A SIMPLIFIED APPROACH TO NOISE FIGURE MEASUREMENTS

Commercially available instruments designed to measure noise performance factors (noise figure, effective input noise temperature, etc.) are typically limited to direct input tuning ranges or fixed frequencies below typically 2 GHz (2.047 GHz for the Maury MT2075C and the Hewlett-Packard 8970B020). Measurements at higher frequencies require equipment setups that include some sort of frequency conversion.

Until recently, technologists faced with such a requirement were limited to one of two alternatives: assembly of a down converter from components and equipment available in their own laboratory; or, use of a commercially available down converter incorporating a tracking preselector (noise figure test set). The latter is very expensive and exhibits a potentially serious degradation of instrumentation uncertainty due to tracking errors in the preselector. The former can be time consuming and contains several pitfalls which can also negatively affect measurement accuracy — particularly if the system designer is unaware of the subtleties involved in the measurement of signals that are truly random in both amplitude and phase.

Modern noise figure meters, such as the Maury MT2075C Noise Gain Analyzer (NGA), with on-board microprocessors for control and data manipulation eliminate much of the complexity involved in the measurement of receiver noise performance factors (noise figure, effective input noise temperature, etc.) and can measure these quantities quickly, easily and accurately at frequencies below typically 2 GHz. If the output frequency of the device or system under test is above this range, frequency conversion external to the NGA is required.

Figure 1: The NGA frequency extenders (lower instrument in the photograph), shown here with the Maury MT2075C Noise Gain Analyzer, represent a simplified, cost effective solution to microwave noise figure measurements.

Technically, modern componentry makes assembly of a frequency converter a simple task on the surface; however, because the measured signals are random in amplitude and phase, there are some conditions such as mixer noise figure, dynamic range, spurious mixing products, and image response which, if not carefully addressed, can lead to serious measurement errors.

Until recently, the only other alternative to the "do-it-yourself" approach to a suitable frequency converter was the use of a commercially available unit commonly referred to as a Noise Figure Test Set (NFTS) which incorporates a tunable YIG filter as a preselector. The purpose of the filter is to eliminate errors due to image responses[1] and odd-harmonic mixing products. In order to perform this function over a broad range of frequencies — typically 1.6 to 26.5 GHz, the preselector tuning is required to track the frequency of a synthesized signal source used as a local oscillator at some specific offset over that same range. Unfortunately, tracking between the preselector tuned frequency and the local oscillator is somewhat less than perfect which leads to a 100 to 300% increase in noise figure instrumentation uncertainty, plus additional errors due to environmental temperature changes. The NFTS also has a relatively high noise figure which can also increase measurement uncertainty. In addition to degrading measurement accuracy, these instruments are difficult to use, very expensive, and are compatible with only one specific manufacturer/ model noise figure meter.

The purpose of this paper is to describe the application and performance of a microwave noise figure measurement system that includes a frequency converter — referred to as a Noise Frequency Extender (NFE) — that: 1) preserves the instrumentation uncertainty of the basic noise figure meter and avoids the error-inducing traps and pitfalls of designs compromised by the need-to-use available equipment; 2) is simple to set up and use; 3) can be used with any noise figure meter — analog or digital — capable of accepting a 30 MHz signal; 4) is highly cost effective — both in terms of basic cost as well as in offering the user a choice of units in frequency ranges up to 26.5 GHz so that he is not required to pay for performance he does not need.

The last point may be important for manufacturers in the commercial communications market since a single sideband frequency extender with a range extending to 4.2 GHz is available for less than one-half the cost of a 26.5 GHz noise figure test set with a tracking preselector.

Measurements Setup

Figure 1 shows the new frequency extender with the Maury MT2075C noise gain analyzer. **Figure 2** is a block diagram of the typical setup. One apparent feature of the setup is the absence of a control connection between the frequency extender and the noise gain analyzer. Since the NFE does not include a tracking preselector, there is no need for control. The captive System Interface Bus (SIB or private line), available on most microprocessor controlled noise figure meters, is used only to control the signal source employed as the local oscillator for the frequency conversion process (and a digital plotter if hard copy capability is included in the setup).

