FIGURING NOISE FIGURE

Measurement technique

Noise figure (or noise factor) 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 requires a stimulus consisting of two known noise levels and a means of accurately evaluating the response of the system or device under test to each stimulus. Measuring the ratio of output noise levels as the input is switched from one input level to the other permits the calculation of noise figure.

There are, of course, other ways of measuring noise figure. Typical among these are the "3 dB method" and the "signal generator" method. The former requires a variable noise level, and the latter depends upon the calibration of the output attenuator of a signal generator. In general, the inherent accuracy limitations of these requirements have led to virtual industry standardization on the "constant excess noise ratio" method.

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 equal the noise generated by a (theoretical) resistor at the standard reference temperature—290K.

$$\text{Excess Noise Ratio (ENR)} = \log_{10}\left(\frac{P_H}{P_O} - 1\right)$$

P_H = power available from the noise source when it is "on" —its high output condition.

P_O = power available from the noise source when it is "off"—its low output condition (equal to the standard reference noise).

The classic representation of noise power is in terms of the temperature of an equivalent thermal noise source:

Noise power = KTB

K = Boltzmann's constant = 1.38×10^{-23} joules/K

T = actual or equivalent source temperature

B = observation bandwidth.

Noise figure (from a measurements standpoint), then, can be described as the reduction in the excess noise ratio caused by the device under test.

The measured noise ratio at the output of the device under test is commonly called "Y-factor". The Y-factor is the ratio of the noise power output of the device under test when the noise generator is turned on (hot) to that when it is turned off (cold or reference noise).

Without going into great detail regarding derivation, noise figure can be related to input stimulus and Y-factor as follows:

$$\text{Noise figure}_{dB} = 10\log_{10}\left[\frac{\frac{T_2}{T_0} - Y\frac{T_1}{T_0}}{Y-1} + 1\right]$$

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

$$\text{Noise figure}_{dB} = 10\log_{10}\left(\frac{T_2}{T_0} - 1\right) - 10\log_{10}(Y-1)$$

$$= \text{ENR}_{dB} - 10\log_{10}(Y-1)$$

The above is presented somewhat vaguely and does not account for a good many potential errors associated with set up and technique (image response, second stage noise, non-linearities, etc.). 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.

Y-factor measurement

An uncertainty in the measured Y-factor is, for low noise devices, transferred almost directly to the calculated noise figure. As noise figure increases, the effect of Y-factor inaccuracies are amplified. Consequently, a considerable emphasis was placed on the accurate evaluation of Y-factor by the instrumentation community.

Early descriptions of noise measurements procedures relied on direct readings from "true power" instruments. In addition to the question of crest factor and the response of the instrument to nonsinusoidal signals, these techniques relied on the direct-reading accuracy of such instruments. Unless very careful attention was paid to these factors, the resulting errors could be quite large (one dB or more).

The need for greater accuracy evntually led to use of the I.F. substitution technique. An accurate, variable attenuator is inserted ahead of the final detector to eliminate the concerns noted above. The Y-factor uncertainty was then reduced to the attenuator accuracy plus the system resolution. The procedure insures that the potentially nonlinear circuits operate at the same signal level.

The "manual Y-factor" function using the I.F. substitution technique is presently implemented in commercially-available, precision, I.F. substitution test receivers. These instruments incorporate waveguide-beyond-cutoff substitution attenuators and highly resolvable indicators. The typical receiver is capable of measuring Y-factors to better than ±0.03 dB. In combination with a hot/cold standard noise generator, such a receiver provides a potential capability of better than ±0.1 dB overall uncertainty—under certain conditions.

Direct reading noise figure meters

A noise figure meter automates the Y-factor measurement and calculates noise figure based on some preset excess noise ratio.

The earliest commercial devices—introduced in the 50's—provided meter readouts with about 30 dB of noise figure crowded onto a single scale. The best resolution attainable was about ±0.5 dB, and the calculation or tracking accuracy was about the same. An interesting result of industry's faith in the calculated ENR of gas-discharge sources was that all these early instruments were calibrated for 15.28 dB (using gas sources). No provisions were made for variations from this nominal.

Laboratory instruments

Today's laboratory instrument provides multiple scales with 3 dB indication spread over 50 percent of the meter arc. The typical resolution is better than 0.05 dB. The circuit improvements offer precision and stability which permit utilization of the expanded scales. Tracking or noise figure calculation accuracy can reach ±0.05 dB.

Within the past few years, digitally indicating noise figure indicators have made their appearance. The latest types incorporate IEEE-488 compatible interfaces and are proving to be valuable assets in automated, calculator or computer-controlled test systems. An even more advanced innovation derived from the basic digital noise figure meter is a recently introduced instrument which calculates gain from the noise characteristics. Thus, the instrument becomes a powerful tool for evaluation and tuning of RF and microwave amplifiers.

The above article was written by William E. Pastori, Eaton Corporation, Electronic Instrumentation Division. It is based on editorial material previously written by Mr. Pastori and is used with permission of Quality Magazine.