S&V Questions and Answers

Accelerometer Dynamic Range

Dave Formenti, Sage Technologies, Morgan Hill, California
Trevor Norsworthy, Sage Technologies, Bellevue, Washington

Question: **How do I determine the dynamic range of an internally amplified (voltage mode) accelerometer that uses a constant current power supply?**

The answer to this question depends not only on the specifications of the specific accelerometer but also on two additional pieces of information: the power supply voltage used to power the accelerometer's internal electronics and the frequency and bandwidth of the signal to be measured.

Let's assume that the accelerometer is powered by a common constant current power supply utilizing three 9-volt batteries (27 V supply) and with unity gain. Such "passive" conditioners do not contribute any significant noise of their own. However if we use an AC powered supply with gain, we very likely would discover that the noise of the power supply might be equal to or greater than that of the accelerometer and thus be the limiting factor to the dynamic range.

We will determine the dynamic range for 3 different signal types:

1. Broadband random, 2.5 Hz to 25 kHz.
2. Narrowband random at 1 kHz with 10 Hz bandwidth.
3. Sine wave at 100 Hz.

Remember that the definition of Dynamic Range is defined as:

$$\text{Dynamic Range (dB)} = 20\log\frac{V_{\max}}{V_{\min}}$$

where $V_{\max}$ and $V_{\min}$ are the largest and smallest signal levels, respectively.

So, the first step to determining the dynamic range is calculating the maximum acceleration that can be measured. Using the accelerometer's product data sheet, look up "Acceleration Range" and "Sensitivity" of the accelerometer. As an example, let's assume our accelerometer has an acceleration range of 80 g peak and a nominal sensitivity of 100 mV/g. Also, assume that our accelerometer has a sensor DC bias voltage of 12 volts. Internally amplified accelerometers of this type use a bias voltage from 8 to 14 volts. The internal amplifier of the accelerometer generates voltages above the bias for positive acceleration levels and below it for negative accelerations. The voltages generated by our accelerometer's internal amplifier become nonlinear as the voltage levels approach our excitation voltage of 27 volts (large positive accelerations) and 0 volts (large negative accelerations). The usable linear range of the amplified output is typically within 2 volts of these extremes, that is 2 to 25 volts. Thus our accelerometer, with a 100 mV/g sensitivity and a 12 volt bias voltage, could measure accelerations up to a positive 130 g (13 volts = 25 volts – 12 volts) and a negative 100 g (10 volts = 12 volts – 2 volts) without any nonlinearity or clipping problems. So we could say that our accelerometer is capable of measuring up to 100 g peak for any of our three signal types instead of the more conservative 80 g peak that is published in the acceler-ometer's product data sheet.

Note, however, that if the battery power supply consists of only two 9-volt batteries (18 volt supply), the same accelerometer would then be limited to 4 volts of positive swing or only 40 g! Or, if the power supply batteries lose charge, the supply voltage will decrease and thereby also limit the maximum acceleration. The lesson to be learned here is that you need to be aware of the bias and supply voltages of your equipment and to make sure you're using fresh batteries.

The next step is to determine minimum signal level that can be measured with the accelerometer. The minimum signal level depends on the transducer's noise floor characteristics. This is where the three different signal types come into play. We will look at each of the three different signal types separately.

Broadband random, 2.5 Hz to 25 kHz. The broadband noise floor is generally listed on the accelerometer's product data sheet. If not, contact the manufacturer and ask for this information. Let's assume that our accelerometer has a 600 µg (600×10^{-6} g) noise floor. This value, although not always stated, is in g RMS.

As a rule of thumb, the minimum signal measurable needs to be 10 dB above the noise floor or in this case 1900 µg RMS. The maximum signal we can measure has already been determined to be 100 g peak. The RMS value of this signal depends on its crest factor (peak to RMS ratio). Let's assume our broadband random signal has a crest factor of 5. This would imply that if the signal's RMS value is 20 g, the broadband signal would occasionally generate peaks of 100 g.