Since system control is not required, the NFE, unlike past and currently available noise figure test sets, is independent of the type of noise figure meter in use. This leads to a highly versatile conversion setup which can be used with any noise figure meter capable of

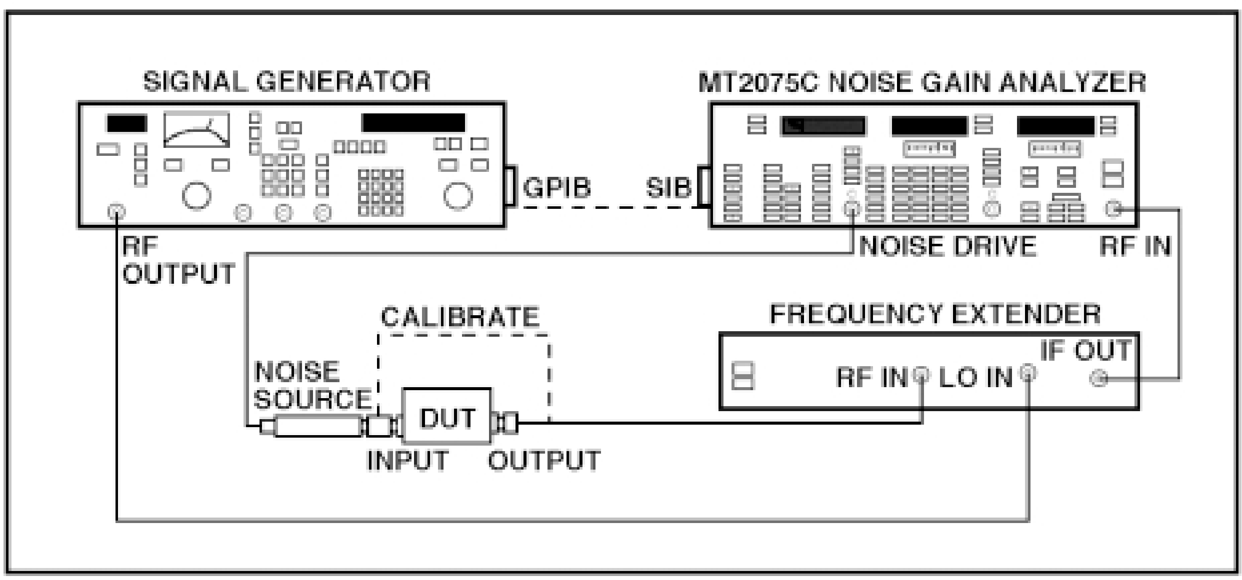

Figure 2: Noise figure measurement setup using a frequency extender.

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accepting a 30 MHz input frequency. These units will operate with all current Maury and HP digital noise figure meters, including obsolete versions such as the HP8970A and Eaton/Ailtech 2075-2A, and even analog units such as the Maury MT7300 system noise monitor series and the older Eaton/Ailtech 7500 series precision automatic noise figure indicators.

An aspect of the setup is the selection of the source used as the local oscillator. Most digital noise figure meters provide the controller capability for setting the frequency of several types of commercially available signal sources used as the local oscillator (the Maury MT2075 series is also capable of controlling the power output). A recent application note from Marconi Instruments[2] outlines the procedure which allows the NGA to control an arbitrary signal source, that is, one whose control codes are not previously stored in the instrument. The example provided is the synthesized source used in the Marconi 6200 series microwave test sets. This leads to the possibility of a multipurpose test set which includes reflection, transmission and noise measurements in a single setup.

Measurement Uncertainty

In general, the instrumentation uncertainty specifications of noise figure meters are probably among the most misunderstood quantities in the industry. Instrument manufacturers provide instrumentation uncertainties for the noise figure meter and a calibration uncertainty for the noise generator. Most users will then assume that the accuracy of the noise figure measurement is equal to the sum or the root-sum-square of these two numbers.

