Frequently Asked Questions About Noise

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Here is a review of noise characteristics, measurement parameters and its applications for measurement of communication circuits and systems

What is noise?

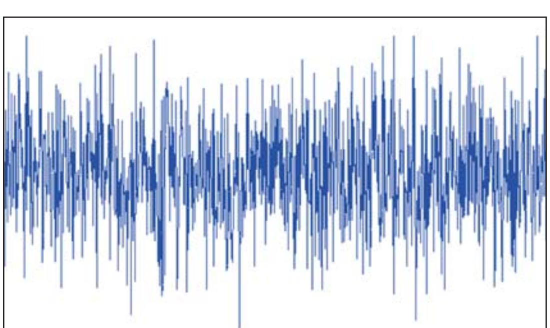
Noise is a random signal inherent in all physical components. It directly limits the detection and processing of all information. The most common form of noise is white Gaussian, due to the many random processes that make up electric currents or thermal agitation of conductive elements.

Why is it important?

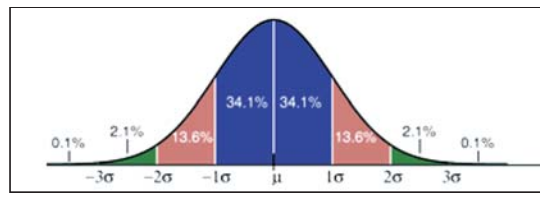
Because electronic noise is ubiquitous, present in all passive and active components, it is critical for engineers to characterize and understand how it limits the transmission of information.

What does the term "Gaussian" signify?

The term Gaussian refers to the voltage distribution of the source of noise. Due to its random nature, the noise voltage of a component is usually a Gaussian distribution. This is characterized by its mean value and random voltage excursions that follow a bell shaped Gaussian curve. See the figures below:



Voltage of noise source versus time.



Plot of voltage distribution of noise source with μ = 0 V.

What does the term "white" signify?

White refers to the noise source power spectral density, which is ideally flat with frequency. In reality, at some point—often due to mismatch—there is a reduction in the measurable noise level.

What is AWGN?

The term Additive White Gaussian Noise (AWGN) refers to the fact that noise eventually is combined with the desired signal and is a major limiting factor in the transmission of information.

What are the common uses of a noise source?

Noise sources are used to measure noise figure, provide a source of AWGN to generate CNR or EbNo to measure error rates, and are used as an economical source of broad band power for built in test applications such as signal strength calibrators and radar applications. They can be used to increase the dynamic range of analog to digital converters by dithering and reducing correlated noise. They are often found in disk drive testing, wireless testing, CATV both analog and DOCSYS, jamming, SATCOM for BER and NF, as well employed as a source of jitter.

What types of noise sources are available?

Noise sources can be a simple noise diode which generates a low level of noise, to amplified noise sources supplied in multiple form factors to instrumentation grade noise generators which amplify, attenuate and process both the noise and a user added signal. Noise diodes come in a variety of packages and can be surface mount or DIP for PCB mount or coaxial for system integration.

What is ENR?

ENR refers to excess noise ratio, which is 10 log [(Th–290)/290], is essentially a normalized measure of how much the noise source is above thermal in its power. At high ENRs >15 dB the density of power can be approximated by adding the ENR to –174 dBm/Hz.

How are noise sources tested and specified?

Noise sources are typically tested according to their output level. Noise sources that are used in noise figure applications are typically 6 to 30 dB in ENR. These usually require a noise figure meter or a dedicated noise radiometer due to their low power levels. Since the ENR value is used to calculate the noise figure directly, low power noise sources typically are supplied with calibrated ENR values. Higher power noise sources typically are supplied with aggregate power measurements such as on a power meter with spectral flatness observed on a spectrum analyzer.

What is the crest factor of a noise source?

Noise sources are characterized by their crest factor, which is the peak to average ratio of the noise. For example a 5:1 crest factor of the noise voltage is 20 log(5), or 14 dB. This is a measure of the quality of the noise distributions and one way to measure its Gaussian nature. Noise theoretically has an unbounded distribution so that it should have an infinite crest factor but the physical realization of the noise generator will limit the output excursions, via the amplifiers, diode junctions etc.

Why and when is crest factor important?

Crest factor is important primarily in bit error rate applications. In low power applications in which noise powers are being compared such as NF, it is largely insignificant. In BER applications it is important because the BER being measured is a direct function of the carrier to noise ratio, and if these noise excursions do not occur as expected the errors will fall off and erroneous results will occur. One important note is that it is the crest factor of the resultant noise in the receiver and its bandwidth that will determine the resultant crest factor. This is significant because often times the required noise is a much larger BW than the receiver, for example a tuned receiver operating over a wide BW requires the noise to cover the entire RF BW. This can put a strain on the realizable crest factor because the wide band high power amplifiers required to cover the entire BW can be cost prohibitive and degrade system accuracy in other ways such as excess current or reliability. Since the noise is often filtered in the receiver, the crest factor of the resultant noise is improved as the excess BW is stripped away, reducing the noise power and leaving the noise farther from the clipping point. Clipped noise becomes Gaussian as the measurement BW is reduced. The required crest factor should take into consideration all of the above.

