ACCURATE AND AUTOMATIC NOISE FIGURE MEASUREMENTS WITH STANDARD EQUIPMENT

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Noise figure measures the amount of noise a receiver or a component adds to a system. Minimizing such noise, because it obscures low-level signals, is an important concern in most of today's microwave systems. Noise figure measurements are necessary at the device level, the component level and the system level. They are necessary during design, manufacture and maintenance. Yet noise measurements have been fraught with non-repeatability. If, for example, a vendor and his customer are to independently measure noise figure so they agree within 0.2 dB, they each must usually use a specially calibrated noise source and tediously and manually remove several insidious effects that must otherwise be accepted as measurement errors. Even then, they often go through a time-consuming and expensive period of exchanging components and measurement equipment to achieve repeatability from system to system.

This paper describes a noise figure measurement system built of ordinary commercial components that routinely makes measurements from one system to another within 0.1 dB. Figure 1 shows the noise figure of a broadband receiver measured three times with three noise sources from different production runs and three sets of the noise power ratio measuring instruments. Because the noise sources were manufactured several months apart, Figure 1 also demonstrates the time stability of the noise source output. The absolute accuracy of the measurement from all known sources of error, although dependent on the SWR of the unit under test, is about ±0.22 dB, a factor of two better than traditional systems assembled from standard instruments

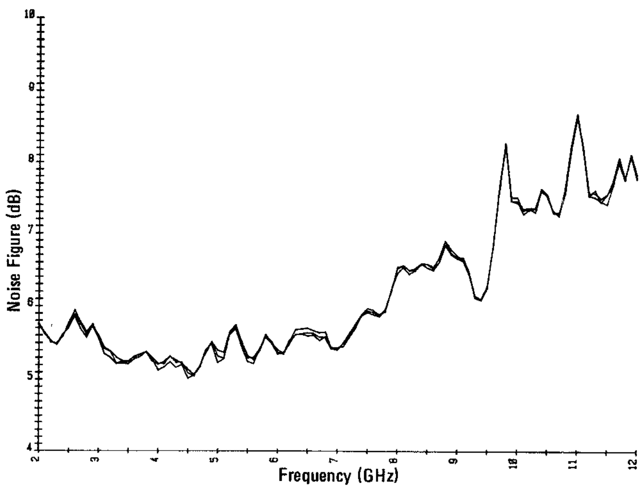


Figure 1. Measurement repeatability as shown by three measurements with three sets of measurement equipment.

This system uses a desktop computer to process data and account for many small effects that, in manual noise measurement systems, are very bothersome to correct, and are often accepted as measurement errors. Such effects include ambient temperature variation and the variation with frequency of the excess noise ratio of the noise source. Correction for these effects is now so routine and simple, that noise figure measurements will likely become an often used tool to replace old, seriously questioned, often postponed routines. These routines were usually dreaded, especially by the occasional user who felt he had to reeducate himself at every new encounter.

Another very significant advantage of this system is that it can measure the gain of the unit under test and display its noise figure without the noise contributions of the more permanent parts of the system. Another way to describe this is that the data is corrected for the second stage noise contributions. Thus when characterizing a microwave preamplifier, for example, the noise contributions of the mixer and IF amplifier are removed from the final result.

## Noise Measurement

Figure 2 is a block diagram for the general purpose microwave noise figure measurement system. The unit under test (UUT) can be all of or any part of the large block shown as the UUT/receiver. The remainder of that block is then considered as part of the measurement system whose noise contributions can be removed before final data presentation. When testing a microwave amplifier, for example, the mixer, local oscillator and IF amplifier are part of the system. When testing a receiver, however, the mixer, local oscillator, and IF amplifier are part of the unit under test.