The result of that assumption is usually quite far removed from the actual measurement uncertainty. This is especially true if the measurement system noise figure (second stage noise) is large relative to the product of the Device-Under-Test (DUT) noise figure and gain (expressed as ratios).

Microprocessor driven noise figure meters, which include just about all those that have been introduced over the past ten years, calculate and display the noise figure of the DUT corrected for the effects of measurement system (second stage) noise. Three independent measurements are made — the overall noise figure of the DUT in cascade with the measurement system, the measurement system noise figure, and the available gain of the DUT. The results are then applied to the cascade noise figure equation[3].

$$\mathrm{Fdut} = \mathrm{Ftot} - \frac{\mathrm{Fms}-1}{\mathrm{Gdut}} \qquad (1)$$

where,

Fdut = DUT noise figure
Ftot = overall measured noise figure of the DUT in cascade with the measurement system
Fms = measurement system noise figure
Gdut = DUT gain

The three measurements each contribute independently to the overall measurement uncertainty and, because they are uncorrelated, can be combined in an RSS fashion to arrive at an estimate of the accuracy of the DUT noise figure [4, 5], ie:

$$\Delta\mathrm{Fdut(dB)} = \sqrt{A^2 + B^2 + C^2} \qquad (2)$$

$$A = \left(1 + \frac{\mathrm{Fms}-1}{\mathrm{FdutGdut}}\right)\Delta\mathrm{Ftot(dB)} \qquad (3)$$

$$B = \frac{\mathrm{Fms}}{\mathrm{FdutGdut}}\,\Delta\mathrm{Fms(dB)} \qquad (4)$$

$$C = \frac{(\mathrm{Fms}-1)}{\mathrm{FdutGdut}}\,\Delta\mathrm{Gdut(dB)} \qquad (5)$$

A word of caution regarding these equations: the calculated uncertainty is expressed in dB as are the uncertainties of the measured quantities; however, the quantities in the multipliers are expressed as dimensionless ratios. The uncertainty relations emphasize the importance of insuring the measurement system noise figure is small relative to the product of the DUT noise figure and gain (sum in dB); ie:

$$\mathrm{Fms} < \mathrm{FdutGdut} \qquad (6)$$

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Note that the instrumentation uncertainties [ΔFxx(dB)] are multiplying factors. This means that an improvement of instrumentation uncertainty from ±0.1 to ±0.05 dB is, in effect, a 2:1 improvement rather than just a 0.05 dB differential. A tunable preselector, because the tracking with the local oscillator is imperfect, can deteriorate noise figure instrumentation uncertainty by factors ranging from 2:1 to 4:1 depending upon frequency. The preselected noise figure test sets also tend to have higher noise figures than the "passive" frequency extenders which, as noted above and illustrated by **Figure 3**, will further degrade the measurement uncertainty.

Figure 3 plots measurement uncertainty versus the sum (in dB) of the DUT noise figure and gain for two measurement systems: one based on the frequency extender, the other on a currently available noise figure test set. Published specifications were used for instrumentation uncertainties and input noise figures, and the plots graphically demonstrate another advantage in using the frequency extender with its lower noise figure and independence from preselector tracking errors inherent in the NFTS.

These considerations, coupled with the complicating need for bus (SIB) control of the NFTS and its restriction to use with just a single type of noise figure meter, provide significant incentive to find some means of eliminating the need for the tunable filter.

Conversion Mode

When a broadband signal, such as random noise, is applied to a typical mixer with no input filtering or sideband rejection, two separate bands of noise are converted to the IF. These are spaced twice the IF apart and centered on the LO, and the conversion mode is referred to as double sided.

