetooth*®-enabled devices to improve audio quality and achieve a competitive advantage.

The focus of this application note will be on the electrical testing of hearables, which is more cost effective than the acoustical testing of hearables, and thus more critical to gaining an edge in this growing market.

Figure 1. An example of hearables



Testing challenges

It is critical that hearables be adequately and effectively tested. It is signficantly more costly and more difficult to test a hearable after it is has been constructed. Therefore, it is essential to test hearables in the design phase in order to produce a low-cost, high-quality product.

However, testing the audio quality of a Bluetooth device is not easy.

– Modern *Bluetooth* devices can support high-quality audio with Advanced Audio Distribution Profile (A2DP) wideband codec. A traditional Bluetooth tester can only perform the low-performance audio test (-50 dB THD+N). Testing high-quality audio signals used in hearables requires a high-performance audio analyzer (-108 dB THD+N), especially during the R&D phase as some *Bluetooth* (BT) chips can achieve -110 dB residual THD+N.
– The audio signal is packed as content in the *Bluetooth* signal. A traditional audio analyzer cannot test *Bluetooth* content from the BT RF signal. Converting the RF signal to a baseband analog audio signal requires a BT tester. This conversion process adds more than $20k to the cost-of-test without improving measurement quality. In fact, measurement quality can decrease because the BT tester can muddy the audio signal and invalidate the results.

Acoustic and electrical testing

Acoustic testing focuses on the quality of sound signals. Electrical testing focuses on the quality of electrical signals, i.e. the signals used to drive the speaker or built-in microphone. Acoustic testing is required by most of the industry standards, for example Bluetooth SIG, because:

- It is impossible to test the electrical signal on a constructed hearable, because there are no test points available. Most hearables remove the earphone jack to achieve a water proof design. So, you cannot get any electrical signal from a hearable.
- Sound is the only signal that a hearable user can experience. Therefore, acoustic testing reflects the real performance of a hearable.

Acoustic testing is expensive and complicated. The acoustics kit and accessories: measurement microphone (artificial ear), speaker (artificial mouth), calibrator, and head simulator are expensive. In addition, most design and test engineers have neither the educational background nor the experience to perform accurate and reliable acoustic tests.

So, electrical testing is the best alternative for design and test engineers to use in order to analyze and evaluate their hearable designs. During the hearble development period, the product is not completed, so you can test the electrical signals on the circuit board and the components.

A design engineer can track a problem from input to output, step-by-step, to identify the cause and resolve the issue.

In this application note, we focus on an easier, more cost-effective method of electrical testing. We also detail the necessary equipment and procedures for baseline acoustic testing of hearables.

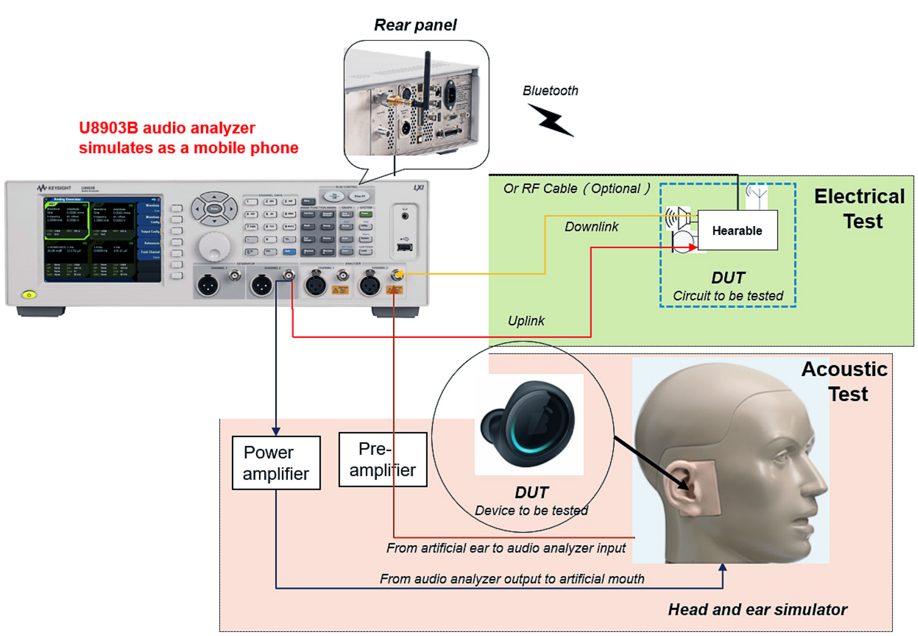


Figure 3. Example acoustic test and electrical test

Instrument Configuration

The Keysight U8903B performance audio analyzer, *Bluetooth* Option (U8903B-BLU and BL2), provides direct high-performance audio testing of the *Bluetooth* RF signal. Therefore, you can rely on the precision and accuracy of the test results.

For the measurements in this application note, a U8903B performance audio analyzer with options U8903B-STD, U8903B-BLU, and N3431A software is used to test hearable designs. An optional acoustic test kit and instructions are included if you need to make acoustic measurements.

Test Instrument	Model/Option	Description
U8903B high-performance audio analyzer	U8903B-STD	A two-channel performance audio analyzer that performs all audio-related measurements, such as frequency response, crosstalk, phase and out-of band measurements.
	U8903B-BLU	This *Bluetooth* option measures the audio quality directly from the *Bluetooth* RF signal. It transmits a maximum output power of 5 dBm, ensuring that you can connect to and accurately test a wide variety of *Bluetooth* devices.
	U8903B-DGT	This digital audio option tests a wide range of digital audio applications. It measures the audio quality in the digital domain, identifying issues such as periodic and random jitter and BER transmission errors.
	N3431A	This software expands the analog input bandwidth up to 1.5 MHz with 24-bit resolution and two-million-point FFT.
	N3433A (optional)	This software tests listening quality using POLQA, ITU-T P.863, and voice quality using PESQ, ITU-T P.862. These listening and voice-quality tests quickly identify hearable design issues.
Acoustic test kit (optional)	GRAS or B&K	This test kit includes a head/ear simulator, artificial ear, artificial mouth, microphone amplifier, and power amplifier.

Hearable audio measurements

Hearables are audio-based devices, so testing is typically done with an audio analyzer. Hearable testing focuses on the quality of the audio signal and the easy identication and fast mitigation of noise interference. Typical measurements include:

- Phone call quality: Tests the audio quality of a phone call, the pick up, hang up, ability to mute and unmute, and more
- Music playback quality: Evaluates the audio quality when a mobile phone plays music on a hearable
- Noise cancellation: Tests the hearable's noise cancellation performance
- Out-of-band noise: Measures the out-of-band signal interference
- Troubleshooting: Analyzes and evaluates product design issues

The following test setup, configuation, and measurement instructions will help you analyze, evaluate and troubleshoot your hearable design.Throughout this document square brackets [ ] indicate hard keys on the equipment, curly brackets { } denote soft keys found on screen menus, and italics identify screen menu selections and settings.

Phone call quality

Since most hearables were developed from *Bluetooth* headphones, they should support phone call related profiles, like Headset Profile (HSP) and Hands-Free Profile (HFP.)
In this section, we will discuss how to measure hearable phone call quality. In order to handle a phone call from a mobile phone, the hearable must incorporate the HSP. This profile defines how headsets and mobile phones operate together, including how to move audio signals to and from a phone, and how to control calls.

The U8903B audio analyzer supports the HFP, which allows a synchronous connection-oriented (SCO) link to be made. Within the HFP, the U8903B can take one of two roles, either acting as the audio gateway, allowing for hearable testing; or the headset role, allowing for cell phone testing. In this application note, the U8903B audio analyzer acts as the audio gateway (HFP AG).

The two most commonly used hearable phone call quality measurements are frequency response and total harmonic distortion plus noise (THD+N.)

Test setup

The U8903B basic configuration has two analog generator channels and two analog analyzer channels which enables the U8903B to test devices with stereo capability. The following test setup is used to perform phone quality measurements.