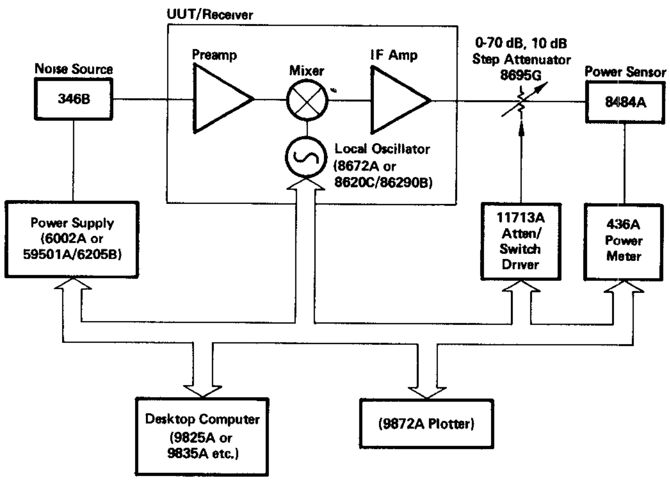


Figure 2. Block diagram of noise measurement system.

Most of the equipment is of a general purpose nature and likely to be available in many organizations This allows the system to be assembled for trial use at minimum expense. The noise source, power sensor, and power meter are the principal accuracy-determining elements of the system and should not be exchanged for alternatives. Otherwise, however, there is great flexibility in selecting equipment.

This system, like most noise figure meters, works by comparing the noise power output from the receiver for two different levels of input noise to the receiver. The ratio of the noise power outputs, corresponding to a noise source being first at temperature

$T_H$ (turned ON) and then at $T_C$ (turned OFF), yields the effective input noise temperature of the UUT/receiver according to

$$T_e = \frac{T_H - T_C Y}{Y-1} \qquad (1)$$

The Y factor is the ratio of the two powers, that is, $Y = N_H/N_C$. For solid state noise sources $T_C$ is the ambient temperature and $T_H$ is related to the excess noise ratio (ENR) of the source by

$$ENR = 10 \log \frac{T_H - T_o}{T_o} \qquad (2)$$

where $T_o$ is the reference temperature of 290 Kelvins. The noise figure in dB is related to the effective input noise temperature by

$$F(dB) = 10 \log(\frac{T_e}{T_o} + 1) \qquad (3)$$

Equations (1) and (3) hold for the noise measurement system by itself to yield the second stage noise contribution, $T_{e2}$ and $F_2$. They also hold when the unit-under-test (UUT) is attached to the input to yield the total noise characteristics $T_{e12}$ and $F_{12}$. The effective input noise temperature of the UUT alone, $T_{e1}$, is given by

$$T_{e1} = T_{e12} - \frac{T_{e2}}{G_1} \qquad (4)$$

where $G_1$ is the available gain of the UUT. But, as will soon be shown, the same measurements of $N_H$ and $N_C$ for the measurement system alone ($N_{H2}$ and $N_{C2}$) and for the UUT attached to the input ($N_{H12}$ and $N_{C12}$) can also yield the gain $G_1$. Then equations (4) and (3) can be solved for the effective input noise temperature and noise figure of the UUT alone.

The difference between the hot and cold noise power outputs leads to gain $G_1$. For the measurement system by itself

$$N_{H2} - N_{C2} = kBG_2 \, (T_H - T_C) \qquad (5)$$

where $G_2$ is the gain of the measurement system. The noise added by the system, being the same when the noise source is hot and cold, disappears from the difference in equation (5). When the UUT is connected to the input of the system

$$N_{H12} - N_{C12} = kBG_1G_2 \, (T_H - T_C) \qquad (6)$$

The ratio of equation (6) to equation (5) is

$$\frac{N_{H12} - N_{C12}}{N_{H2} - N_{C2}} = G_1 \qquad (7)$$

The above equations show that accurately known noise output from the noise source and accurate power measurement equipment combined with the above equations can yield the noise properties of a unit-under-test. Although the equations can be solved by hand, this is likely to be done at only one or two frequencies. The desktop computer of this system solves those equations, and also synchronizes the operation of the noise source, gathers the power measurement data, tunes the frequency of the local oscillator, interpolates the proper ENR of the noise source from stored calibration data and outputs the results to a printer and/or plotter in scarcely any more time than it takes to make the power measurements alone.

## Equipment Alternatives

An important aspect of this system is the great flexibility in selecting equipment. The IF frequency can be anywhere in the 10 MHz to 18 GHz range of the power sensor. The IF gain·bandwidth product should be large enough for the power meter to read above -49 dBm where it reads most accurately and quickly. This means a minimum gain of about 50 dB for a 10 MHz bandwidth or 60 dB for a 1 MHz bandwidth.

