Mixer Noise Figure Concerns and Measurements

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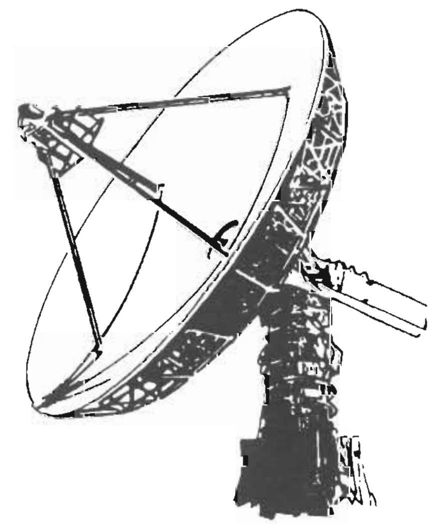
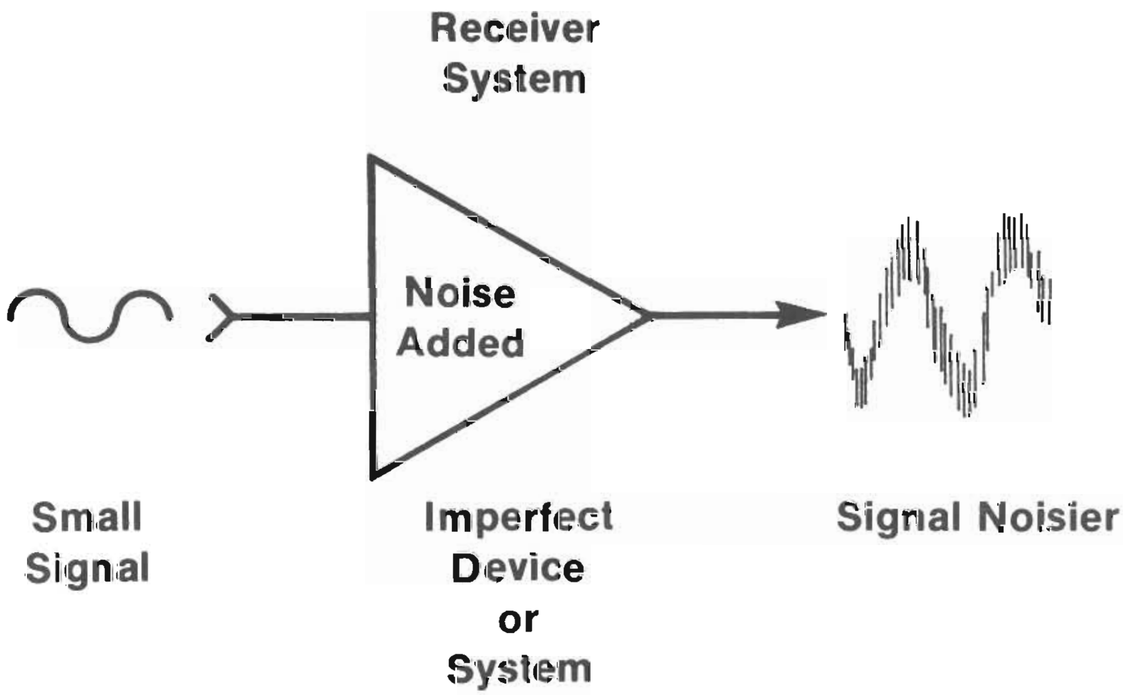
RF & Microwave Measurement Symposium and Exhibition



HEWLETT PACKARD

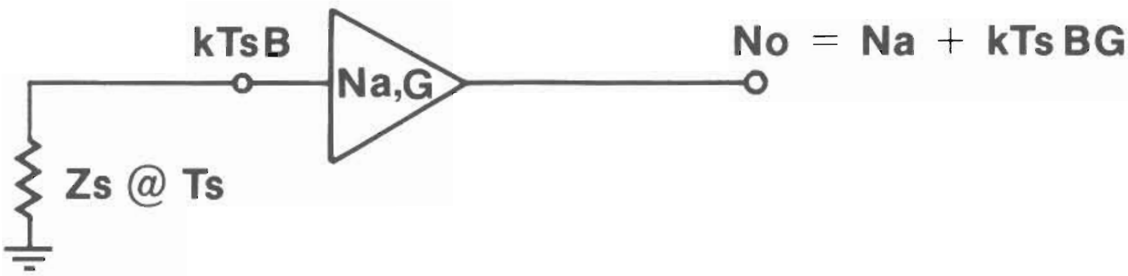
Why Is Noise Important?