Figure 4 illustrates this definition as well as the two single sideband conversion modes. Noise figure, however, is defined[1] as a comparison (ratio) of the noise

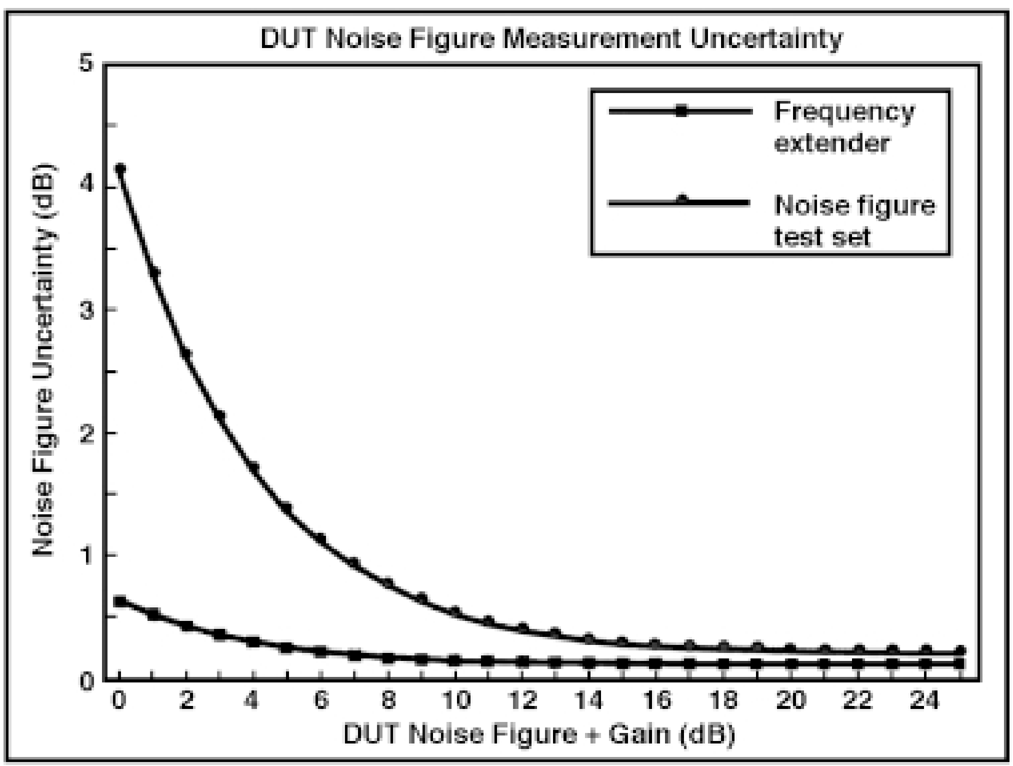

Figure 3: **The effect of measurement system noise performance on measurement uncertainty as a function of noise figure and gain of the Device-Under-Test.**

