Keysight U8903A
Understanding the Decibel in Audio Measurements

Application Note

[Image of Keysight U8903A instrument]
Introduction

The decibel in audio measurement

In the radio frequency (RF) microwave test and measurement world, engineers often deal with the power measurement unit of dBm instead of wattage, which is commonly known as watt (W). However, engineers entering the audio measurement arena will need to understand one more measurement unit known as dBu, which is decibel (dB) relative to 1 mW into 600 Ω. This application note explains dBu and provides useful tips to assist you in accurately making and understanding audio measurements.
Back to Basics

Understanding the decibel (dB)

The decibel is a very commonly used yet often misunderstood unit of measurement. The "bel" in "decibel" comes from the name of Alexander Graham Bell. He was interested in the way in which the human ear responds to sound intensity. He used a logarithmic scale to express this sound intensity, in which range from the softest sound to the loudest (threshold of pain) sound, is one to a billion (10^{12}) or zero to 12 bels. The decibel is one tenth of a "bel" and is abbreviated as dB.

There are two primary benefits to using dB. The first is to express very large or very small ratios in a compact way; for example, +63 dB to –153 dB is more concise than 2 x 10^6 to 0.5 x 10^{-15}. Another advantage is apparent when comparing quantities used to multiply the gain or divide the loss of several cascaded devices. dB simplifies the mathematic process, in that multiplication of numeric gain is replaced by addition, and division of numeric attenuation is replaced by subtraction.

Definition of decibel (dB)

dB is a logarithmic unit expressing the ratio of two quantities. In power measurement, the relative power is defined as

\[ dB_{\text{ref}} = 10 \log_{10} \frac{P_1}{P_{\text{ref}}} \]

and in voltage measurement, the relative voltage is defined as

\[ dB_{\text{ref}} = 20 \log_{10} \frac{V_1}{V_{\text{ref}}} \]

To describe dB as an absolute value, a reference point must be known. There are a number of different reference points, as defined below:

- dBm represents the power level P1 with reference to 1 mW
- dBW represents the power level P1 with reference to 1 W
- dBV represents the power level V1 with reference to 1 Vrms
- dBmV represents the power level V1 with reference to 1 mVrms
- dBuV represents the power level V1 with reference to 1 uVrms

dBm is the most commonly used unit in power measurement. For instance, if an engineer is working in a known industry standard environment, the impedance of the test system is usually 50 Ω in RF engineering, 75 Ω in television engineering, and 600 Ω in audio engineering. A conversion formula will help engineers to convert power measurement of dBm to any unit of dBV, dBmV, or dBuV. Refer to the rule of thumb shown on the column on the left.

Rule of thumb

- For 50 Ω system
  - dBV = dBm – 13 dB
  - dBmV = dBm + 47 dB
  - dBuV = dBm + 107 dB
- For 75 Ω system
  - dBV = dBm – 11.25 dB
  - dBmV = dBm + 48.75 dB
  - dBuV = dBm + 108.75 dB
- For 600 Ω system
  - dBV = dBm – 2.22 dB
  - dBmV = dBm + 57.78 dB
  - dBuV = dBm + 117.78 dB
Introduction to U8903A

The U8903A is a digital signal processing (DSP) based audio measurement system that combines both an audio generator and analyzer. This test set consists of two channels each for the audio generator and analyzer, and the output and input configurations are fully independent of each other.

The U8903A audio generator has a frequency range of 5 Hz to 80 kHz, and the sine wave amplitude range can cover from 0 Vrms to 8 Vrms (11.3 Vp) for the unbalanced test output configuration and 0 Vrms to 16 Vrms (22.6 Vp) for the balanced output configuration. When using the audio generator, you can generate not only a basic sine waveform, but also square, dual sine, variable phase, noise, DC, multitone, and arbitrary waveforms.