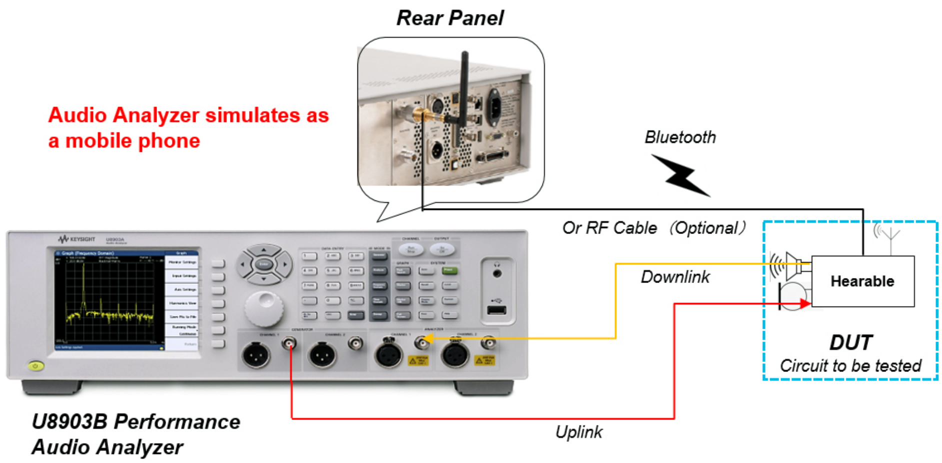


Figure 4. Testing hearable phone call quality and phone call handling

  - Set up the *Bluetooth* link between the U8903B performance audio analyzer and the hearable, which is the device under test (DUT), as shown in Figure 4.
  - Connect the U8903B to the DUT, the hearable, as shown in Figure 4. During the product development period, the test points on the circuit should be available. You can connect the U8903B *Bluetooth* RF connector to the DUT with an RF cable. If an RF connection is not available on the DUT, use the wireless link. Connect the U8903B audio analyzer output (generator) to the DUT's microphone input and connect the audio analyzer input (analyzer) to the DUT's speaker output.
- Test the signal paths.
  - Test the downlink audio quality
    The U8903B audio analyzer generates a high-quality *Bluetooth* RF signal, which is an ultra-low distortion sine-wave signal. This test signal is sent to the DUT's RF input. From the DUT's speaker output, the test signal is sent back to U8903B for analysis.
  - Test the uplink audio quality
    The U8903B audio analyzer generates a high-quality analog audio sine-wave signal, which is sent to the DUT's microphone input. From the DUT's RF output, the U8903B receives a *Bluetooth* RF signal, which is a degraded sine-wave signal from the DUT. The U8903B analyzes the RF signal directly, without converting it back into an analog audio signal.
  - Configure the audio analyzer to establish a *Bluetooth* link between the audio analyzer and the DUT.
  - Setup the downlink audio quality test configuration

    A. Set the U8903B upper display to BG1(*Bluetooth* Generator channel 1) by pressing [Interface] and [Generator/Analyzer] on the front panel.

    B. Press {Link Config} followed by {Device Scan}. The U8903B will search and pair with the DUT.

    C. The U8903B will connect with the HFP profile of the DUT. The HFP profile includes both HFP and HFP AG.

    D. Press {Return} and {Device Action} followed by {HFP Operation}. Then, select Connect. Now, the audio connection between the U8903B and the DUT has been established. This connection simulates the hearable "listening" to a call from another phone. Please note that the *Bluetooth* link will disconnect after a few minutes if there is no *Bluetooth* transaction, because the DUT goes into sleep mode. If this happens, you will need to turn the DUT on again and the U8903B will automatically reconnect.

    E. Press {Return} twice to go back to the main BG1 display.
      (1) Press {Waveform config} to set the Amplitude to 1 FFS. All other parameters remain at their default values.
      (2) Press [On/Off] on the front panel. Now, BG1 is generating a *Bluetooth* RF signal (sine wave, 1 kHz, 1 FFS amplitude.)

    F. Press [Arrow] to highlight the lower display.
      (1) Set the U8903B lower display to AA1 (Analog Analyzer channel 1) by pressing [Interface] and [Generator/Analyzer] on the front panel.
      (2) Set the measurement functions by pressing {Function}, followed by {Function No.} and {Meas Func}. The U8903B can implement up to 4 measurements simultaneously on each display. Measurement functions will be discussed in the following measurement sections.

– Set up the uplink audio-quality test configuration. The steps are similar to the downlink test configuration.

A. The *Bluetooth* link between U8903B and DUT should remain connected. If not, please follow steps A through D above to set up the *Bluetooth* connection.

B. The audio connection between the U8903B and the DUT has been established. This connection simulates the hearable "talking" to another phone.

C. Set the measurement functions, by pressing {Function}, followed by {Function No.} and {Meas Func}. Measurement functions will be discussed in the following measurement sections.

D. Press [arrow] to move the highlight to the lower display. Set the U8903B lower display to AG1 (Analog Generator channel 1) by pressing [Interface] and [Generator/ Analyzer] on the front panel.

E. The U8903B will generate an analog test signal (sine wave, 1 kHz). The amplitude of the signal will depend on the input range of the DUT microphone. Use the full range of the microphone to determine the signal-to-noise ratio (SNR.)

F. Press BA1 on the upper display of the U8903B to start the audio-quality measurement test of the Bluetooth RF signal from the DUT.

G. The link configuration for both downlink and uplink is shown in Figure 5.

Frequency response measurements

Frequency response is a measure of the magnitude of the output, as a function of frequency, in comparison to the input. When a sine wave is injected into the hearable input at a given frequency, the hearable response (magnitude and phase) is measured. This is repeated for each frequency of the sweep.

The downlink frequency response settings on the U8903B display should look like the screen-shot shown in Figure 6.

Generator settings

1. Set the lower-left display as BG1 (*Bluetooth* Generator channel 1).
2. Set the Amplitude at 1 FFS by pressing **{Waveform Config}** and **{Amplitude}**.
3. All other parameters remain at their default values.

Analyzer settings

1. Move highlight to AA1 display (lower-right display).
2. Press **{Function}**, set **{Function No.}** to 1 and set **{Meas Func}** to AC Voltage. Set **{Function No.}** to 2 and set **{Meas Func}** to None. Now, the lower-right display shows only one measurement: AC Voltage.

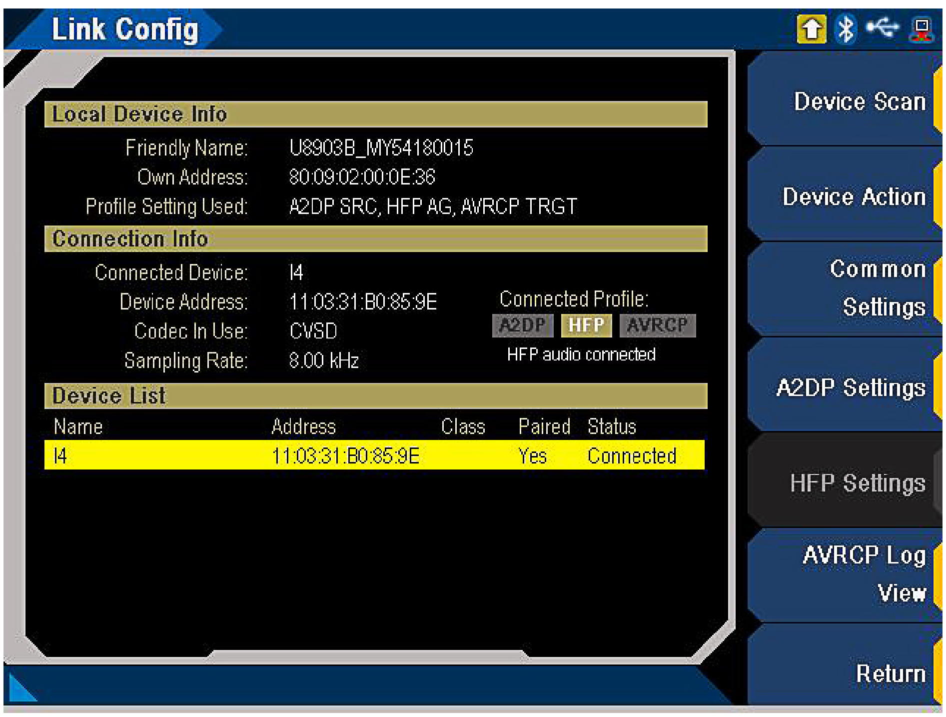


Figure 5. Link configuration

Sweep settings

1. Move highlight to the upper display.
2. All parameters remain at their default values.

Press [On/Off] on the front panel to start the measurement. After the measurement is complete, the result is displayed as a curve as seen in Figure 7.

