Amplifier Noise Metrics

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March 12, 2003

This brief note summarizes the various metrics used to describe amplifier noise.

All electronic amplifiers generate noise. Noise generated in an amplifier limits how small an input signal can be detected. The dynamic range of an electronic amplifier expressed in decibels is 20 times the common log of the ratio of the largest signal that can be handled without distortion to the smallest signal that can be resolved from the noise generated by the amplifier. A good amplifier can achieve a dynamic range of 80 dB or more. An excellent amplifier can achieve a dynamic range of over 100 dB. The electronic noise generated by an amplifier can be minimized with careful design.

There are three common metrics to describe amplifier noise. In all cases, the noise refers to an equivalent noise at the input of an ideal noiseless amplifier. The most fundamental metric is Noise Factor and is defined as:

Noise Factor = 1.0 + (equivalent amplifier noise at input / thermal noise at input)^2

Noise Factor is simply a ratio and therefore has no unit. The two other metrics are derived from Noise Factor as follows:

Noise Figure = 10 * log10(Noise Factor) and is expressed in dB

Noise Temperature = Reference temperature * (Noise Factor - 1) and is in degrees K where Reference temperature is typically 290 degrees Kelvin

Converting between noise metrics

Metric:	Unit:
Noise Factor =10^(Noise Figure / 10)	dimensionless
Noise Factor = 1.0 + (Noise Temperature / Reference Temperature)	dimensionless
Noise Figure = 10 * log10(Noise Factor)	dB
Noise Figure = 10 * log10(1.0 + Noise Temperature / Reference Temperature)	dB
Noise Temperature = Reference Temperature * (Noise Factor - 1)	degrees Kelvin
Noise Temperature = Reference Temperature * (10^(Noise Figure/10) - 1)	degrees Kelvin

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Some Examples:

Amplifier Noise Quality	Noise Factor	Noise Figure	Noise Temperature
Ideal (noiseless)	1.00	0 dB	0 degrees Kelvin
Excellent (very low noise)	1.26	1 dB	75 degrees Kelvin
Good (low noise)	2	3 dB	290 degrees Kelvin
Fair (moderate noise)	10	10 dB	2,610 degrees Kelvin
Poor	100	20 dB	28,710 degrees Kelvin
Awful (very noisy)	1000	30 dB	289,710 degrees Kelvin

With careful design it is possible to obtain Noise Figures of a fraction of a dB. It was not uncommon for older spectrum analyzers to have Noise Figures of 20 to 30 dB – this was an engineering tradeoff that had to be made to achieve other desirable characteristics. It is generally not possible to optimize every characteristic of an amplifier simultaneously. Priority has to be given to the most important attributes at the expense of less important attributes. What is important depends on the application – there is no universal design.

It is important to note that the amplifier noise metrics discussed here are independent of the bandwidth used for the measurement. While it is true that a smaller bandwidth will reduce the absolute noise signal but all of these noise metrics are ratios. A smaller bandwidth reduces both the numerator and denominator by the same factor thus the ratio is not altered. In the amplifier noise quality examples, an excellent amplifier is excellent regardless of the bandwidth used and a poor amplifier is poor regardless of the bandwidth used. Filtering can not convert a poor amplifier into an excellent amplifier. A common error in measuring amplifier noise is failure to use a consistent bandwidth – depending on the error the amplifier can appear either much better or much worse than actual.

The total input noise is the rms sum of the input thermal noise and equivalent amplifier input noise and represents a lower limit or floor as to how small a signal can be detected. The term, noise floor, is often used to describe the equivalent total input noise level of an amplifier or instrument. Noise floor is often given in dBm. Signals that are below the noise floor generally can not be detected. The thermal noise floor represents the input noise at an amplifier due to the thermal noise of the resistance of the signal source in combination with the input resistance of the amplifier. The noise floor can be lowered by reducing the bandwidth – because of the square root function of bandwidth it takes a factor of 100 reduction in bandwidth to reduce the noise floor by a factor of 10 or 20 dB. The bandwidth must not be reduced below what is required for the signal of interest.