Noise limits the detection of weak signals. As a signal is passed through a device or system, noise is added, thus degrading the signal to noise ratio. Noise figure is a measure of this degradation.

Noise Figure Definition

$$F = \frac{\text{Total Output Noise Power}}{\text{Output Noise Power Due To Input Noise @ 290K}}$$



$$F = \left. \frac{Na + kTsBG}{kTsBG} \right|_{Ts = 290K}$$

$$F_{dB} = 10 \log F$$

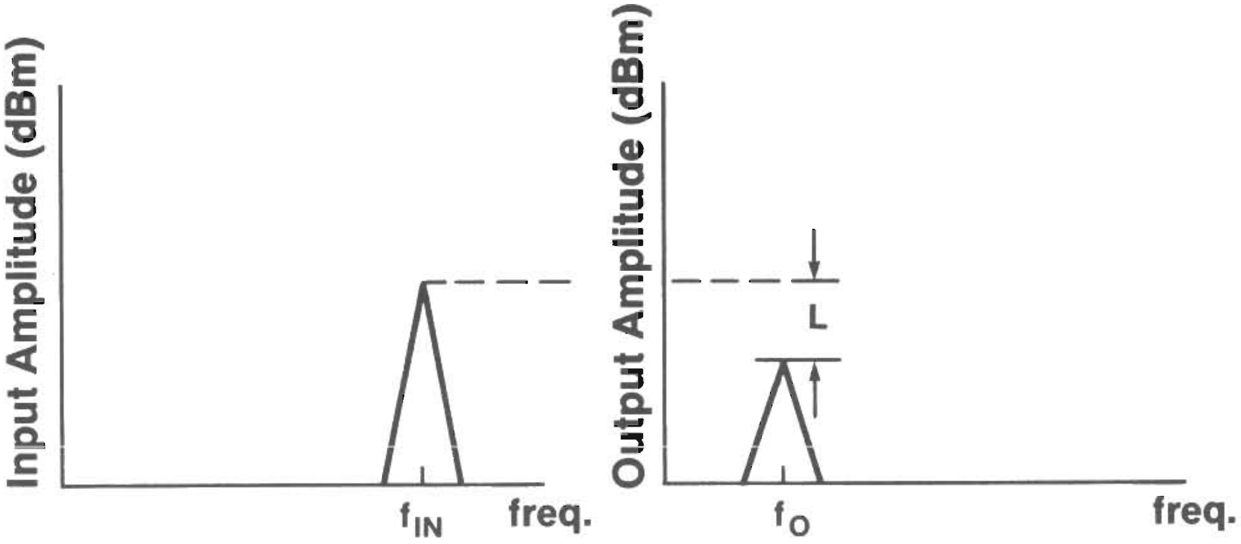
Noise figure is a measure of signal to noise ratio degradation of any device or system that has at least one input and one output. It applies to systems as well as components of the system.

Why Is Mixer Noise Figure Important?

- A low noise preamplifier (to reduce the effect of the mixer noise figure) is not always appropriate in a system design
- Manufacturers specify it; it needs to be verified

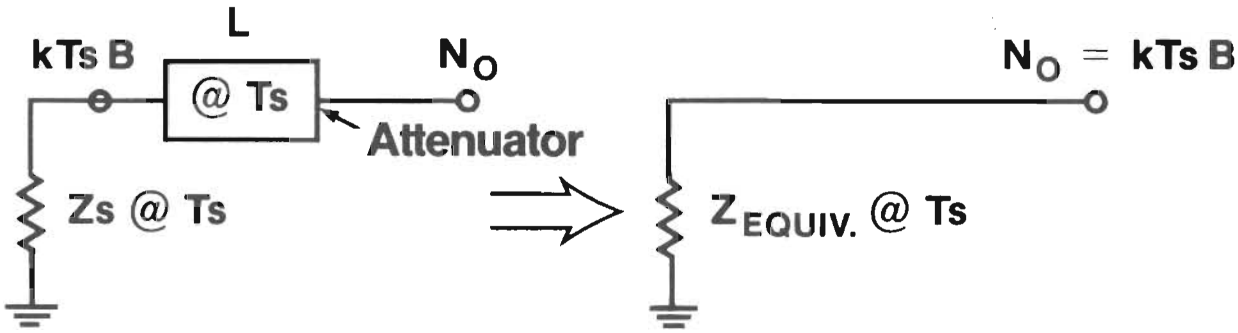
Some receiver systems precede their mixer with a low noise preampifier to reduce system noise figure. Cost, reduced dynamic range, etc. may prohibit the use of preamplifiers in other systems; in these systems, mixer noise figure is very important.