You can save the test results as a CSV datasheet file for further analysis on a PC by pressing {Save Pts}; or you can print the test result as an image file and export it to a USB storage device by pressing [Shift]+[Print].

Figure 6. Frequency response configuration

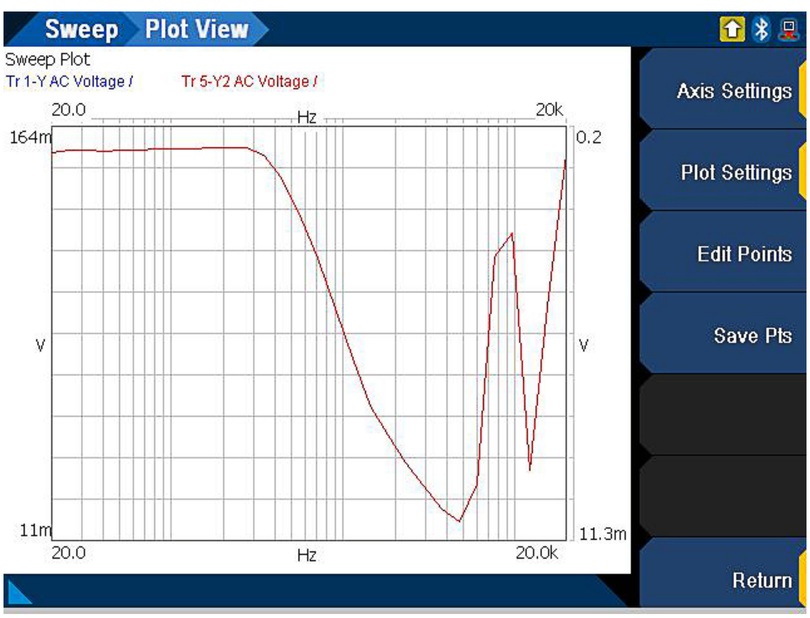


Figure 7. Frequency response test result

The test results in Figure 7 shows a curve with the X-axis as the frequency and the Y-axis as the amplitude of the signal. The frequency scale is logrithmic, so you can see more detail at the lower-frequency range.

Total harmonic distortion plus noise measurements

Total harmonic distortion plus noise (THD+N) is defined as the ratio of the sum of the powers of all harmonic components and noise compared with the power of input signal and noise. THD+N is used to characterize the linearity of audio systems. In audio systems, lower distortion and noise indicates how accurately the components in a loudspeaker, amplifier, microphone, or hearable reproduce the input signal. We will use the downlink measurement as an example. The uplink measurement is similar.

Generator settings

1. Select BG1 (*Bluetooth* Generator channel 1).
2. Set Amplitude at 1 FFS.
3. Set Frequency at 1 kHz.
4. Select Sine as the test signal Waveform.
5. Press **[On/Off]** on the front panel to start generating the test signal.

Analyzer settings

1. Select AA1 (Analog Analyzer channel 1).
2. Set Function 1 as AC Voltage, set Function 2 as Frequency. The Frequency and AV Level measurements help you make sure you receive the test signal correctly.
3. Set Function 3 as THD+N Ratio.
4. Press **[On/Off]** on the front panel to start the THD+N Ratio measurement. The measurement results are shown in Figure 8. The THD+N Ratio is –17.52 dB. Note the AC Voltage is 77.884 mV and the Frequency is 999.99 Hz. This proves you are testing the correct signal because you set the generator to generate a 1 kHz signal.

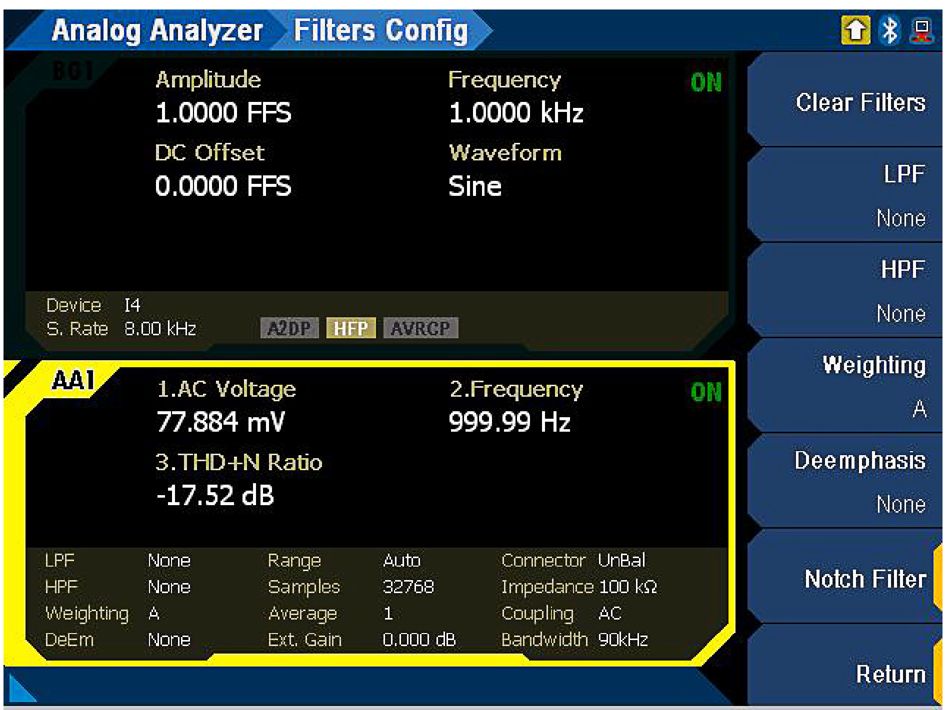


Figure 8. THD+N measurement setting and result

You may need to apply filters to simulate a human's auditory response to the sound. To do this, apply an A-weighting filter, which is set by pressing {Filters Config} in AA1.

The analyzer displays two screens: the signal generator settings on the upper screen and the test results on the lower screen. As shown in Figure 8, the AC Voltage, Frequency and THD+N Ratio test results show up on the lower screen. The Frequency and AC Voltage measurements help you verify that you are testing the correct signal. Compare the generator's 1 kHz signal with the analyzer's 999.99 Hz displayed on the lower screen. If the frequency displayed on the lower screen is unreasonable, you may be testing the wrong signal or no signal is coming back from the DUT.

During the development of your hearable design, you may need to perform other audio tests. The U8903B performance audio analyzer has more than 50 built-in audio tests. Please read the descriptions and test instructions included in the U8903B User's Manual for more detail.

Music playback quality

The Bluetooth A2DP profile supports high-quality stereo music playback, which requires the use of two hearables, one in each ear. Below is the procedure for measuring the music playback quality of your hearable design.
Test setup

1. Set up the Bluetooth link between the U8903B performance audio analyzer and the hearable, which is the device under test (DUT), as shown in Figure 9.
2. Set the U8903B upper display to BG1 (Bluetooth Generator channel 1).
3. Press {Link Config} followed by {Device Scan}. The U8903B will search and pair with the DUT.
4. Press {Device Action} followed by {Profle Connection} and select Connect A2DP. The U8903B will connect the DUT with the A2DP profile.
5. Press {A2DP Operation} and select Open Media Connection. This will establish an audio connection between the U8903B and the DUT as shown in Figure 10. The U8903B simulates a mobile or an MP3 device to playback music and streams it to the DUT.
6. Connect the U8903B input channel 1 and channel 2 with the left and right speaker outputs from the circuit board of the DUT (hearable to be tested).