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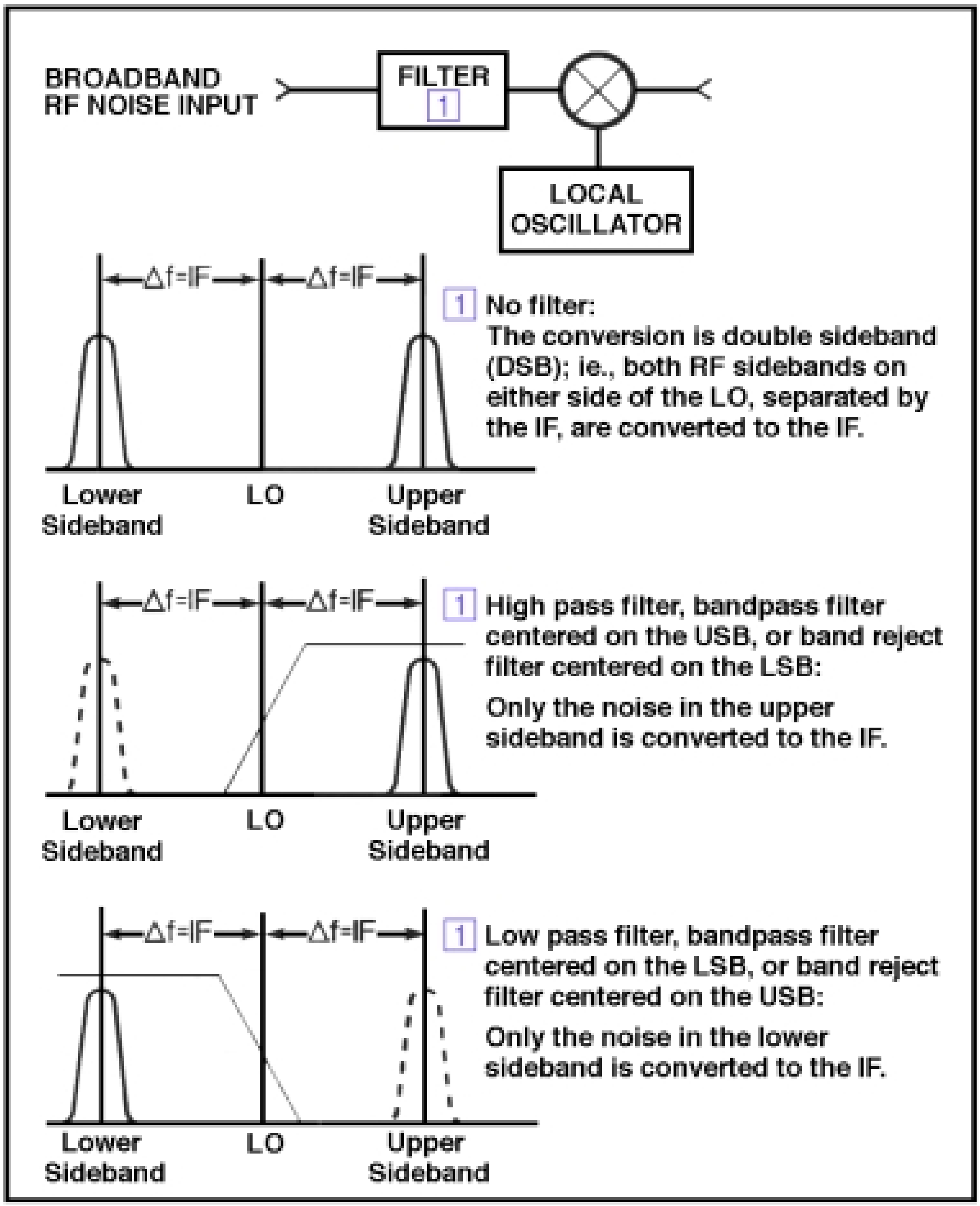

Figure 4: **Conversion sideband definitions.**

output of the actual transducer (amplifier, receiver, etc.) to that of an ideal but otherwise identical transducer with the added note that the noise output of the "ideal" is that which appears in the output via the primary signal frequency transformation. Since the signals used by most receiver systems will occupy only one of the two available sidebands, the definition, in effect, states that the ideal should not be encumbered by a useless image channel which simply introduces additional noise to further obscure the desired signal (some may recognize that if the noise and gain of the signal and image paths are identical, this will lead to the famous—or infamous—3 dB correction used in mixer noise figure measurements).

The most publicized rationalization for the use of a tracking preselector is the elimination of the image sideband and any associated errors in the measurement of microwave amplifiers whose output noise spans both sidebands; however, as referenced[6] and shown below, this is often an unnecessary complication and expense.

