

S&V Questions and Answers

Dynamic Range

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Question: What is Dynamic Range?

Rather than use a more rigorous explanation, a simpler approach fits the confines of this article and is still useful. The following explanation applies to individual components in the measurement chain or the whole measurement chain. It applies to vibration, acoustical or any other measurement system, even a school child's plastic ruler. The dynamic range is a ratio between the level of the largest signal and the level of the smallest signal a device can measure. Dynamic range L_r in dB is mathematically represented by:

$$L_r = 20 \log \frac{\text{max. signal level}}{\text{min. signal level}}$$

Largest Signal. Our measurement system can be illustrated by the Transduction Curve shown on Figure 1. The true physical phenomena comes in from the left and what we measure (usually in volts) comes out at the bottom.

Life is usually pleasant if the level of the physical phenomena falls within the straight (another source of discussion for another day) part of the curve. The slope of the curve is simply our "cal factor" or sensitivity (mV/physical quantity). Whatever physical quantity we want to "put into" our Transduction Curve comes out as a correct representation. The slope of the curve just changes the apparent amplification but we can easily deal with this.

The trouble comes when the signal exceeds the straight part of the curve. As the level of the physical phenomena increases, there will come a point when the measurement device can no longer put out a proportional signal. The value we would enter into the equation above would be the level just below this point. For electromechanical devices with moving elements such as microphones and accelerometers without integral electronics, the sensing element will first become nonlinear (the bent part of the curve) and then hit physical limits and maybe break. For analog electrical devices such as amplifiers and accelerometer systems with integral electronics, the electrical output will become nonlinear and then the maximum electrical output will be reached. This is when you hear terms like "overload," "clipping" and "saturation." For the school child's 1 foot ruler, unless we make a crayon mark at 1 foot and caterpillar the ruler, we cannot measure dimensions greater than 1 foot.

Figure 2 shows a sinusoid encroaching into the bent (nonlinear) part of the Transduction Curve. Often it is difficult

to notice this by looking at the time waveform if the signal has not been severely "clipped." The spectrum shows the problem more clearly. A sinusoid is supposed to produce just a single peak in the spectrum but a sinusoid hitting "overload" will be distorted and produce extra peaks at multiples of the true signal frequency (harmonics). It is useful to visualize this by thinking of a clipped sine as looking like a square wave and then remembering that the spectrum of a square wave is a large peak with many harmonics.

Smallest Signal. The smallest signal is controlled by the inherent noise of the measurement device. For analog electrical devices such as accelerometers, microphones, amplifiers and recorders, the noise is analog electrical noise. For digital devices such as analog to digital converters (ADC), DAT recorders, and modern signal analyzers, the noise floor is quantization and analog noise. For the school child's plastic ruler, the noise is from "guesstimating" a dimension that is smaller than the smallest marked interval.

We can use Figure 3 to illustrate the point. It is a measurement of a very small sinusoid barely large enough to be seen above the noise. We can determine the smallest signal our device can measure by decreasing the level of the sinusoid until we can no longer discern it within the instrument noise spectrum.

Practical Measurement of Dynamic Range. We can also use Figure 2 to explain a useful mental experiment. Imagine that we had a device that could produce a pure sinusoid such as a signal generator and we injected the sinusoid into our measurement device such as an FFT analyzer. We increase the level of the signal until just before the analyzer overloads. We display the spectrum with a logarithmic vertical scale. The dynamic range would be the vertical distance from the peak of the sinusoid to the highest-level noise component. We must remember that noise does not contain only broadband random components but also spikes due to 60 Hz line noise (ground loops), harmonics of the true signal – any components that are not the sinusoid to be measured.

The dynamic range of FFT analyzers is affected not only by analog circuitry and quantization, but also by other truncations and approximations within the FFT process. For example, some analyzers use integer arithmetic for speed instead of floating point. Most manufacturers of FFT equipment agree upon a "two-tone"

power spectrum test to measure the analyzers overall dynamic range. The test comprises the sum of two pure tones: one set to full scale (unclipped) response, the other of lower and adjustable level. The lower tone is adjusted until it is just "lost in the noise floor" or no higher than spurious noise spikes. The dynamic range is then reported using the equation.