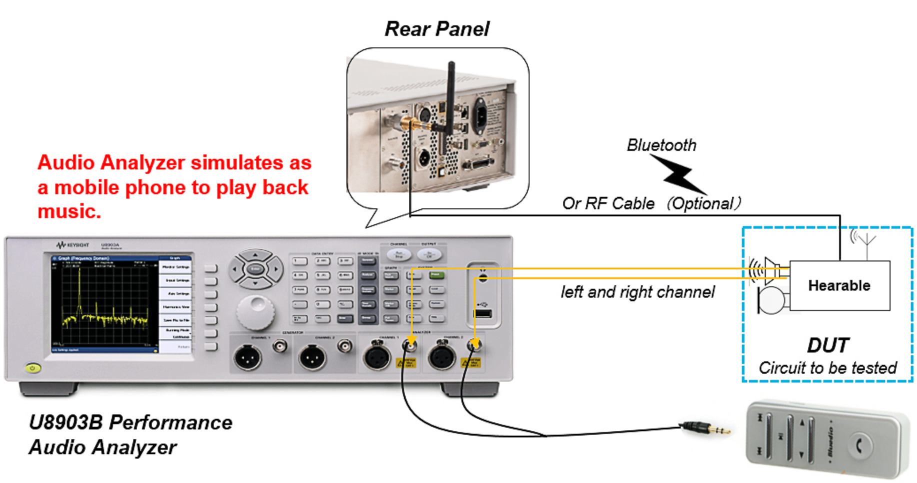


Figure 9. Testing hearable music playback quality

The audio analyzer's *Bluetooth* Generator produces a high-quality test signal (sine wave) and sends it to the DUT via the RF *Bluetooth* link. This simulates music being sent from a mobile phone or other *Bluetooth* device to the DUT. The DUT converts the test signal from an RF *Bluetooth* signal to analog audio, and outputs the analog signal from the DUT via the left and right speaker outputs. The test signals are then sent from the DUT back to audio analyzer channel 1 and 2 for analysis. The U8903B analog analyzer displays the test results on the lower screen.

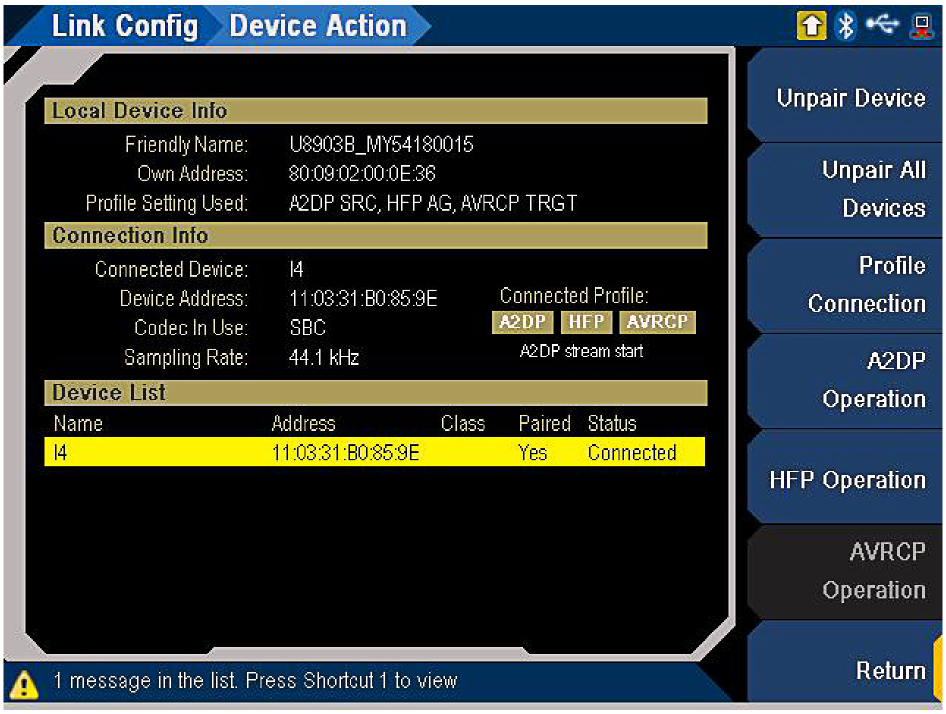


Figure 10. *Bluetooth* link configuration for music playback

Crosstalk between the left and right channels

Crosstalk refers to signal leakage across channels. For example, when a user listens to stereo music on a hearable it is common for the signal of one channel to bleed over at a reduced level into the output of the other channel. Crosstalk is usually expressed in dB (default) or as a percentage. Crosstalk is a measurement of the ratio of the signal amplitude in an unused channel relative to that of a known signal on another channel. The unused channel should be grounded or set to an appropriate bias point. Crosstalk is largely due to capacitive coupling between the channel conductors in the device and generally varies with frequency. During the circuit design, crosstalk is inevitable, especially in a hearable's densely-packed electronic circuit. The R&D or test engineer's job is to reduce crosstalk to the lowest level possible.

The U8903B performs standard crosstalk measurements. Some industries may require the addition of a special filter to the test setup. The U8903B has several built-in filters that can be used when measuring crosstalk.

Generator settings

1. On the U8903B upper display, select BG1 (*Bluetooth* Generator channel 1).
2. Set Amplitude at 1 FFS.
3. Set Frequency at 1 kHz.
4. Press **{Waveform}** and select Sine as the test signal waveform.

Analyzer settings

1. Select AA1 (Analog Analyzer channel 1).
2. Set Function 1 as AV Level.
3. Set Function 2 as Frequency.
4. Set Function 3, and set **{Multi-Chn}** as X-talk. The default **{Reference channel}** is channel 1 which means U8903B is measuring the leaking signal from channel 1 to channel 2.

The settings and measurement for crosstalk measurement are displayed in Figure 11. In this example, the crosstalk (X-talk) results displayed on the lower screen is 0.000 dB. In this case, the crosstalk is so minor that the U8903B cannot detect any signal from the neighboring channel.

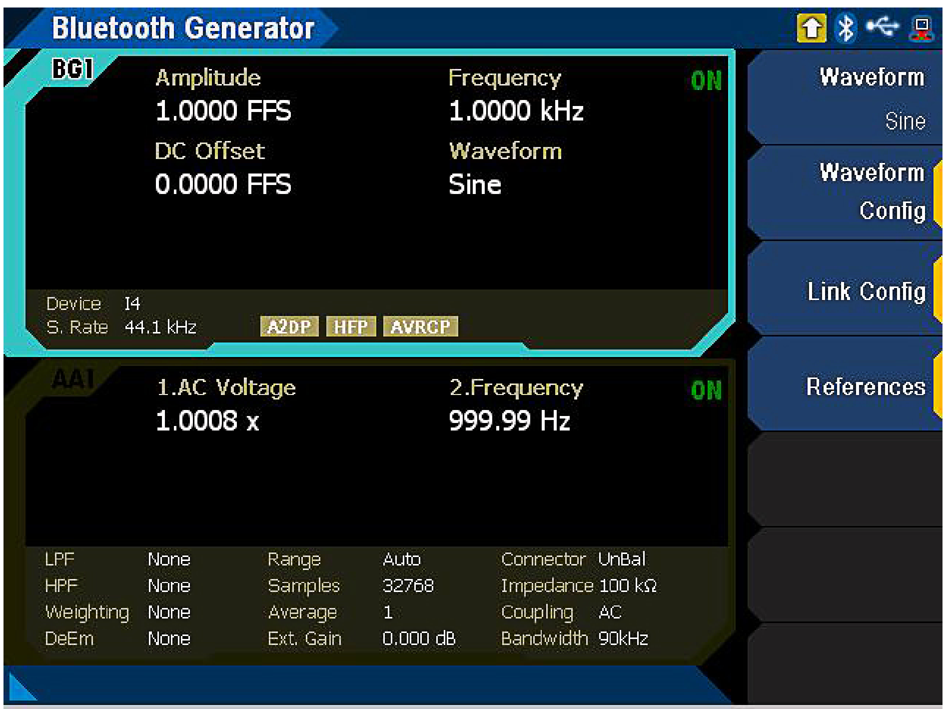


Figure 11. Crosstalk measurement for music playback

Interchannel phase measurement between the left and right stereo channels

Phase describes the time offset between the left and right channels in a periodic waveform cycle (such as a sine waveform). The phase angle is expressed in degrees (°). In a stereo audio system, the delay between the left and right channel will cause a "drift" in the stereo field. In an extreme example, if the left and right channel have the same signal level and the phase between left and right channel is 180°, the stereo signal will be cancelled.