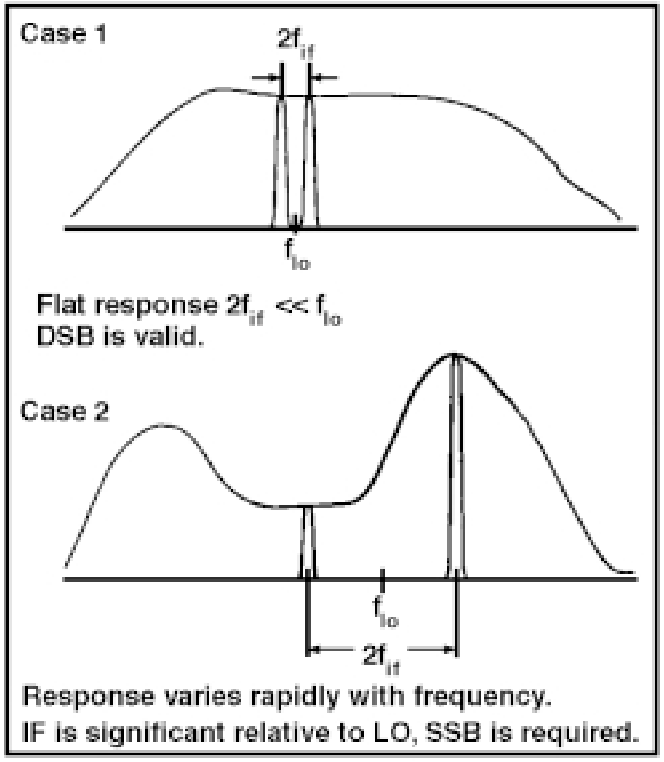

Figure 5: **Conditions indicating validity of a DSB measurement.**

Figure 5 illustrates the conditions which dictate whether or not the additional RF sideband can be ignored in the measurement.

As shown in Case 1, if the response of the device under test varies slowly with frequency, and the IF is small relative to the LO frequency, then, relatively speaking, the two sidebands are virtually a single spectral line, and the measured double sideband noise figure is essentially equal to a single sideband result. In Case 2, the response varies rapidly with frequency and differs significantly at each sideband. In this instance, a double sideband would have considerable error (a noise figure meter would read the average of the noise figures at each frequency).

Case 1 is generally the governing situation for most broadband microwave amplifiers, particularly those designed to operate at the higher microwave frequencies, while Case 2 is most prevalent for devices operating in the lower microwave regions (eg <3 GHz).

In the system described here, the user is offered a choice of units: a single sideband converter (with no preselector) for the lower microwave regions applicable to situations like Case 2, and double sideband converters to cover the broadband applications with a minimum of complication and expense. Both types of frequency extenders avoid the use of tunable filters thus eliminating the tracking errors inherent in noise figure test sets and the need for frequency control of the converters (bus connections are not required) which, in turn, reduces the complexity and cost of the setup.

Table 1 is a comparison of noise figure data (corrected for second stage noise effects) taken on a 2 to 18 GHz amplifier with about 23 dB nominal gain over the passband. The data in the column marked "NFE DSB Noise Figure" was taken using a double sideband frequency extender (Maury MT7551B) for the frequency conversion and the Maury MT2075C noise gain analyzer as the noise figure meter (column marked). The data in the column marked "NFTS SSB Noise Figure" was obtained using a single sideband noise figure test

TABLE 1
Double and single sideband noise figure measurement comparison

Frequency (GHz)	NFE DSB Noise Figure (dB)	NFTS SSB Noise Figure (dB)	SSB CW Noise Figure (dB)
2	6.86	7.05	6.99
3	6.14	6.26	6.28
4	5.75	5.81	5.78
5	5.38	5.40	5.34
6	5.04	5.04	5.06
7	4.84	4.87	4.85
8	4.50	4.53	4.49
9	4.88	4.93	4.89
10	4.90	4.99	4.89
11	4.96	5.07	—
12	5.07	5.12	—
13	5.42	5.57	—
14	5.62	5.77	—
15	5.95	6.06	—
16	6.29	6.37	—
17	6.67	6.74	—
18	7.49	7.68	—

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set with a tracking preselector for the conversion and a Hewlett-Packard 8970B noise figure meter. The data in the column marked "SSB CW Noise Figure" was obtained by using an amplifier followed by a filter (different at each measurement frequency) and a mixer with a high IF capability as the converter.

At each frequency, the filter cutoff and the IF was selected to effectively remove the image (this arrangement is often referred to as a block downconverter). Unfortunately, suitable filters were unavailable for measurements above 10 GHz.

The same noise generator (Maury MT7618E) was used for all three sets of measurements to avoid discrepancies related to noise generator calibration uncertainty (one of the more significant factors affecting noise figure measurement uncertainty). The data is plotted in **Figure 6**.

