Figuring noise figure

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Abstract. Noise figure (or noise factor) according to Pastori (1979) is a figure of merit that does not truly exist in the same sense as voltage, current or power. As a consequence, its measurement is necessarily indirect. The measurement technique - while subject to considerable refinement over the years - has remained essentially unchanged since the concept was standardized by the IEEE in 1957. Here the hot-cold-method is presented to make an estimate of a receivers noise figure using a local noise source.

Key words. Noise figure, excess noise, Y-factor, temperature.

1. Excess noise ratio

Excess noise ratio is a term used to describe the output of the noise source used as an input stimulus. For the figure to be valid, however, the lower noise level must be equal to the noise generated by a (theoretical) resistor at the standard reference temperature of $T_{ref} = 290K$.

$$ExcessNoiseRatio(ENR) = \log\left(\frac{P_H}{P_O} - 1\right) \tag{1}$$

where P_H means power available from the noise source when it is "on" - its high output condition and P_O means power available from the noise source when it is "off" - its low output condition (equal to standard reference noise). The classic representation of noise power P is in terms of the temperature of an equivalent thermal noise source

$$P = k\ T\ B \tag{2}$$

where k is the so called "Boltzmann Constant", $k = 1.38066210^{-23} J/K$, T is the actual or equivalent source temperature given in $Kelvin$. B is the observation bandwidth given in Hz. Noise figure (from a measurement standpoint), then, can be described as the reduction in the excess noise ratio caused by the device under test DUT. The measured noise ratio at the output of the DUT is commonly called "Y-factor". The Y-factor is the ratio of the noise power of the DUT when the noise generator is turned on (hot) to that when it is turned off (cold reference noise). Without going into great detail regarding derivation, noise figure can be related to input stimulus and Y-factor as follows

$$NF_{dB} = 10\log\left[\frac{T_2/T_0 - Y(T_1/T_0)}{Y-1} + 1\right] \tag{3}$$

or in the case where T_1 (representing the "cold" condition of the noise source) equals the standard reference temperature, $T_0(290K)$:

$$NF_{dB} = 10\log\left(\frac{T_2}{T_0} - 1\right) - 10log(Y-1) \tag{4}$$

which can be simplified to

$$NF_{dB} = ENR_{dB} - 10log(Y-1) \tag{5}$$

The above is presented somewhat vaguely and does not account for a good many potential errors associated with set up and techniques (image response, second stage noise, nonlinearities, etc., see also Kraus (1965)). It serves primarily as preamble. The main purpose is to point out that, in terms of equipment accuracies, there are two major factors to consider: the noise source output and our ability to ascertain the Y-factor. These two set a minimum uncertainty for any noise figure measurement.

2. Basic accuracy considerations

Instrument related noise figure measurement accuracy can be evaluated by examining the accuracy of the noise source output and the accuracy with which the Y-factor can be evaluated. The effects of these uncertainties on the measurement is a function of how the measurement is performed.

References

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