The U8903B can measure phase differences for analog, digital, and *Bluetooth* stereo signals. In order to test phase differences in music playback, the U8903B always uses channel 1 of the analog generator as the reference channel. Channel 2 displays the interchannel phase delay on the lower screen of the audio analyzer. The settings and measurement results for an analog phase measurement are displayed in Figure 12.

Phase measurements are generally not level-sensitive, as long as the signal is well above the noise and below the distortion. For example, to test the left and right channel phase delay of a stereo system, you inject two independent signals: 1 Vrms, 1 kHz sine waveform using *Bluetooth* generator channels 1 and 2. The DUT's output left channel is connected to the analog analyzer channel 1. The DUT's output right channel is connected to the analog analyzer channel 2. Set the analog analyzer to measure phase.

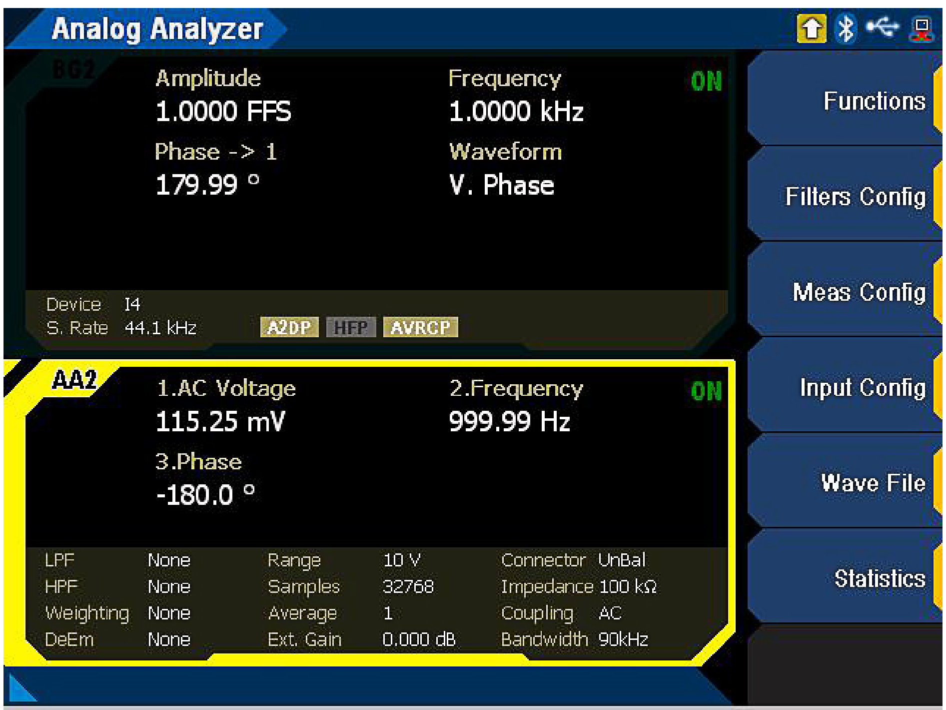


Figure 12. Phase measurement for music playback

Generator settings

1. On the U8903B upper display, select BG2 (*Bluetooth* Generator channel 2).
2. Set up the *Bluetooth* link as described in the previous section.
3. Press **{Waveform}** and select V. Phase as the test signal waveform.
4. Set Amplitude at 1 FFS.
5. Set Frequency as 1 kHz.
6. Set Phase –>1 as 180°.
7. Press **[On/Off]** on the front panel to start generating test signals in both channels.

Analyzer settings

1. Set lower display as AA2.
2. Set Function 1 as AC Voltage.
3. Set Function 2 as Frequency.
4. Set Function 3, and set **{Multi-Chn}** as Phase.
5. Press **[On/Off]** on the front panel to start the phase measurement.

In the measurement shown in Figure 12, the phase difference between the DUT's input and output is only 0.01 degree, which can be ignored. This means the DUT is not causing a phase shift on the music signal. When measuring phase with the U8903B, always uses channel 1 as the reference channel and channel 2 as the phase delay. Remember to select BG2 as the signal generator cannot send a V. Phase waveform while in BG1 mode.

Level differences between the left and right channels

Level differences between the left and right channels are also called “stereo channel unbalance.” Although the signal source outputs the same level and frequency, one channel may be weaker than the other. The listener can hear a distinct volume difference between left and right channels. In a hearable design, several scenarios can cause level differences between the left and right channel, including amplifier gain differences between the left and right channel, the quality of the speakers, and the amplitude and frequency of the input signal. Slight differences between the left and right channels may not be perceived by human ears. However, the audio analyzer can measure the difference accurately.

In order to measure the level differences of a stereo signal from the left and right channel, the audio analyzer must configure 2 generators to output the same signal. In this instance, the waveform is a sine wave with exactly the same amplitude (volume) and frequency (pitch). The waveform is sent to the DUT (hearable) via *Bluetooth*.

The U8903B always uses channel 1 of the analog generator as the reference channel. The results will display as the difference between the reference signal, channel 1, and the DUT, channel 2. The generator settings and measurement results for the level difference measurement are displayed in Figure 13.

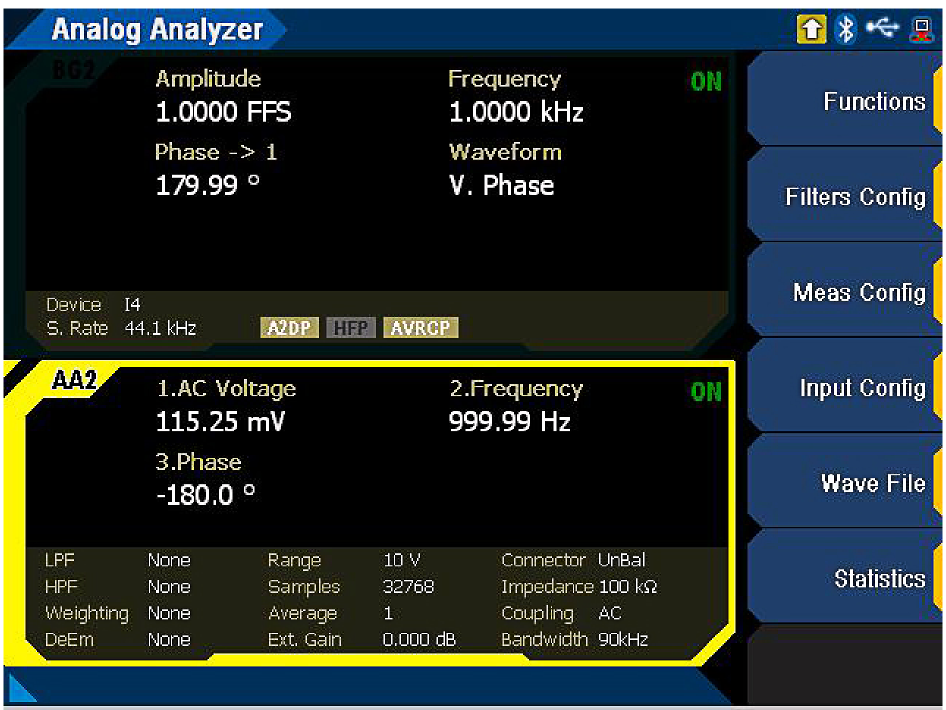


Figure 13. Channel unbalance measurement for music playback

Generator settings

1. Select both BG1 and BG2 as the signal generators (to generate the left and right channels of the stereo signal).
2. Set up the *Bluetooth* link as described in “Test setup” section,
3. Select Sine as the test signal waveform for both BG1 and BG2.
4. Set the Amplitude as 1 FFS for both BG1 and BG2.
5. Set the Frequency as 1 kHz, for both BG1 and BG2.
6. Press [On/Off] on the front panel to start generating test signals on BG1 and BG2 respectively.

