A Brief Review of Noise Measurements and Parameters

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Noise is usually considered something we want to be rid of in RF and microwave systems, but we can never completely eliminate it. In a sense, noise is an ever-present test signal — and our measurements of its characteristics can tell us much about the performance of our circuits and systems.

Following is a summary of the most common noise-related measurements and a review of the parameters that define intentionally-generated noise test sources.

Noise figure

Noise figure is the measurement of how much noise a circuit or subsystem adds to the incoming signal. It is a measurement that indicates sensitivity, since it, along with the bandwidth of the system, establishes the threshold below which signals will be masked by the added noise. Noise figure is defined as [1]:

NF = 10 log (noise factor)

Noise factor is further defined as:

$$\text{Noise Factor} = \frac{\text{Signal}_{in} / \text{Noise}_{in}}{\text{Signal}_{out} / \text{Noise}_{out}}$$

$$= \frac{\left(V_{in}^2 / 4kTBR_{gen}\right)}{\text{Signal}_{out} / \text{Noise}_{out}}$$

where: V is the input signal voltage,
k is Boltzmann's constant, 1.37×10^{-23} J/K
T is the temperature in Kelvins
B is the bandwidth in Hz
R is the source resistance in ohms
$kTBR_{gen}$ is the input noise voltage

Measurement of noise figure can be done directly from the last equation if the input signal voltage and the system noise bandwidth are both known. The output signal-to-noise ratio is measured, identifying all the variables in the equation.

The difficulty in making this type of measurement is in accurately determining the noise bandwidth of the system. Narrowband systems can usually be approximated by using the –3 dB bandwidth, but any system that does not have a steep rolloff at the passband edge will be much harder to define.

A direct measurement of noise figure can be made using a noise source with a known excess noise ratio (ENR), where

ENR = (thermal + source noise) / (thermal noise)

Such a noise source will typically be calibrated in ENR versus frequency, making it useful for measurements at different operating frequencies. With the right test configuration, noise figure measurements can be made extremely fast, enabling real-time adjustment or high production line throughput.

Phase noise

Another imperfection that can be characterized by its noise content is the sideband energy of a signal source. Nearly all of this noise is phase or frequency related because oscillators operate at or near saturation, which removes amplitude variations. High gain in following amplifier stages can add amplitude noise, but it will still be very small compared to the phase noise.

In past years when quartz crystals were the primary frequency-determining elements, phase noise was a minor issue. Crystals have such a high Q that they have relatively low phase noise. In addition, those earlier systems did not often push the limits of channel capacity or operate in an extremely crowded RF environment.

Synthesized frequency control changed the the situation. Low Q LC oscillators have significant phase noise energy in their sidebands. While the loop bandwidth of the synthesizer reduces off-frequency phase noise, the noise inside the loop bandwidth and near the passband edges can be critical to overall system performance.

Leeson's equation has become widely used to quantify oscillator noise, since it closely fits experimental data [2, 3].

$$L(f_m) = 10\log\left[\frac{1}{2}\left(\left(\frac{f_0}{2Q_l f_m}\right)^2 + 1\right)\left(\frac{f_c}{f_m} + 1\right)\left(\frac{FkT}{P_s}\right)\right]$$

Phase noise measurements are specified in terms of the offset from the center frequency f_c and the amplitude relative to f_c (in dB). The amplitude assumes a 1 Hz bandwidth and one sideband only (SSB). For example, a typical wireless VCO might be specified as having a SSB phase noise of –100 dBc/Hz @ 10 kHz, meaning the noise in a 1 Hz bandwidth at a frequency 10 kHz away from the f_c is 100 dB below f_c.

Further details on phase noise could fill an entire book, so readers are encouraged to review the references noted at the end of this article.

Noise sources

Noise can be a useful signal source for many kinds of testing. In addition to noise figure testing noted earlier, it has received much recent attention for testing the integrity (measured as bit-error rate or BER) of digital communications systems under fading conditions and varying signal-to-noise ratios.

A key parameter is *randomness*, usually referenced to the gaussian probability density function. This can also be considered to be the noise *whiteness*, using an earlier and less well defined term. Noise must be sufficiently random to maintain the validity of statistical analysis. Because noise theoretically has infinite bandwidth, bandpass filters may be used to limit noise power while maintaining acceptable randomness over the frequency range of interest. Gaussian noise is random in amplitude, resulting in very high peak-to-average ratios. Circuits and measuring equipment must avoid saturation or other improper operation if accurate noise-based measurements are to be achieved.

Finally, the "noise" of a randomly varying (fading) signal path is an important factor in mobile communications. This noise has a Rayleigh probability density function. Where gaussian noise is additive, resulting in a signal+noise situation, Rayleigh fading is multiplicative, since it results in fluctuations in the level of the desired signal. Measurements and analysis based on these types of random functions have enabled the development of robust wireless communication systems that function reliably in the real world. ■

References

1. W. Sabin and E. Schoenike, eds., *HF Radio Systems & Circuits*, revised 2nd ed., Noble Publishing, 1998.

2. R. Rhea, *Oscillator Design and Computer Simulation*, 2nd ed., Noble Publishing, 1995.

3. U. Rohde, *Microwave & Wireless Synthesizers*, John Wiley & Sons, 1997.