As expected, the most significant deviations occurred at the band edges; however, all the data correlated well within the typical uncertainty limits for microwave noise figure measurements. What is clear, though, is that for many broadband measurements, a simplified, less costly converter is available which can provide measurements with an overall uncertainty related to just the instrumentation uncertainty of the basic noise figure meter with no impact from inaccuracies related to dynamic filter/LO tracking or high noise figure.

Instrumentation Compatibility

A key feature of the noise frequency extenders described here is compatibility with a wide variety of noise figure meters. As noted earlier, noise figure test sets utilizing tracking preselectors require control commands from the noise figure meter to maintain tracking with the local oscillator (also under the control of the noise figure meter) and to insure that the appropriate noise generator excess noise ratio is being used for the noise figure calculation[7]. Control of the LO and the NFTS is via the captive, GPIB compatible system interface bus. The NFE are GPIB passive; that is, control is not required because there is no dynamic tuning. The net result is that these converters can be used with any

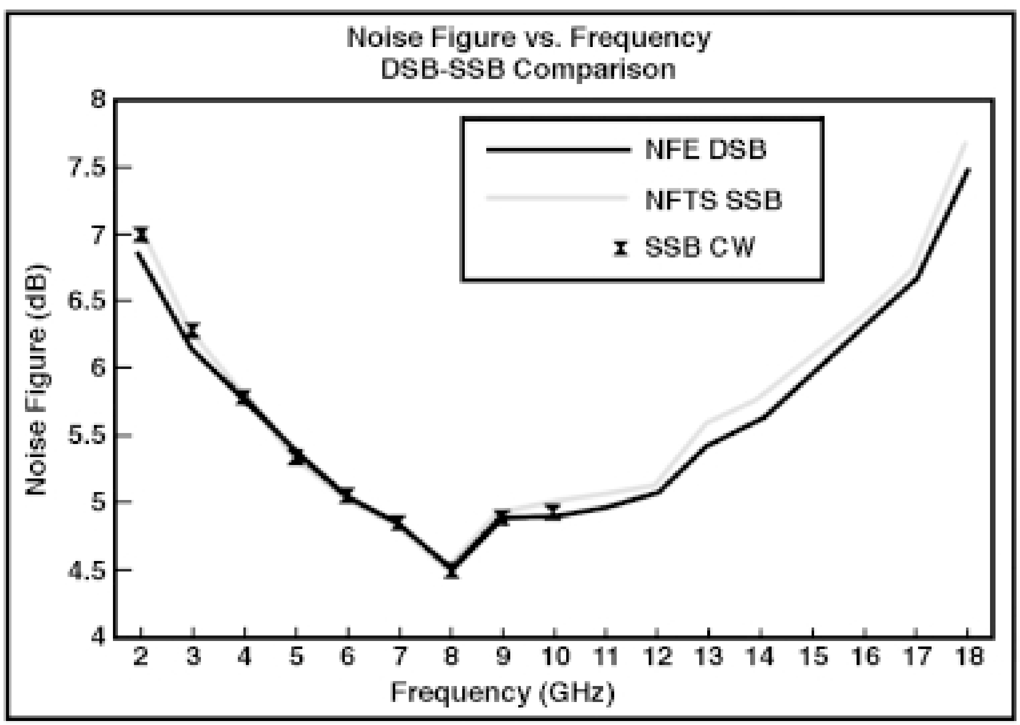

Figure 6: **Comparison of measured single and double sideband noise figures of a 2 to 18 GHz amp using a frequency extender, a noise figure test set, and an SSB block downconverter.**