The attenuator at the output of the IF is used to keep the power meter readings from going above -20 dBm, the maximum for the power sensor. The maximum allowed value of attenuation during measurement should be about 30 dB. If a larger value is needed, the IF input power is above +10 dBm and is likely to be approaching saturation and decreased accuracy.

Signal generators and sweep oscillators usually make good general purpose local oscillators for use with double balanced mixers. The important quality of a local oscillator is that the noise level at the IF frequency away from the local oscillator frequency be low. Yig tuned and cavity tuned oscillators tend to have low enough noise. Signal generators are sometimes needed for good frequency resolution or for power level control. An example of such a case is characterizing the noise figure and conversion loss of a mixer vs. local oscillator drive level. For many receiver applications, such as some TV and EW applications, an electronically tuned local oscillator can be tuned through its frequency range by the desktop computer with an appropriate D to A converter.

## Accuracy

The high inherent accuracy of the system arises from the noise source, which has low SWR and a stable, calibrated excess noise ratio, and from the power meter and its power sensor. The system measures the output noise power ratio for the hot and cold noise source to an accuracy of ±0.04 dB. Traditional noise figure meters can measure the noise power output ratio to an accuracy of ±0.15 dB. Re-reflections of noise power between the UUT and noise source cause the measurement uncertainties shown in Figure 3. A typical value, for a noise source SWR of 1.1 and a UUT

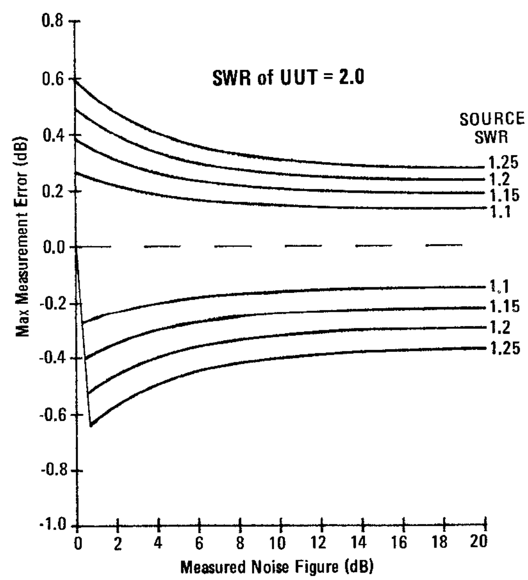


Figure 3. Mismatch uncertainty limits in noise figure measurement due to re-reflection between the noise source and unit under test.

SWR of 2.0, yields an uncertainty of ±0.15 dB. Doubling the noise source reflection coefficient, as must be done with many models of noise sources, approximately doubles the uncertainty. ENR calibration uncertainty arises from many different sources that tend to combine like random variables. The RSS measurement uncertainty due to ENR, including an allowance for interpolation between calibration frequencies, is about ±0.15 dB. If an allowance for receiver nonlinearities of ±0.05 dB is included, the overall root-sum-of squares measurement uncertainty is ±0.22 dB.

## Operation

The special function keys of the desktop computer, pictured in Figure 4, are the operating controls of the measurement system. They allow selection of measurement frequencies, the form of presenting output data, initiating a new calibration, and certain manual operations for checking operating power levels, integrity of connections, etc. during startup.

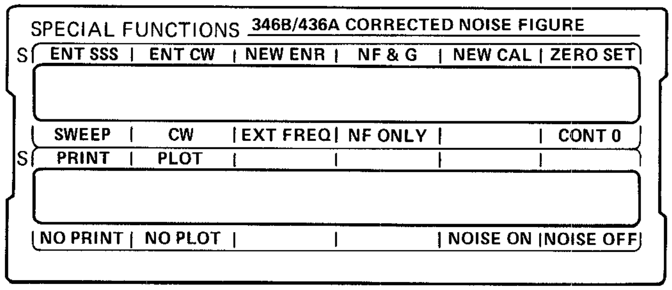


Figure 4. Special function keys of the desktop computer for operating the system.