Analyzer settings

1. Select AA1 on the signal analyzer.
2. Set Function 1 as AC Voltage.
3. Set Function 2 as Frequency.
4. Set Function 3 and 4 as None.
5. Press {Function}, {More}, {Set Result as Ref. from.} Select channel 2. This will show the result of the AC Level in channel 1 as the reference value from channel 2.
6. Press {More}, {Unit}, select x. Now the AC Level is displayed as the AC Level in channel 1 divided by the AC Level in channel 2.
7. Press [On/Off] on the front panel to start the measurement.

Figure 13 shows the measurement result. The DUT’s channel unbalance is about 0.08 % or (1.0008–1) x 100 %. A human ear cannot perceive such a small difference. In fact, very few people can identify 10 % (or 1 dB) difference on left and right channels.

Noise cancellation

Noise cancellation is a standard feature of most hearables. This feature makes it possible to listen to music without raising the volume, even in a very noisy environment. It can also help passengers sleep in a noisy vehicle, such as a bus or an airplane.
Most noise-cancelling hearables in the consumer market generate a noise-cancelling waveform with analog technology. They generate a signal that will either phase shift or invert the polarity of the original signal (noise). This inverted signal (in antiphase) is then amplified and a speaker creates a sound wave directly proportional to the amplitude of the original waveform, creating destructive interference. This effectively reduces the volume of perceivable noise. In contrast, other active noise and vibration control products use digital processing. In this section, we only discuss analog noise-cancellation testing.

A noise-cancellation speaker inside a hearable must have the same audio power level as the source of the unwanted sound (noise). And the noise-cancellation speaker must be located where sound attenuation is wanted (e.g. the user's ear.)

The key tests for noise cancellation are phase and gain measurements. Basically, the phase measurement test is similar to the phase measurement instructions we introduced in the section on “Testing music playback quality”. The only difference is that the previous phase measurement was an “interchannel phase measurement”. This section focuses on “input to output phase measurement” as shown in Figure 14.

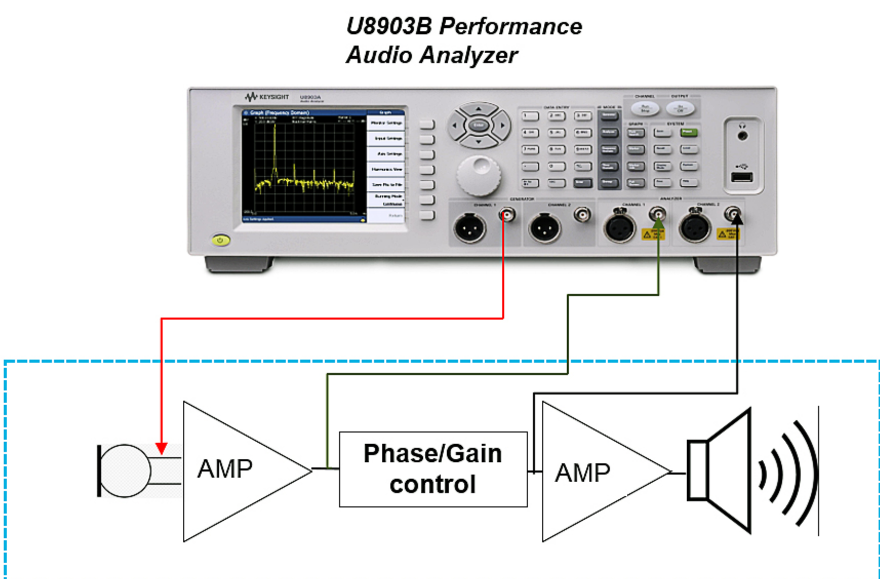


Figure 14. The input to output phase measurement

Noise-cancelling hearables increase the SNR (signal-to-noise ratio) significantly more than passive-noise attenuating headphones. Therefore, SNR is used to measure a hearable's noise cancellation performance. The U8903B configuration and test results for SNR measurements, which are acoustic tests, are displayed in Figure 15.

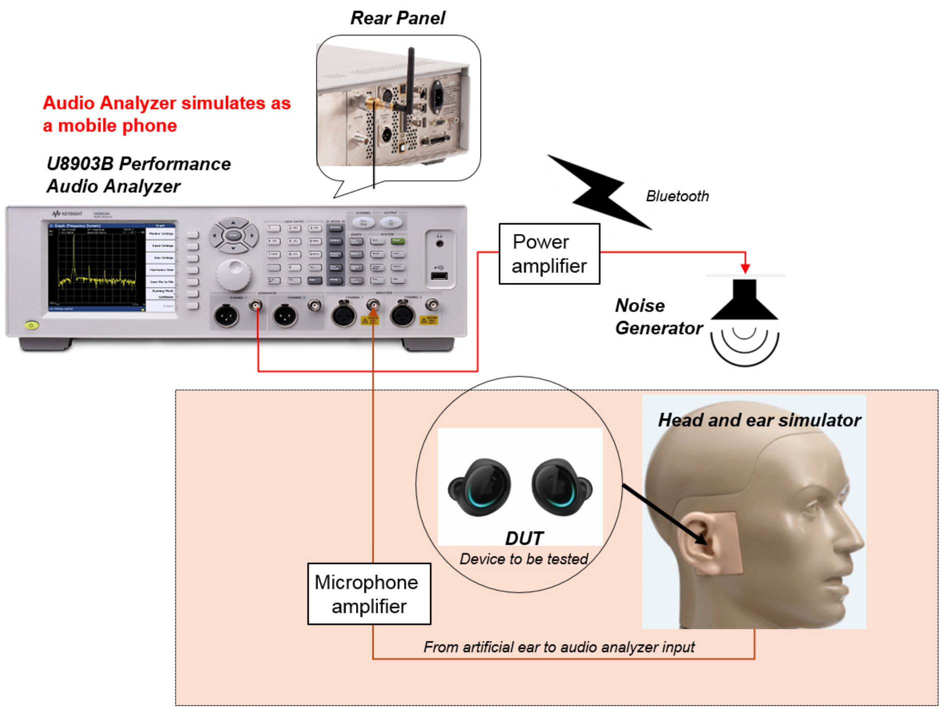


Figure 15. SNR measurement for noise cancellation

Generator settings

Set up the analog generator to generate noise.

1. Move highlight to the upper display, press [Interface] and [Generator/Analyzer] to set AG1 as the noise generator.
2. Connect AG1 to an external noise generator (a loud speaker.) to generate environmental noise.
3. Select Pink Noise as the test signal waveform.
4. Set Amplitude to a proper level which is below the maximum range of the connected power amplifier.

Set up the *Bluetooth* generator.

5. Press [Interface] and [Generator/Analyzer] to set BG1 as the *Bluetooth* signal generator.
6. Set up the *Bluetooth* link as described in the "Test Setup" section on page 11.
7. Select Sine as the test signal waveform.
8. Set Amplitude as 1 FFS and Frequency as 1 kHz.