Conversion Loss



Conversion loss represents the loss to a signal in a frequency-translating (converting) device or system.

Noise Figure/Loss Of An Attenuator



$$F = \frac{\text{Total Output Noise Power}}{\text{Output Noise Power Due To Input Noise @ 290K}}$$

$$F = \frac{kT_s B}{kT_s B/L} \quad \Big|_{T_s = 290K}$$

$$F = L$$

The thermal (Johnson) noise power available from a conductor is dependent only on the temperature of that device. Two conductors at the same temperature will therefore have the same available thermal noise power as one device at that temperature. In the noise figure equation, the total output noise power, kTs B, is divided by the attenuated input noise power. The result: noise figure equals insertion loss.

Diodes Are.....Different

Depending on where on its V-I curve a diode is operating a diode emits...

—Shot Noise
Available Shot Noise Power = $\frac{1}{2} k T_{AMB.} B$

($T_{AMB.}$: Ambient Temperature)

—Johnson Noise
Available Johnson Noise Power = $k T_{AMB.} B$

Therefore...

$$\tfrac{1}{2} k T_{AMB.} B < N_{DIODE} < k T_{AMB.} B \text{ (can be higher)}$$

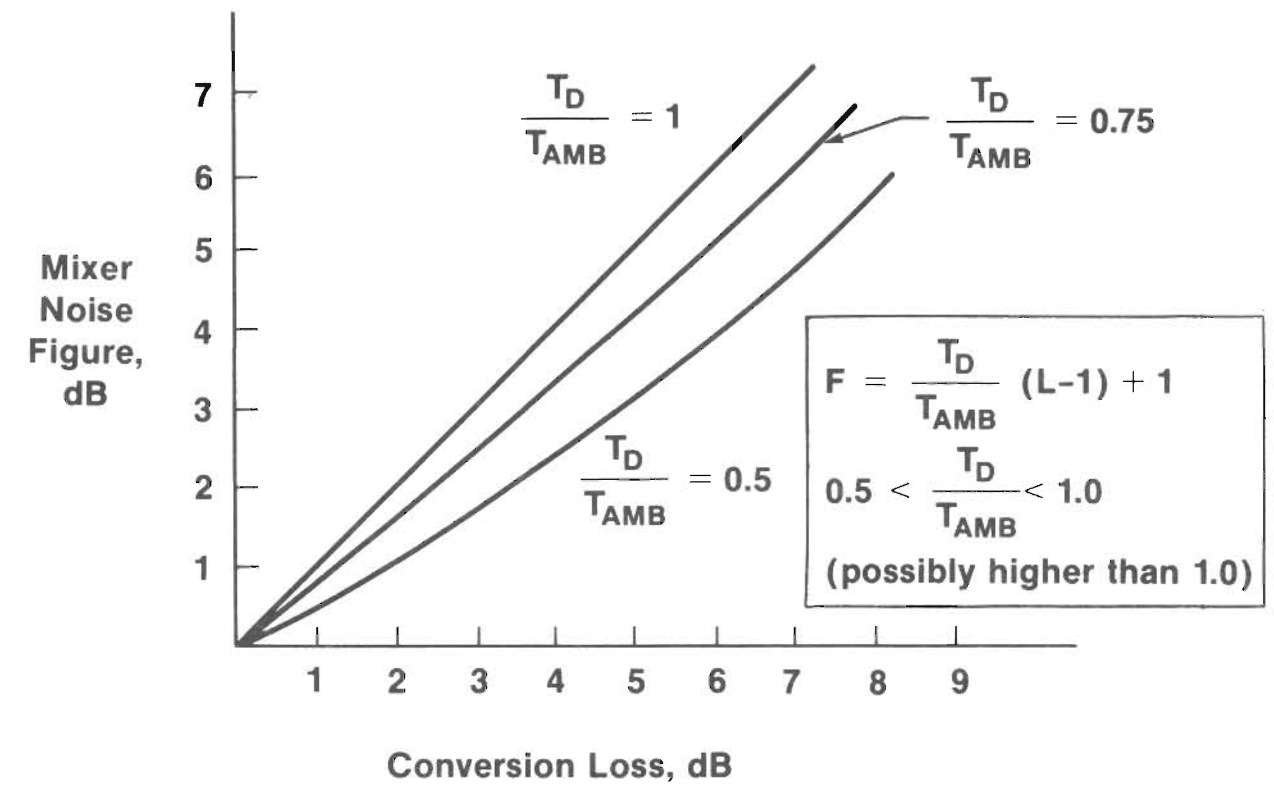
Or

$$\tfrac{1}{2} < T_D < 1 \text{ (again, can be higher)}$$

(T_D: Diode Temperature)

Because the dominant noise mechanism over most of a diode's v–i curve is shot noise (rather than Johnson noise) a diode's equivalent temperature, T_D, can range down to ½ T_{AMB}. Diode temperature can also be greater than T_{AMB}, especially with high LO power. What does all this have to do with the noise figure/conversion loss relationship?

Mixer Noise Figure vs. Conversion Loss

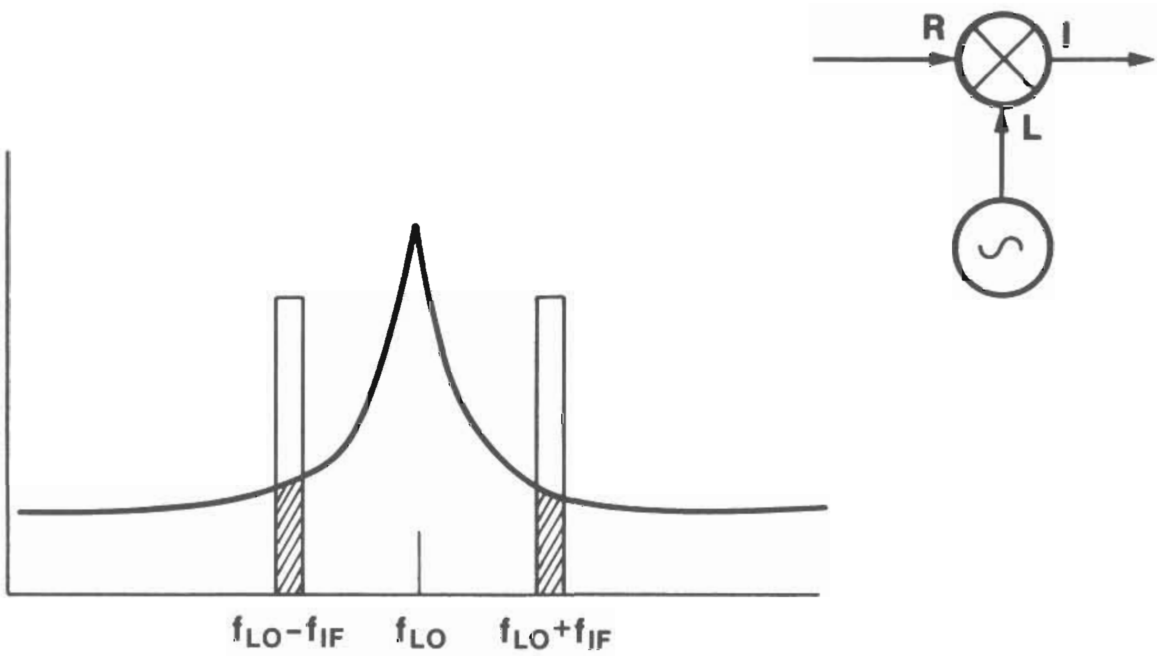


W.L. Pritchard's* noise figure/conversion loss equation illustrates the difference in noise figure and conversion loss in mixers. (There are other equations that describe the mixer noise figure and conversion loss relationship; they all illustrate that there is a difference in F and L due to diode temperature, T_D).

Due to the above mentioned difference, it may be very desirable to measure noise figure and conversion loss separately—a noise figure meter will do just that.