Many users of this system will find it best to modify the program. Consider, for example, a production test application where only a few measurement situations are encountered. The tasks performed by the special function keys may be changed. Several of the keys, for example, might each direct the program to a specific CW measurement frequency for making tuning adjustments while observing the calculator LED output of noise figure and gain. Then another key might be programmed to make a final broadband sweep at pre-programmed frequencies while both plotting and printing the measurement results at each frequency. The operator would not need to be asked to input the several frequencies and plotting limits.

## Measurement Results

Although Figure 1 showed the repeatability of the measurement equipment, some of the traditional non-repeatability when measuring amplifiers is associated with non-repeatable interactions between the mixer and the UUT. Figure 5 shows the corrected noise figure and gain of an X-band amplifier as measured by this system for two different mixers. There was a 3 dB attenuator included on the RF port of each mixer to minimize the interaction. But the noise contribution of the attenuator was easily corrected by the computer.

Similar measurements are also possible on mixers. Figure 6 shows the corrected noise figure and conversion loss of a doubly balanced mixer. Here the broadband property of the 10 MHz to 18 GHz noise source is used to measure the IF noise contribution.

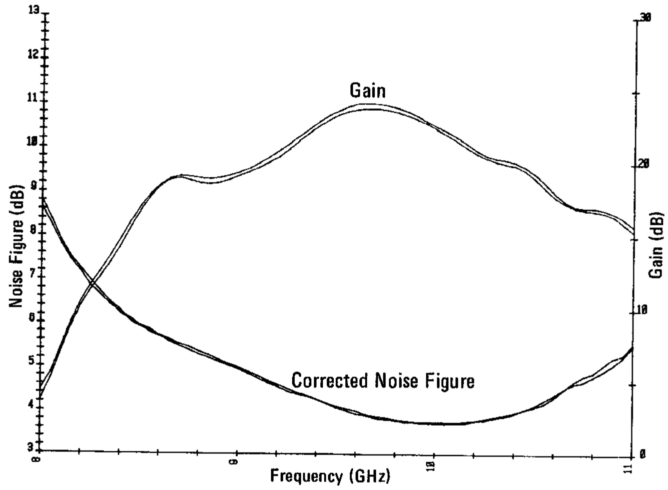


Figure 5. Corrected noise figure and gain of an X-band amplifier measured with two different mixers on the receiver.

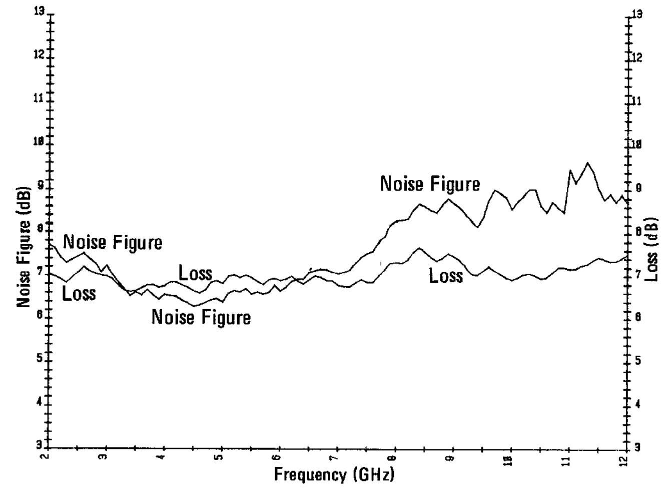


Figure 6. Corrected single sideband noise figure and conversion loss of a double balanced mixer as measured by the system from 2 to 12 GHz with 100 MHz frequency spacing.

Although noise figure and conversion loss are usually assumed to be identical because of traditional difficulty in making such measurements, Figure 6 shows that they are quite different. The relative position of the two curves is a function of local oscillator power. The time for measuring and plotting the results of Figure 6 is about 70 seconds.

This noise figure measurement is not only applicable to production testing. Its high accuracy, arising mainly from a low SWR, well-calibrated noise source and a very accurate power ratio detector, makes it a factor of two more accurate than traditional systems assembled from standard instruments. This system ought to be considered in any critical noise measurement application, especially where repeatability is necessary.

## Reference

1. Mumford, W.W. and Scheibe, E.H., "Noise Performance Factors in Communication Systems," Horizon House, 1968