The U8903A audio analyzer has a frequency measurement range of 10 Hz to 100 kHz with an amplitude measurement range of <1 μVrms to 140 Vrms (200 Vp). In addition, the U8903A is equipped with frequency and time domain graph functions, as well as sweep capability for frequency, amplitude, and phase. This allows you to perform a wide range of audio parameter measurements consisting of voltage; frequency; total harmonics distortion, plus noise (THD + N); signal, noise and distortion (SINAD); signal-to-noise ratio (SNR); noise level; SMPTE inter-modulation distortion; difference frequency distortion (DFD); phase; and crosstalk.

The U8903A also supports the industrial standard of instrument connectivity such as GPIB, USB, and LAN.
Features of U8903A

Audio generator
- Frequency range: 5 Hz to 80 kHz
- Amplitude range:
  - 0 Vrms to 8 Vrms (11.3 Vp) for the unbalanced output
  - 0 Vrms to 16 Vrms (22.6 Vp) for the balanced output
- Waveforms:
  - Sine
  - Dual sine (SMPTE IMD, DFD)
  - Square
  - Variable phase
  - Noise
  - DC
  - Multi-tones generation
  - User-defined arbitrary waveforms
- Output connector:
  - Balanced (XLR)
  - Unbalanced (BNC)
- Output impedance:
  - 50 Ω
  - 600 Ω

Audio analyzer
- Frequency range: 10 Hz to 100 kHz
- Amplitude range: <1 μVrms to 140 Vrms (200 Vp)
- Input connector:
  - Balanced (XLR)
  - Unbalanced (BNC)
- Input coupling:
  - DC
  - AC
- Input ranging:
  - Auto
  - Manual
- Filters/bandwidth:
  - Low pass (none/15 kHz/20 kHz/30 kHz/custom)
  - High pass (none/22 Hz/100 Hz/400 Hz/custom)
- Weighting (A-weighting/CCIR 1k/CCIR 2k/C-Message/CCITT/custom)
- Detectors:
  - RMS
  - Peak-to-peak
  - Quasi Peak
- Measurement:
  - AC level
  - DC level
  - Frequency
  - Phase
  - THD+N (ratio)
  - THD+N (level)
  - SINAD
  - SNR
  - Noise level
  - SMPTE IMD
  - DFD
  - Cross talk
- Sweep capability:
  - Voltage
  - Frequency
  - Phase
- Graph display views of the input signals:
  - Time domain
  - Frequency domain
  - Selectable measurement time
- Trigger mode:
  - Free run
  - External
  - GPIB, LAN, and USB remote interface
**dBu (dB relative to 1 mW into 600 Ω)**

The Keysight U8903A audio analyzer is a complete audio measurement system that combines a low-distortion signal source with a signal analyzer. The signal source has a selectable output impedance of either 50 W or 600 W. For most traditional test equipment, the source impedance uses only 50 Ω, but for audio test applications the 600 Ω source impedance is more commonly used. In audio test applications, the engineer has to consider another decibel formula in the unit of voltage measurement: dBu. dBu is defined as dB relative to 1 mW into 600 Ω. It is a logarithmic unit expressing the relative voltage measurement with reference to a voltage value of 0.7746 Vrms (voltage drops across 600 Ω that results in 1 mW of power).

**Maximum output power**

As mentioned earlier, 50 Ω is the most commonly used source impedance. 50 Ω source impedance can result in higher short-circuit current (for a constant voltage), and 10 times the frequency response over a given length of cable than with 600 Ω source impedance.

The U8903A has the maximum voltage source for unbalanced output (Vs) of 8 V, and the following figures illustrate the maximum power transfer the U8903A can deliver into various load-impedance scenarios using the source impedance of 50 Ω or 600 Ω.