What is BITE?

BITE stands for built-in-test and refers to the utilization of an internal noise source to test a system. For example, the noise source may be put on a PCB via a TO-8 can, DIP or surface mount package, with a coupler or a switch to selectively inject the noise into the circuit. By turning on the noise source and detecting the system output power, various system performance parameters can be verified automatically and remotely. The noise source can also be used to calibrate the receiver's noise figure by comparing its known value to the receiver's. Noise temperature, frequency response, sensitivity and gain are among the additional parameters that can be measured using BITE.

What is Eb/No?

Eb/No stands for energy per bit divided by noise density. It is essentially a normalized carrier-to-noise ratio for digital systems. Typically Eb/No is plotted versus BER to measure the effectiveness of the information transfer.

What is CNR?

CNR is carrier-to-noise ratio and it is the relative power level of the carrier signal to the noise level in a system. It typically determines the quality of the system and BER is plotted against CNR. Carrier refers to the information signal in this case.

What is BER?

Bit error rate is the frequency of errors that occur when bits are transmitted in a digital system. Critically, it is a function of signal to noise ratio or carrier to noise ratio.

What is Noise Figure (NF)?

Noise figure is defined as the ratio of the signal to noise power at the input to the signal to noise power at the output of a device, in other words, the degradation of signal to noise ratio as the signal passes through the device. Since the input noise level is usually thermal noise from the source the convention is to adopt a reference temperature of 290°K. The noise figure becomes the ratio of the total noise power output to that portion of the noise power output due to noise at input when the source is 290°K. The well-known Hewlett Packard (now Agilent Technologies) App. Note 57-1 describes these definitions and calculations.

How is noise figure measured and calculated?

Noise figure is typically determined by using a calibrated noise source which is traceable to international standards. This noise source is essentially compared to the unknown noise figure and by measuring this difference noise figure is computed:

$$NF = ENR\ dB - 10 \log (Y - 1) + Tcorr$$

Tcorr is a temperature correction factor that can be applied if the temperature deviates significantly from 290°K. Y is the Y factor which is the ratio of the output power with the noise on to the output power with the noise off. By employing this method of measuring the Y factor, only relative accuracies are significant which makes the measurement easier than attempting to measure exact powers which can be quite low and tough to measure.

How do noise powers add?

Noise powers add as incoherent signals which means that their powers must be added. For example if your inject a noise source into a spectrum analyzer and see that the noise floor increases 3 dB, then the actual noise source power is at the original noise floor level. This relationship allows you to calculate the noise power of signals below the measurement noise floor:

$$10 \log [\{\text{Inverse log } (diff/10)\} - 1)]$$

Where diff is the dB difference in measured powers. Of course, small changes in power occur as the unknown noise is far below the known and this results in increasing inaccuracy as the power goes much lower.

Why can't I see my noise source on a spectrum analyzer?

If you are attempting to measure a lower power noise source, <30 dB ENR, in all probability the spectrum analyzer Noise Figure, which usually is at a minimum of 25 dB and many times is 35 dB, is above the noise level of noise source. At these levels we can approximate Noise Figure and ENR and compare directly to see if the noise source will be detectable. This source could be measured with an LNA in front of the spectrum analyzer, although to get an exact ENR we would need to know the NF of the LNA and its gain. However, we can usually see if the approximate deflection occurs. For example, a 15 dB ENR noise source should change the noise level about 10 dB if the noise figure of the LNA is about 5 dB, as long as the LNA gain is sufficient to overcome the noise figure of the analyzer. Higher power noise sources can be measured on a spectrum analyzer for flatness and on a power meter for output power.

Why test at high power levels?

Sometimes it is convenient to test at higher power levels. For example, BER measurements are a function of carrier to noise ratio, and they can be quite sensitive with large changes in BER resulting with small changes in CNR. Rather than test at low power levels that are very difficult to measure, often times it is easier to inject more noise power and test at levels that are easier to establish what is the actual CNR. Also often times tests are done at lower CNR so that the BER is higher and the low BER results are extrapolated, which saves test time because the errors come so infrequently at high CNR.

What is noise power spectral density?

Typically referred to as No, this is the amount of power the source will output in a one hertz bandwidth. It is essentially a normalized output power. Since noise power is proportional to bandwidth, No is used to compute the power in any bandwidth.

What is –174 dBm/Hz?

This is a convenient number to use, it represents the amount of power in a one hertz bandwidth that a thermal noise source has at the reference temperature of 290°K, which is approximately room temperature. This results from the equation $P = kTB$ where k = Boltzmann's constant, T is temperature in degrees K, and B is the bandwidth in Hz. For example the available thermal noise power in a resistor in a 1 MHz bandwidth would be –114 dBm, because 10 log (1 MHz), or 60 dB, is added to the –174 dBm/Hz.