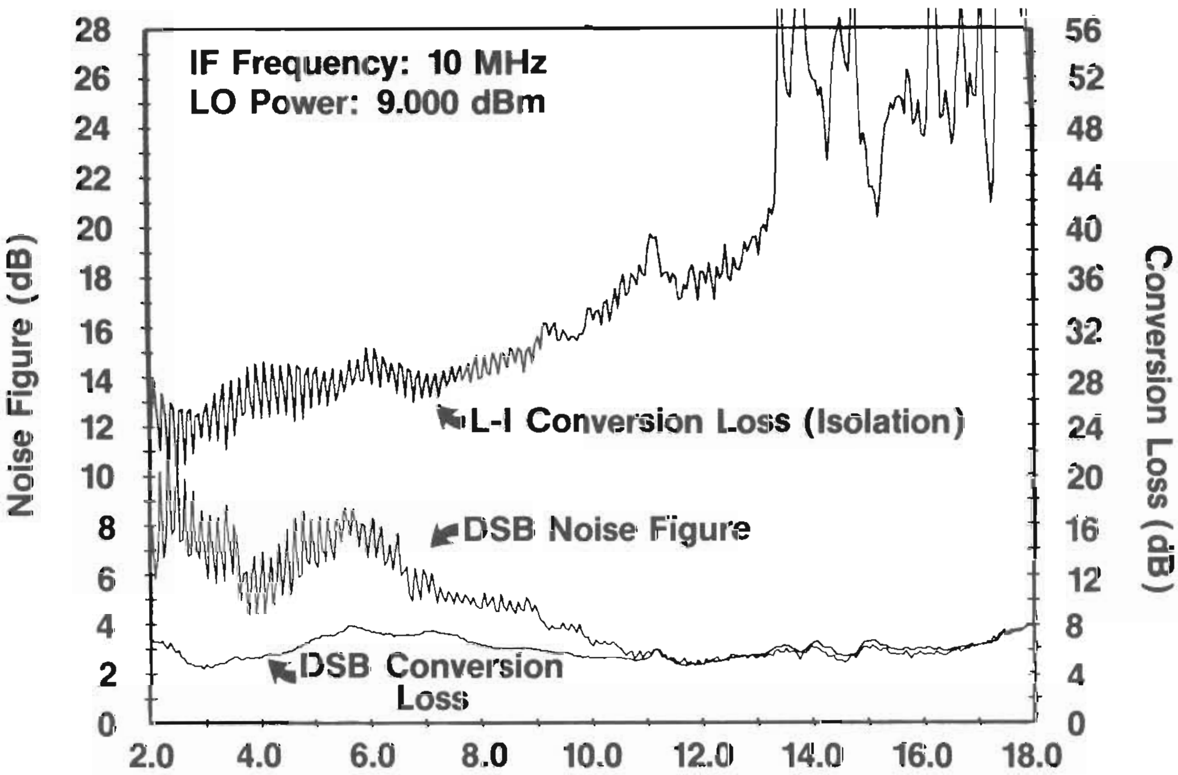
*W.L. Pritchard, "Notes on a Crystal Mixer Performance," PGMTT, p 39 (January, 1955).

Noise Is Added By LO



The noise present $\pm f_{IF}$ from the LO frequency will be downconverted by the mixer, attenuated by the L to I conversion loss and added to the noise generated by the mixer itself.