**1. Source and load impedance (50 Ω for both)**

\[
V_L = \frac{50}{50 + 50} \times 8 = 4 V
\]

\[
I_L = 80 mA
\]

\[
P_{50Ω} = 25.1 \text{ dBm}
\]

**2. Source impedance of 50 Ω and load impedance of 600 Ω**

\[
V_L = \frac{600}{600 + 50} \times 8 = 7.385V
\]

\[
I_L = 12.3 mA
\]

\[
P_{600Ω} = 19.6 \text{ dBm}
\]
Maximum output power (continued)

3 Source impedance of 600 Ω and load impedance of 600 Ω

\[ V_L = \frac{600 \times 8}{600 + 600} V = 4 \, V \]

\[ I_L = \frac{6.67 \, mA}{600 + 600} \]

\[ P_{600\Omega} = 14.3 \, dBm \]

4 Source impedance of 600 Ω and load impedance of 50 Ω

\[ V_L = \frac{50 \times 8}{50 + 600} V = 0.615 \, V \]

\[ I_L = \frac{12.3 \, mA}{50 + 600} \]

\[ P_{50\Omega} = 8.8 \, dBm \]

Understanding output voltage

Nowadays, due to the advancement of DSP-based RF test equipments, some RF engineers are able to perform audio measurements on RF instruments and then correlate the test results with other audio instruments. Sometimes engineers encounter problems with their RF signal analyzer when measuring two different sources of supply that are identical in stimulus setup: for example, output frequency \( F_L \) and output voltage \( V_L \). The RF signal analyzer receives very divergent measurement results that show both inputs are unequal in amplitude or bandwidth. Scenarios 1 and 2 illustrate these situations.

Scenario 1

One signal generator that combines audio signal and RF carrier with 50 Ω output source impedance (see Figure 1).

Figure 1. Signal analyzer results for scenario 1
Understanding output voltage (continued)

Scenario 2
Two standalone audio generator and one RF modulator (see Figure 2).

Due to the default setting of the audio generator, its source impedance has to be set to 600 Ω. Therefore, the output voltage $V_L$ for scenario 2 is no longer equal to scenario 1.

The correct output voltage ($V_L$) for both scenarios is shown below.

Scenario 1
One signal generator that combines audio signal and RF carrier with 50 Ω output source impedance.
Scenario 2
Two standalone audio generator and one RF modulator.

\[ V'_L = \frac{1}{13} V'_S \]

In order to match these two scenarios and to get an equal voltage output, \( V'_L \) must be equal to \( V'_S \). Therefore, the source voltage output in scenario 2 must be set to

\[ V'_S = \frac{13}{2} V_S \]

Case study
If an engineer sets the voltage output of an audio generator that comes with a fixed source impedance of 50 \( \Omega \), \( V'_S = 2 \) V (8.24 dBu), then its voltage will drop across at 50 \( \Omega \) load impedance, \( V_L = 1 \) V (see Figure 3).

If the engineer sets up another output of an audio generator with source impedance of 600 \( \Omega \), then in order to get the output performance similar to the previous 50 \( \Omega \) system, the engineer needs to set a higher output voltage of \( V'_S = 13 \) V (24.5 dBu). Therefore, it will also deliver \( V'_L = 1 \) V to the same 50 \( \Omega \) load impedance (see Figure 4).

dBu (in 50 \( \Omega \)) to dBu (in 600 \( \Omega \)) conversion is a technique for verifying and confirming that the source impedance of the audio analyzer is the reason for the divergent measurement results in the RF signal analyzer. As a rule of thumb, \( \text{dBu (in 600 } \Omega) = \text{dBu (in 50 } \Omega) + 16.26 \text{ dB} \).

The U8903A comes with a switchable source impedance of 50 \( \Omega \) or 600 \( \Omega \). Once the engineer has verified and confirmed the root cause, he or she just needs to modify the setting of the output source impedance in order to get the appropriate output voltage.
The application note is not intended as a textbook, but rather to refresh engineers’ knowledge of the decibel and to provide an introduction to new users of the U8903A in audio measurement. It is important that every engineer reviews these concepts, understand, familiarize these measurements from time-to-time. This basic review will help many engineers carry out their day-to-day engineering tasks more effectively and efficiently in various test applications such as those in manufacturing environment, R&D design, and QA inspection.

### Summary

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