What is No and how is it used to calculate noise output power?

No is the noise density of the noise source. It is the output power per hertz that the source provides. To calculate the power that the source will have in a BW the No is increased by the BW in dB. For example, a –80 dBm/Hz amplified noise module with 1 GHz BW will have a minimum of –80 dBm/Hz + 10 log (1 GHz) = –80 dBm/Hz + 90 dB = +10 dBm. If this source is measured on a spectrum analyzer with the Resolution BW set to 1 MHz then –80 dBm/Hz + 10 log (1 MHz) = –20 dBm will be displayed. In actuality, the noise source will have some out-of-band noise and the resolution BW has a noise equivalent BW greater than its setting so some adjustment of these numbers will be needed for a more accurate number. For many applications this first order approximation will suffice. Aggregate output power should be measured on a power meter, although it could be approximated by adding 10 log (BWns/RBW) to the number on the spectral analyzer. Also, when performing power calculations on noise sources if the ENR is known the output power density can be approximately calculated by adding the ENR to –174 dBm/Hz.

This is accurate to less than 0.2 dB at 15 dB ENR and less than .01 dB for ENRs greater than 30 dB. For example a 34 dB ENR noise source would have a noise spectral density of –174 dBm/Hz + 34 dB = –140 dBm/Hz. In a 10 MHz BW this would result in –140 dBm/Hz + 70 dB = –70 dBm. For lower ENRs, the Th has to be obtained directly from the definition of ENR, then the noise density 10 log kTh would be computed.

Why is Noise Power proportional to BW?

Since noise is a random signal, its power is distributed over its usable bandwidth, BW, and the noise source is considered "white" due to its constant spectral density. This results in the power measured being proportional to BW. If a certain power is measured in X BW, then if the BW is increased to 2X the power measured is double, or 3 dB higher. This should be noted when measuring high level noise sources on a spectrum analyzer. This is critical because as a system's BW increases to allow for more information to be processed, this will also introduce more noise power and reduce the CNR and potentially reduce the dynamic range of the system. This is a major trade off in all communication systems.

How do I calculate the overall output power of my noise source?

Use the No noise density and add 10 log of the BW of the device in which you wish to measure the noise.

Why is the bandwidth of the measurement device important ?

Since noise is a distributed broadband signal its power is proportional to the bandwidth of the measurement device, as long as it is in the noise source's frequency range. Higher power noise sources are typically measured with a power meter that covers greater than the frequency range of the noise source so all of the power is measured. A true RMS power meter and sensor should be used. Due to the noise source's Gaussian nature, errors can result when diode detectors are used.

How can I measure Noise Figure on a spectrum analyzer?

Spectrum analyzers can be used to measure noise figure with a coaxial calibrated noise source. The DUT is assumed to be an amplifier. The noise source is connected to drive the amplifier input. On the spectrum analyzer the noise power is noted at the frequency of interest when the noise source is on and when it is turned off. This is the Y factor in dB. Convert the Y factor to linear and plug into the equation NF(dB) = ENR dB – 10 log(y – 1). There are various pitfalls to watch out for in this measurement detailed in the next section.

What are some pitfalls to watch out for with noise measurements on a spectrum analyzer?

Care must be used when making noise figure measurements on a spectrum analyzer. There are multiple possible sources of potential error. Since noise sources are very broadband their powers can increase quickly as gain is added. Couple this with the fact that the noise has large peaks that can start to compress the amplifier, which, when combined with the high noise figure of spectrum analyzers, results in less range available then one might think.

What type of noise source should I choose for my application?

If you are attempting to make a noise figure measurement, typically you should choose a calibrated coaxial noise source, with either 6, 15 or 30 dB ENR. This will allow you to measure noise figure using the calibration points provided with a noise figure meter or a spectrum analyzer. 15 dB is the most common as it can comfortably measure high and low noise figures. Very low noise figures can use a 6 dB source which will have reduced VSWR uncertainty and reduced Y factors. 30 dB sources are used in high noise figure applications, when the noise may be injected via a coupler, or with a high loss device.

If you are looking to make BER measurements, typically you would want to choose a higher power noise source like an amplified module or an instrument. This will allow you to set carrier-to-noise ratios easier. Although it can be done with a low power noise source, the measurement is difficult at these low powers. Since the BER depends primarily on the ratio of the carrier to noise, typically the CNR is set at higher powers with a power meter and a calibrated filter, or by measuring on a spectrum analyzer.

Author Information

Ed Garcia is the founder of NoiseWave Corporation, which focuses on broadband noise sources and their application. He has 20 years of experience in RF/Microwave and related high frequency design. He has served in the capacity of design engineer, Chief Engineer and various technical management positions. His primary focus has been on noise source components and noise-based instrument design. He can be reached by e-mail at: egarcia@noisewave.com, or by telephone at 973-386-1119.