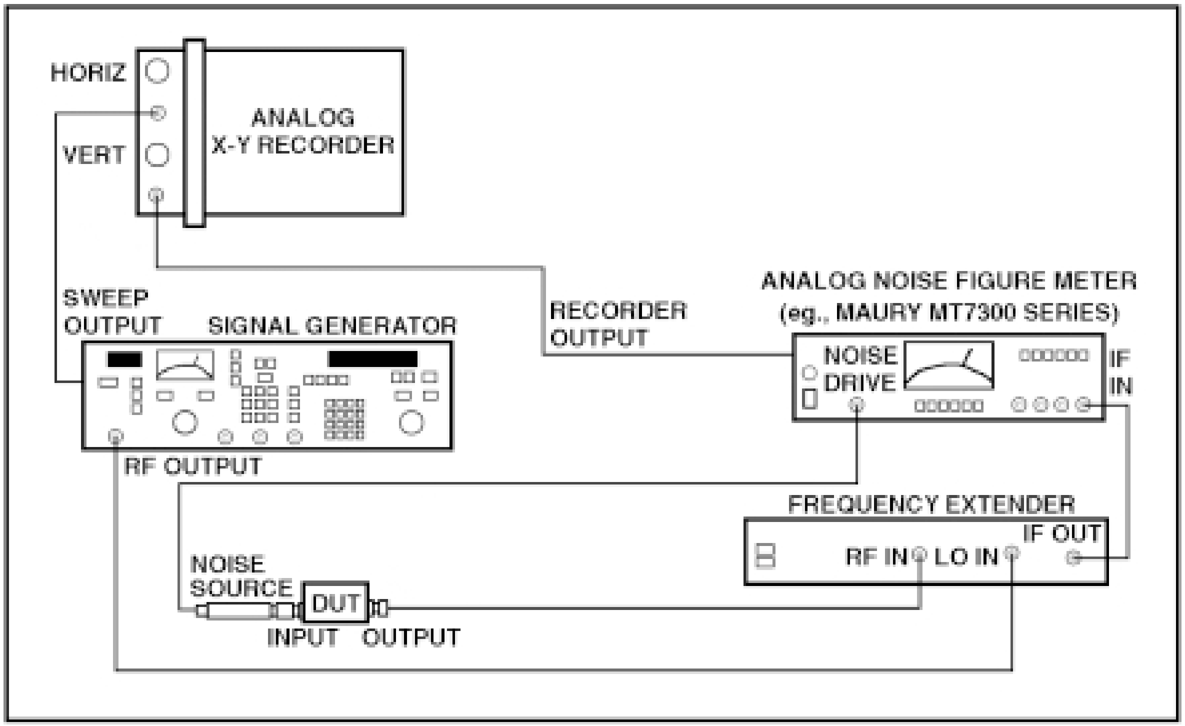

Figure 7: **Typical noise figure measurement setup using a frequency extender and an analog noise figure meter.**

noise figure meter (or, for that matter, with any receiving instrument) capable of accepting a 30 MHz input (the units actually have a 10 to 500 MHz usable IF range).

As an illustration of this versatility, **Figure 7** is a block diagram of a swept noise figure measurement system using a typical analog noise figure meter and an X-Y recorder to provide hard copy output — an oscilloscope could be substituted for display purposes if hard copy is not required. The importance of this capability lies in the investments made by industry over the years in noise figure instrumentation of various types which represent an established base of instruments such as the Eaton/Ailtech 2075-2A and 2075B, HP8970A, and a wide variety of analog units. Such instruments can now be utilized for accurate microwave noise figure measurements extending the useful life of the investment while avoiding the necessity to purchase a completely new measurements system.

Conclusions

Noise figure measurements at microwave frequencies can be as accurate as those made directly by a noise figure meter. Noise frequency extenders provide for down-conversion of noise signals with no deterioration of measurement uncertainty due to inaccuracies in tracking between a tunable filter and the local oscillator. A low input noise figure also reduces the uncertainty due to the effects of second stage (measurement system) noise. Typical instruments utilize single sideband conversion in the lower microwave range where response variations could result in "image response errors", and double sideband conversion for broadband applications where the potential for such errors is small.

Elimination of the need for control of a tracking filter and its associated control circuitry results in: a) a simplified, more reliable instrument with costs ranging from 25% to 50% of the typical noise figure test set, and b) a highly versatile series of units that are not limited to operation with a single type of noise figure meter.

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