

## How Do We Define ‘Overall’ and ‘Broadband’?

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This month’s Q&A column question was suggested by Larry Meidell of Chadwick-Helmuth Co., El Monte, CA.

**Question: What are the standard or most widely accepted definitions of ‘overall’ and ‘broadband’ vibration measurements and are they the same?**

**Answer:** The term ‘overall’ is typically used in the context of the overall or total amount of energy contained in a signal. This is usually measured and expressed as the RMS (Root Mean Squared) amplitude of the signal. The RMS value of a signal is directly related to the energy or destructive ability (for vibratory systems) of the signal.

The term ‘broadband’ is used to describe a signal’s energy content as a function of frequency. A broad band signal is comprised of a distribution of energy over all frequencies in a frequency range of interest. Conversely a “narrow band” signal has energy concentrated at discrete frequencies. A typical broadband signal, such as the noise floor of an accelerometer, would be random in nature. The overall RMS amplitude of a signal can be determined over a broad frequency range of the signal or over a band-limited range.

Before the advent of digital signal processing and even today, the RMS amplitude of a signal was measured using a “true RMS” voltmeter as shown in Figure 1.

Mathematically the RMS value of a signal  $v(t)$  is defined by:

$$V_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T v^2(t) dt}$$

The above equation illustrates that the RMS value is nothing more than the square root of the area of the signal  $v(t)$  squared, normalized by the measurement time  $T$ . The analog “true RMS” voltmeter implements this equation with analog circuitry. Today’s digital signal processing instruments do the calculation digitally. Using digital instrumentation, we can calibrate the measured voltages to engineering units (EUs). Thus, instead of measuring a signal’s RMS value in terms of volts we can use EUs such as acceleration in g RMS. When the term ‘overall’ is used to describe a signal’s amplitude, we are generally referring to the signal’s ‘overall’ RMS amplitude.

A complicating factor when measuring a signal’s overall RMS amplitude is the frequency range or bandwidth of analysis. Signals can be filtered using “low pass,” “high pass” or “band pass” filters to determine the amount of energy in the signal for a particular frequency range or band. Indeed this is one use of today’s

spectrum analyzers. Historically this type of measurement was made using one or more analog filters as shown in Figure 2.

In a similar sense, spectrum analyzers determine a signal’s energy over a specified frequency range. The frequency range can be from 0 Hz to a specified maximum frequency (base band measurement) or a ‘zoomed’ frequency range analogous to a band pass filter. So, when we refer to a signal’s RMS amplitude we should also define the frequency range over which the RMS value was measured.

This frequency range issue leads us to the second part of this month’s question: What does the term ‘broadband’ refer to. Signals generally fall into two categories: “narrow band” (Deterministic Signals) and/or “broad band” (Random Signals).

**Deterministic Signals.** Stationary, deterministic signals are entirely made up of sinusoids at discrete frequencies. The frequency analysis resolution is determined by the filter bandwidth used. Ideally, only one sinusoid should lie within the filter passband at any given time. In this situation, the power transmitted by the filter is independent of the analysis bandwidth. Because of this, the signal is, therefore, scaled in terms of power (mean square) EU<sup>2</sup> or root mean square (RMS) EU. Typical units in the vibration field include RMS, m/s<sup>2</sup>, m/s, m, g, in./sec and mils.

**Random Signals.** Continuous, stationary random signals have spectra, which are continuous in the frequency domain. For this reason, there is a frequency distribution within the filter passband and the power transmitted by the filter depends on its bandwidth. By dividing the transmitted power by the filter bandwidth, we can eliminate its influence. This division gives us the Power Spectral Density or PSD which is a measure of power per unit bandwidth. You may see the units expressed in EU<sup>2</sup> RMS/Hz or the square root of this value EU RMS/ $\sqrt{\text{Hz}}$ .

Let’s look at a couple of examples. First a narrow band signal that is comprised of a single 3-volt (0-peak) sine wave at 1000 Hz. Figure 3 shows the sine wave and its power spectrum. The ‘overall’ RMS amplitude of this signal is measured as 2.1 volts RMS. The spectrum shows the RMS amplitude of the peak at 1000 Hz to be 2.1 volts RMS. We know the relationship of the RMS amplitude of a sine wave to the peak amplitude to be:

$$\begin{aligned} V_{\text{RMS}} &= 0.707 V_{\text{peak}} = 0.707 (3.0) \\ &= 2.1 V_{\text{RMS}} \end{aligned}$$

Now let’s complicate the example

slightly by adding another sine wave at 1100 Hz to the original 1000 Hz signal. Figure 4 shows the new signal along with its associated power spectrum. This signal still is a “narrow band” signal with all the energy at two distinct frequencies instead of only one as before. Notice that the time history is no longer a simple sine wave. The spectrum now shows two frequency components (or spectral lines), one for each sine wave component. The overall RMS level of the signal is now 4.7 volts RMS and is comprised of two frequency components with two different amplitudes. The first component is the 1000 Hz sine wave with the RMS amplitude of 2.1 volts RMS and the second component is the 1100 Hz sine wave with an amplitude of 4.2 volts RMS. The overall amplitude of this signal is related to the individual components by the following equation:

$$\begin{aligned} \text{Overall}_{\text{RMS}} &= \sqrt{(2.1)^2 + (4.2)^2} \\ &= 4.7 V_{\text{RMS}} \end{aligned}$$