The definition of what is considered noise can start a debate (and perhaps another article) but the tester should use engineering judgement to determine what frequency components are going to hinder an accurate depiction. For example, if we are interested in signals above 1 kHz, we would downplay the typical "ski slope" noise in the low frequency region.

Bits and Dynamic Range. We have seen and heard claims that the dynamic range of a digital device is 6 dB per bit. So an analyzer with a 16 bit digitizer has a dynamic range of $6 \times 16 = 96$ dB. While there may be some textbook evidence to support this, this is misleading. The useful dynamic range is always lower. As shown in Figure 4, the 6 dB per bit rule of thumb pertains to just the ADC (an ideal one) and ignores other factors such as the analog noise inside the analyzer and the straightness of the Transduction Curve. Fortunately, most analyzer manufacturers report the useful dynamic range of their products as described in the previous section.

The useful dynamic range of an analyzer digitization process is a function of the analog signal conditioning, the sample-and-hold circuit and the stability of the time base used. All these factors are involved when evaluating the dynamic range of an analyzer. The effective bits of an ADC will be less than the number of physical bits in the ADC. This effective number of bits defines the useable dynamic range of the system.

The effective bits of an analyzer can be shown to be a function of frequency and amplitude of the test signal. As the frequency of a test signal is increased, the effective bits fall off indicating a decrease in usable resolution. Increasing the amplitude of the signal also results in a loss of effective bits. Ideally a two-tone dynamic range test would use various frequencies and amplitudes to map an analyzer's dynamic range characteristics.

Next month's Q&A column answers the question: **How do I determine the noise floor and dynamic range of my accelerometer or microphone system.**

Send your questions or comments to:

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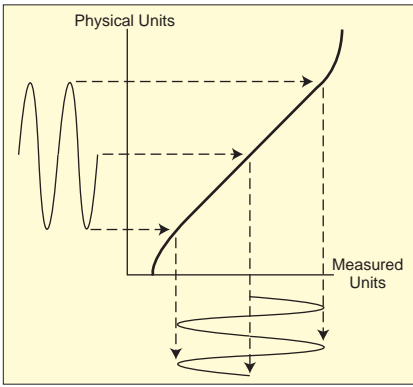


Figure 1. Transduction curve.

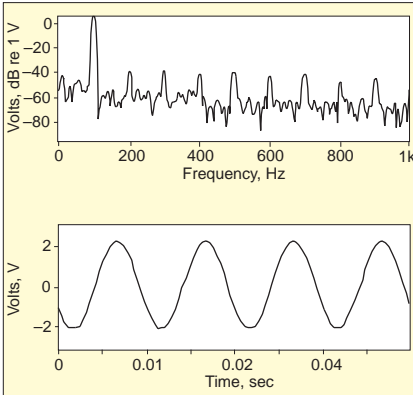


Figure 2. Nonlinear region of transduction curve.

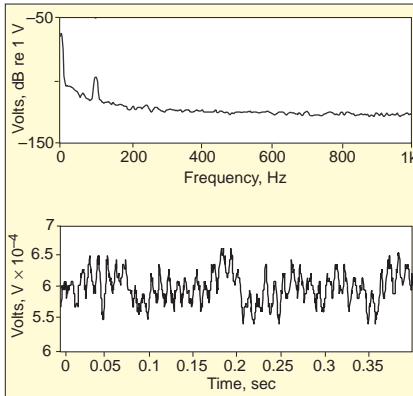


Figure 3. Small signal relative to noise.

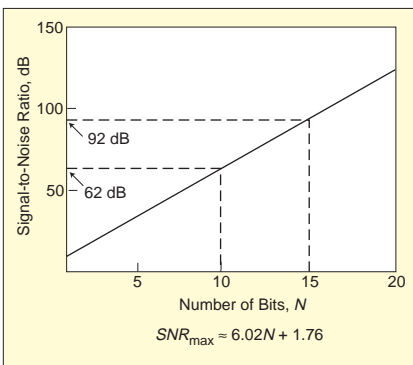


Figure 4. Theoretical signal-to-noise ratio for an analog-to-digital converter.