Thus our dynamic range for measuring a broad band random signal would be:

$$20\log\frac{20}{1900\times10^{-6}} = 80.5 \text{ dB}$$

Narrowband random, 10 Hz bandwidth at 1 kHz. The noise characteristics of electronic devices are generally not uniform as a function of frequency. They usually have more noise at lower frequencies and less at higher frequencies. This characteristic can be quantified with a Power Spectral Density ($g^2_{\text{RMS}}/\text{Hz}$) or Spectral Density ($g_{\text{RMS}}/\sqrt{\text{Hz}}$) measurement. Some product data literature will have a nominal noise floor spectral density or a tabular listing of nominal spectral density values at specific frequencies. If this information does not appear on your accelerometer's data sheet, contact the manufacturer. Let's assume the noise density of our accelerometer at 1 kHz is stated as 5 µg per root Hz.

Our signal has a 10 Hz bandwidth at 1 kHz, thus the noise we are concerned with is:

$$\sqrt{\left(5\,\mu\text{g}/\sqrt{\text{Hz}}\right)^2 \times 10 \text{ Hz}} = 15.8\,\mu\text{g}$$

Thus, for this signal, our accelerometer can measure from 10 dB above its noise floor or 50 µg RMS, up to 20 g RMS (see example 1 above).

Our dynamic range in this case is:

$$20\log\frac{20}{50\times10^{-6}} = 112 \text{ dB}$$

This is 32 dB greater than in our first example because the narrowband nature of our signal provides a lower noise floor.

Sine Wave at 100 Hz. This might qualify as a trick question: we know that our accelerometer will clip or distort with a peak sine wave above 100 g, but what is its noise floor when dealing with a pure sine wave?

The sine wave is the extension of our second example all the way down to zero bandwidth, thus zero noise. The accelerometer is not the determining factor when measuring a sine wave. The bandwidth of the measurement instrument determines the noise and thus the dynamic range of the system. Use a narrow enough bandwidth-measuring instrument and almost an infinite dynamic range can be achieved when dealing with a sine wave.

For example, let's assume we use an FFT analyzer to measure the amplitude of our 100 Hz sine wave. Further, assume the analyzer is set to use 800 lines of resolution and maximum frequency range of 250 Hz. This setup defines a nominal resolution bandwidth Δf of:

$$\Delta f = \frac{250 \text{ Hz}}{800 \text{ lines}} = 0.3125 \text{ Hz}$$

The 0.3125 Hz *nominal bandwidth* does not define the susceptibility of this analyzer to broadband noise. However the *noise bandwidth* does. The noise bandwidth, which is also referred to as the *effective noise bandwidth*, is numerically equal to the nominal bandwidth multiplied by an adjustment factor reflecting the choice of window function (a subject for a future column) setup in the analyzer. For a common Hanning window, the factor is 1.5; for a flattop window the factor is larger and varies slightly with analyzer manufacturer. The flattop window would be the window of choice for amplitude accuracy of a narrow band signal such as our sine wave.

Assuming a Hanning window was

used, the noise bandwidth becomes 1.5 × 0.3125 Hz = 0.469 Hz. Thus the noise in our measurement becomes:

$$\sqrt{\left(5\,\mu\text{g}/\sqrt{\text{Hz}}\right)^2 \times 0.469\ \text{Hz}} = 3.4\ \mu\text{g}$$

and our dynamic range is:

$$20\log\frac{0.707\times 100}{3.4\times 10^{-6}} = 146\ \text{dB}$$

By using an analyzer with more lines of resolution or through zoom processing, the nominal bandwidth along with the noise bandwidth becomes smaller, thereby increasing the dynamic range even further.

Next month's Q&A column answers the question: **How should a condenser microphone be tested for damage?**

Send your questions or comments to:

Dave Formenti
Sage Technologies
16675 Buckskin Court
Morgan Hill, CA 95037
Phone: (408) 776-1106
Fax: (408) 776-1107
Email: dformenti@thesagesite.com