Another very important point to be made here is that there is no longer any relationship between a signal’s RMS amplitude, whether it’s for individual frequency components or the overall signal to the signal’s actual peak amplitude. In this example the signal’s overall RMS amplitude is 4.7 volts RMS but the signal’s actual peak amplitude is 8.9 volts. This is much larger than a single sine wave with RMS amplitude of 4.7 volts RMS that would have a peak value of 6.3 volts (see the above relationship between the RMS and peak amplitudes of a sine wave).

Now let’s finally look at an example of a ‘broadband’ signal. We will use two different internally amplified piezoelectric accelerometers to measure the PSD of floor vibrations in a laboratory. The accelerometers used in this example have a sensitivity of 10 mV/g and 1000 mV/g, respectively. The noise floor of the 1000 mV/g accelerometer is <3  $\mu\text{g RMS}/\sqrt{\text{Hz}}$  whereas the noise floor of the less sensitive accelerometer is 350  $\mu\text{g RMS}/\sqrt{\text{Hz}}$ . Figure 5 compares the accelerometers measuring the PSD of floor vibrations at the same location in the laboratory. Notice that the high noise floor of the less sensitive accelerometer dominates the overall amplitude of 0.12 g RMS. The more sensitive accelerometer measures the more accurate overall floor vibration of 940  $\mu\text{g RMS}$  because of a much lower noise floor.

Next month’s Q&A column is about analyzing the mode shapes of a structure using two different impact testing techniques to collect frequency response functions. One technique uses a fixed reference tri-axial accelerometer while impacting various points of interest only in one direction (Z, for instance). The other technique involves impacting the same point on the structure in the same

direction (Z, for example) while moving a roving tri-axial accelerometer. In both of these techniques, the same number of Frequency Response Functions (FRFs) are measured at the points of interest on the structure being analyzed. The question is: **Do mode shapes determined from two different impact testing techniques contain the same information?**

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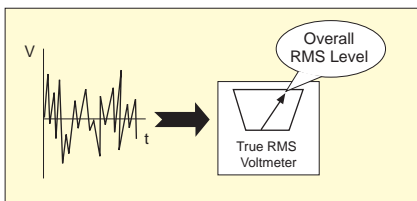


Figure 1. Signal measured using "true RMS" voltmeter.

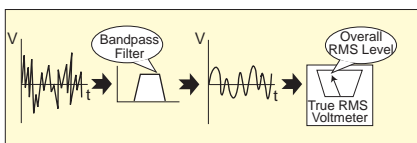


Figure 2. RMS level of a filtered signal.

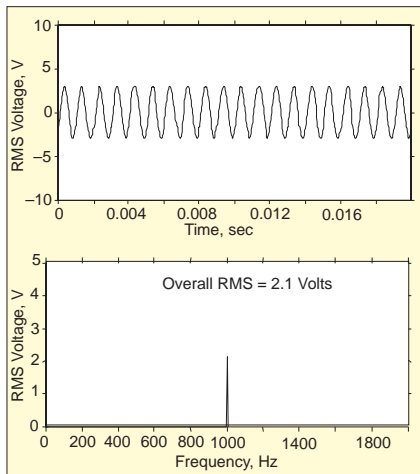


Figure 3. Single sine wave.

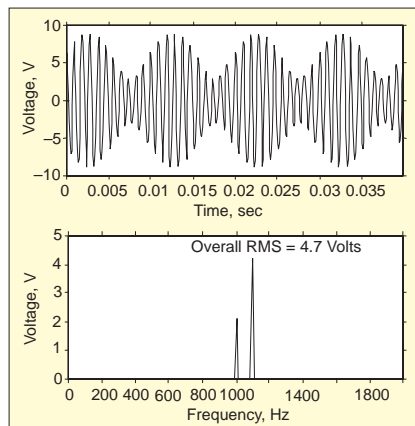


Figure 4. Dual sine waves.

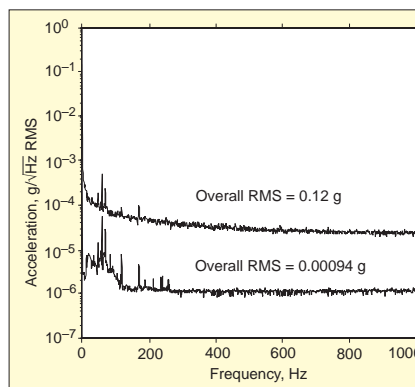


Figure 5. Comparison of noise floors for accelerometers with two different sensitivities.