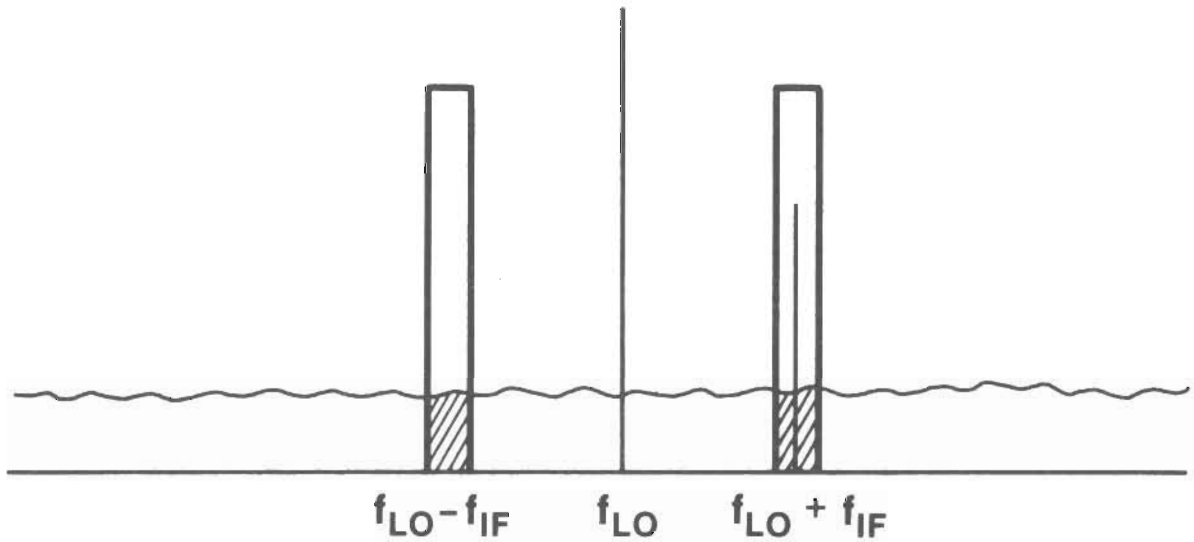
LO Noise Makes
F ≠ L



In a receiver, the noise from the LO is perceived (by the system) as noise added by the mixer; mixer gain (conversion loss) is not affected. LO noise can, therefore, contribute to a substantial difference between noise figure and conversion loss.

Mixer noise figure can be thought of as an indication of total health—it not only reflects signal degradation due to internally generated noise, but also indicates the mixer's susceptibility to external noise (i.e. LO noise).

Image Noise Will Degrade Noise Figure



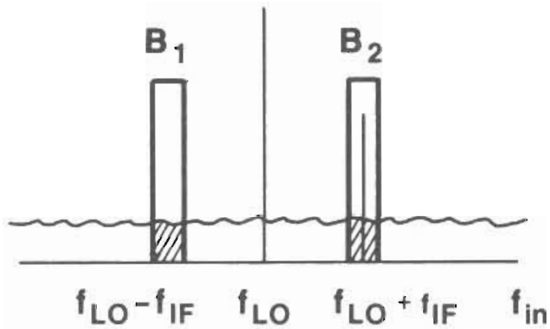
In addition to noise translated from the signal band, and the noise added by the mixer itself, further degradation of mixer noise figure results from noise translated from the image frequency band. For SSB systems that allow the passage of the image noise, the noise figure of the system should reflect this degradation in its noise figure.

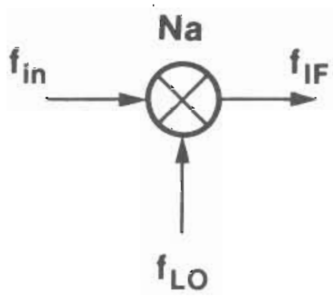
Noise Figure Of Multiple Input Response Devices

$$F = \frac{Na + kT_0B_1G_1 + kT_0B_2G_2 + \ldots}{kT_0B_{SIG}\ G_{SIG}}$$

The IEEE definition of noise figure states that the numerator of the noise figure expression should represent ALL output noise while the denominator should only represent noise translated from frequency bands that contain signal information. Let's see how this affects the noise figure of a mixer in specific applications.

Single Sideband Noise Figure (Multiple Response System)

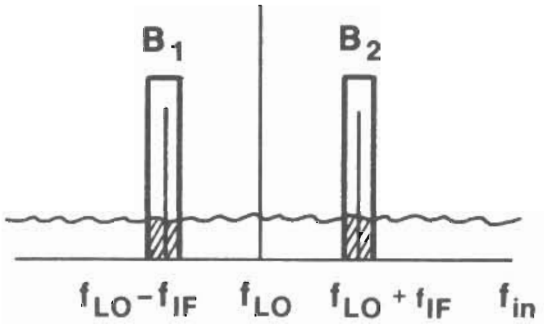


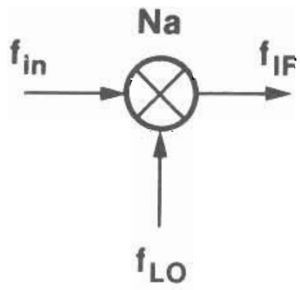


$$F_{SSB} = \frac{Na + \dfrac{kT_0B_1}{L_1} + \dfrac{kT_0B_2}{L_2}}{\dfrac{kT_0B_2}{L_2}}$$

For a mixer used in an SSB system (i.e. a system that processes information found in only one downconverted frequency band) the denominator of the noise figure expression represents the input noise found in only one of the two sidebands. In other words, the denominator represents the noise that accompanies the signal on its way to the IF

Double Sideband Noise Figure (Multiple Response System)





$$F_{DSB} = \frac{Na + \dfrac{kT_0B_1}{L_1} + \dfrac{kT_0B_2}{L_2}}{\dfrac{kT_0B_1}{L_1} + \dfrac{kT_0B_2}{L_2}}$$

In DSB systems (i.e. systems that downconvert useful information from two frequency bands) the denominator of the noise figure expression represents input noise from two frequency bands.