Analyzer settings

1. Move the highlight to the lower display, press [Interface] and [Generator/Analyzer] to set AA1 as the signal analyzer.
2. Set Function 1 as AC Voltage, set Function 1 unit as dBr.
3. Set Function 2 as Frequency.
4. Set Function 3 and 4 as None.

Measurement Instructions

1. On BG1, set the Amplitude as 0 FFS, which means the test-signal (sine wave) amplitude is 0.
2. On AA1, select {Functions}, {More}, {Set to 0 dB}. The AC Voltage should now show 0 dBr. At this step, set the noise floor as 0 dB.
3. On BG1, set the Amplitude to 1 FFS, which means you generate the full scale of test signal (sine wave).
4. On the AA1 AC Voltage shows signal level: 41.31 dBr.

Since you have set the noise level as 0 dB, the current AC Voltage should show the signal-to-noise ratio, or SNR, as displayed in the AA1 screen of Figure 16.

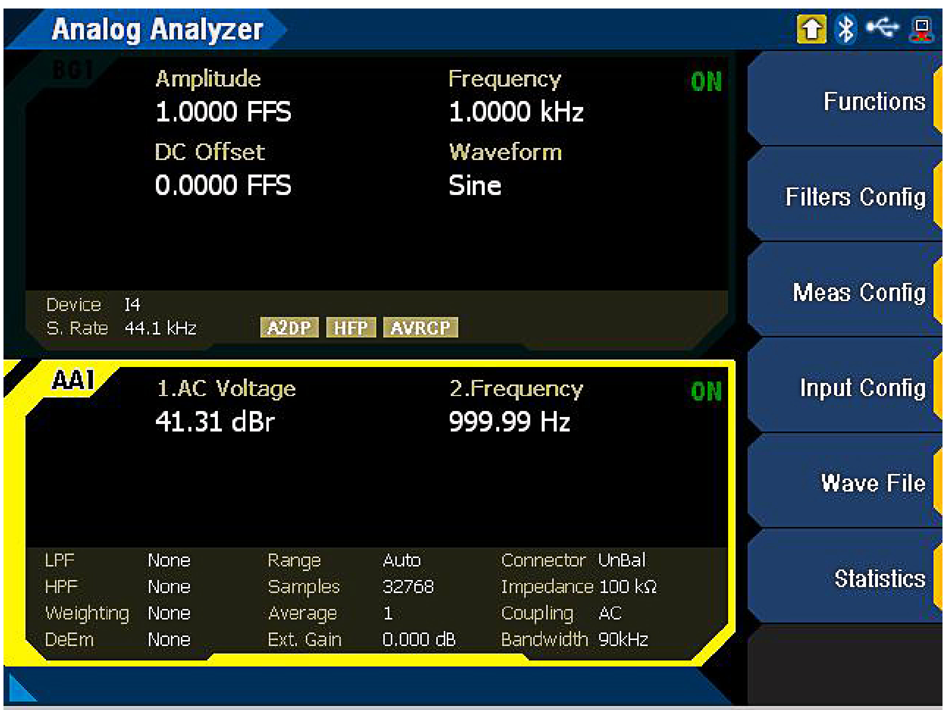


Figure 16. SNR settings and measurement results

To test the noise cancellation effectiveness of your design, you can change the parameters of the U8903B to simulate:

- Different spectrums of environmental noise
  - Pink noise
  - Gaussian noise
  - Rectangle noise
  - Arbitrary noise: you can record a specific noise and play it back as an arbitrary waveform on the U8903B (for example: a recording of jet engine noise)
- Noise amplitude
  Adjust the amplitude of noise to test the noise cancellation on different noise levels.
- Multi-noise generators
  Set more than one noise generator to test the noise cancellation on different noise sources and locations. The U8903B analog generator can support two noise generators, each generator can generate independent noise waveforms and amplitudes.

Out-of-band noise

For any hearable, the audio codec and digital-to-analog converter (DAC) are the key components that determine audio quality. However, out-of-band noise exists more or less in any audio codec and DAC. In this section, we discuss how to use the audio analyzer to examine the out-of-band noise measurement for the audio codec and DAC. The U8903B performance audio analyzer, as configured for this application note, has an input bandwidth up to 1.5 MHz with 24-bit resolution and two-million-point FFT, which makes it an effective tool for identifying out-of-band noise.

What is out-of-band noise?

In audio systems, out-of-band noise comes from frequencies beyond the audio frequency band. The audio frequency band is defined as 20 Hz to 20 kHz, the normal range in which the human ear can hear. Speaker response to frequencies above 20 kHz generally decreases proportionally to 1/f2, so a loudspeaker is not good at reproducing frequencies above 20 kHz.

Why does out-of-band noise exist?

Audio codecs are typically designed using a Sigma-Delta (S-D) architecture for the ADC's and DAC's. One of the characteristics of an S-D converter is that the noise transfer function (NTF) is not flat. The S-D modulator in these converters shifts quantization noise from the low frequencies (audible band) to the high frequencies (out-of-band). This gives audio codec devices excellent noise performance, which is measured by signal-to-noise ratio (SNR.)

However, the disadvantage of S-D architecture is that it produces high-frequency out-of-band noise. You cannot hear the noise, because it is beyond the audible band, but it causes undesirable effects on a hearable's audio signal. The level of out-of-band noise is determined by the order of modulator, oversampling rate, and analog filters.

How out-of-band noise effects audio quality?

When a signal containing significant out-of-band noise is reprocessed by another component such as a PWM modulator in a Class-D amplifier or another A/D converter, the out-of-band noise is modulated or aliased back into the audio band, which degrades the audio quality. For this reason, anti-aliasing low-pass filters are recommended between the codec outputs and the Class-D amplifier or A/D inputs. However, the filtering is not perfect, so some out-of-band noise will still exist in the audio signal.

How do you measure out-of-band noise?

Traditionally, a spectrum analyzer is used to measure out-of-band noise, because only a spectrum analyzer can provide wideband (>1 MHz) FFT measurements. The drawback with using a spectrum analyzer to measure out-of-band noise is its resolution. A spectrum analyzer cannot provide 24-bit measurement resolution, which is only available in audio analyzers. However, the audio analyzer's standard measurement bandwidth is just 100 kHz. These problems are solved by using the Keysight U8903B performance audio analyzer with N3431A software. The U8903B has 24-bit resolution and the N3431A software expands the measurement bandwidth to 1.5 MHz. These features make the U8903B the ideal tester for out-of-band noise measurement. In addition, the U8903B provides a variety of built-in filters that make testing out-of-band noise more accurate and convenient.

The test setup is simple. Connect the U8903B input to the DAC, Codec or class-D amplifier's output, either before or after the analog filter. Use a shielded BNC cable for the connection in order to eliminate environmental interference.

Generator settings

1. Not required.

Analyzer settings

1. Select AA1 or AA2.
2. Press **{Input config}** and **[Bandwidth]** to set the measurement bandwidth to 1.5 MHz. If you cannot select 1.5 MHz please check if the N3431A option is installed.
3. Do not apply any filter to the 1.5 MHz wideband measurement.

Measurement instructions

1. Press **[Graph]** and then **[On/Off]** on the front panel to change the U8903B display to graphic mode.
2. Press **{Axis Settings}** and set Right to 1.5 MHz. Now the display shows the test signal's spectrum in a 1.5 MHz bandwidth, just like a spectrum analyzer.
3. If you want to increase the FFT resolution to see the more details, press **{Graph Settings}** and change the Sample size to greater points, for example 252144 points. Now, the signal spectrum become sharper and more details shows up; however, the display's refresh rate will be slower. The U8903B can support up to 2 million points for 1.5 MHz bandwidth, which means 0.75 Hz FFT resolution for spectrum analysis. The U8903B is the only audio analyzer that achieves this resolution.
4. You can also press **[zoom]** to have a closer look at the spectrum of a specific section of frequency range. Press **[Shift]** + **[zoom]** to change the zoom settings.
5. The result of out-of-band measurement is shown in Figure 17.
6. In graphic mode the U8903B operates just like a spectrum analyzer, oscilloscope or network analyzer. For example, you can use marker, axis settings, channel setup, time domain, phase domain, and PSD for advanced measurements. Please read the U8903B User's Manual for detailed instructions.

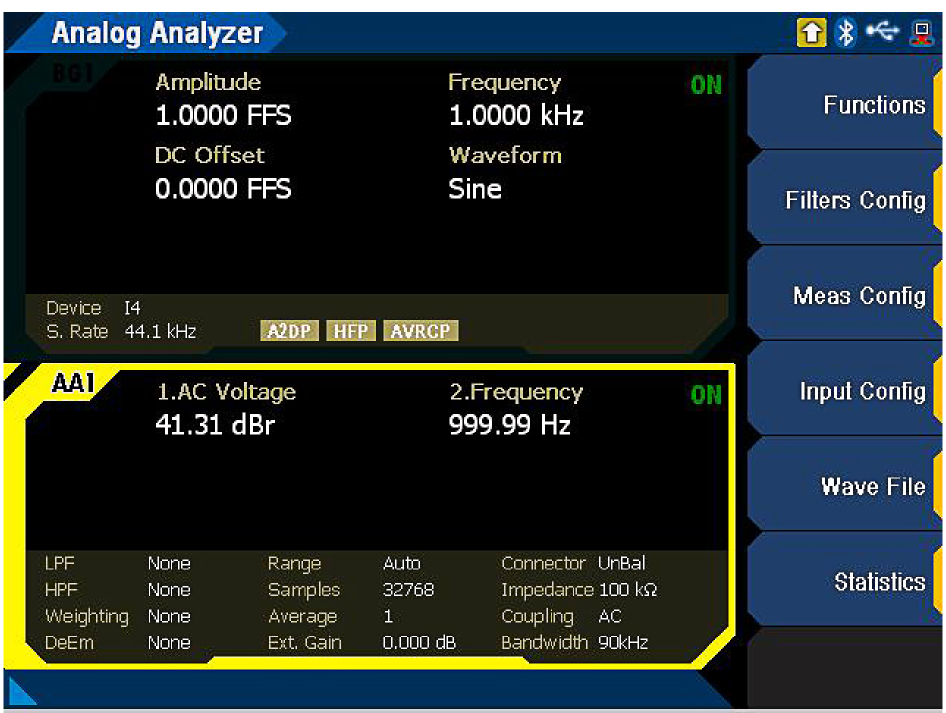


Figure 17. Example out-of-band measurement

Baseline out-of-band measurements

A baseline out-of-band measurement shows the performance of the hearable without any filtering or circuitry. The first baseline measurement is when no signal is injected through the DAC of the hearable. In this instance, the frequency spectrum result should be flat and low level because the modulator is not working. The second baseline measurement is the output spectrum after a signal is injected through the DAC and then stopped (no input). The modulator is now turned on and the out-of-band noise spectrum indicates higher noise.

Filtered out-of-band measurements

By adding a low-pass filter before the output, measurements can be made that accurately reflect the performance of the codec. The filter is designed as a low-pass filter with a cutoff frequency of approximately 22 kHz. This allows the filter to attenuate the higher frequencies and leave the audio band frequencies unaffected.

In summary, the use of a low-pass filter is recommended to reduce the out-of-band noise and prevent any interference with the hearable measurement. The results of an out-of-band measurement made using the U8903B are displayed in Figure 17.

Troubleshooting

If you are a design engineer, you know that troubleshooting is inevitable during the test and validation of a circuit design. In this section, we discuss how to use the U8903B performance audio analyzer for troubleshooting hearable designs. From a hardware point of view, the core technology behind a hearable is the *Bluetooth* headset, with its built-in sensors, GPS receiver, and health monitor. A hearable high-level block diagram with test points is displayed in Figure 18.

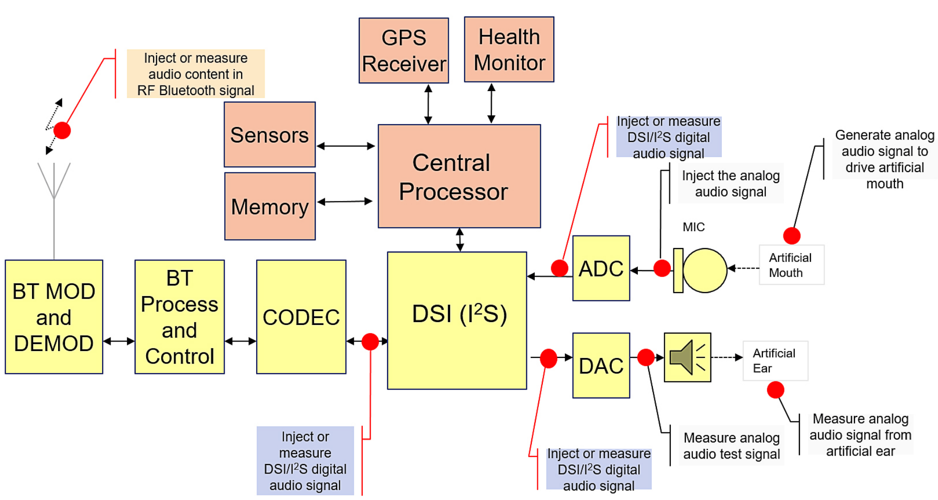


Figure 18. A hearable high-level block diagram with test points

Uplink signal path

The microphone picks up the user's voice and converts it from acoustic sound into analog electrical signals. The analog electrical signals are converted to digital audio format (DSI or I2S.) The digital audio format is sent to the CODEC for coding. The coded signal is enveloped within the *Bluetooth* signal and protocol (SCO format.) After modulation, the SCO format is converted into an RF signal and sent from the *Bluetooth* antenna.

Downlink signal path

The downlink signal path is similar to the uplink signal path explained above, only it operates in the reverse direction.

In order to locate a problem in your hearable design, you will need to inject an analog audio signal into the input of the circuit or a specific component, and measure the analog audio signal at the output. For example, you can inject an analog sine wave at the microphone input and measure the same signal from the *Bluetooth* transmitter. This measurement will tell you the signal quality of your hearable design. Sometimes, the signal quality from the *Bluetooth* transmitter is not as good as you expected. In this case, you must check each section of the design, from the microphone all the way to *Bluetooth* transmitter, to identify the problem.

A hearable circuit consists of three types of audio signals: analog audio, digital audio (DSI/SPDIF and DSI/I2S) and *Bluetooth* audio. The U8903B performance audio analyzer supports all three types of audio signals. You can inject any type of audio signal at the input, and measure any type of audio signal at the output. For example, you can inject a sine wave, such as an RF *Bluetooth* signal, and measure that same sine wave at the analog audio or speaker output.

Summary

In order to save time, improve signal quality, reduce scrap, and the costs associated with rework we recommend that you fully validate your hearable design in the development phase. The U8903B performance audio analyzer can help ensure that your hearable design has the audio signal quality necessary to meet consumer demand in the rapidly-growing wearable technology market.

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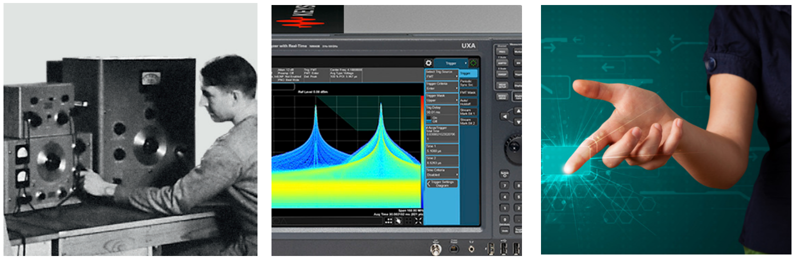

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