SSB/DSB Noise Figure Relationship (Multiple Response System)

If $L_1 = L_2$

$$F_{SSB} = \frac{Na + 2\left(\frac{kT_0 2}{L}\right)}{\frac{kT_0 B}{L}}$$

$$F_{DSB} = \frac{Na + 2\left(\frac{kT_0 B}{L}\right)}{2\left(\frac{kT_0 B}{L}\right)}$$

$$F_{SSB} = 2F_{DSB}$$

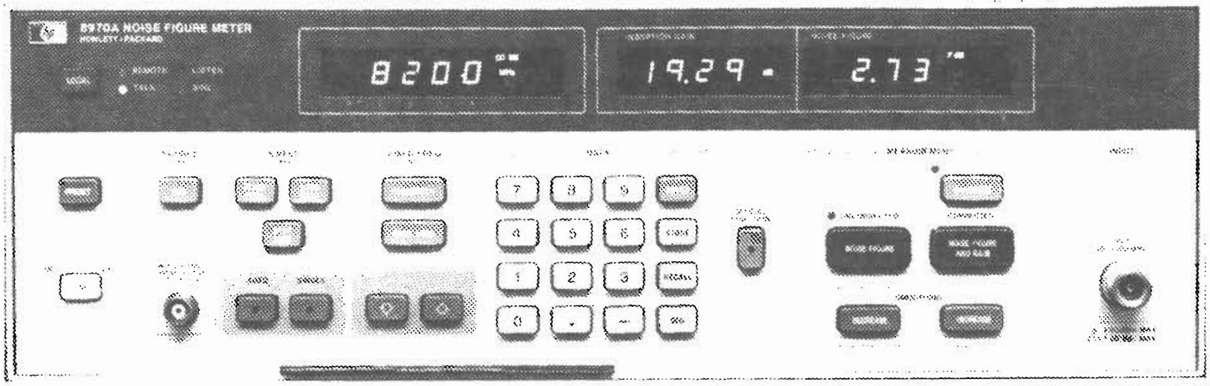
$$(F_{SSB})_{dB} = (F_{DSB})_{dB} + 3\ dB$$

If $L_1 \neq L_2$ (where L_2 contains signal)

$$F_{SSB} = \left(1 + \frac{L_2}{L_1}\right) F_{DSB}$$

For a mixer used in a multiple response system, SSB noise figure will be 3dB higher than DSB noise figure (assuming L_1 and L_2 are equal). This is valid ONLY for the multiple response systems (i.e. systems that respond to more than one input for every output).

HP 8970A
Noise Figure Meter Features



- Tunable IF range .... 10 to 1500MHz
- Sensitivity .... No external gain required
- Simultaneous measurement of noise figure and conversion loss
- Controls the external LO
- Built-in digital storage for output of swept measurements to scope

When Does $F_{SSB} = F_{DSB} + 3dB$ Apply?

ONLY When....

1) Converting SSB (non-filtered) performance from a DSB measurement

And....

2) $L_1 = L_2$

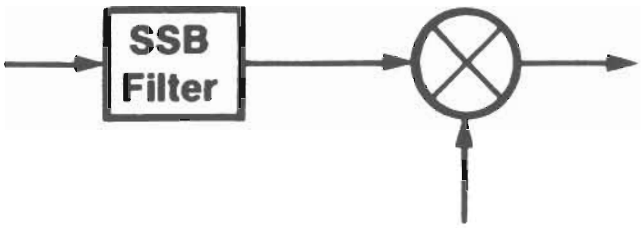
NOT When....

1) Predicting SSB (filtered) performance from a DSB measurement (only an approximation)

Or....

2) $L_1 \neq L_2$

Preselected SSB Noise Figure (i.e. Single Response System)



$F_{SYSTEM} \neq F_{DSB} + 3dB$

The image noise is no longer passed to the IF, therefore....
Mixer noise figure degradation due to image noise is not a factor

How do you determine preselected SSB noise figure?

ANS: Measure Noise Figure of Mixer/Filter Combination

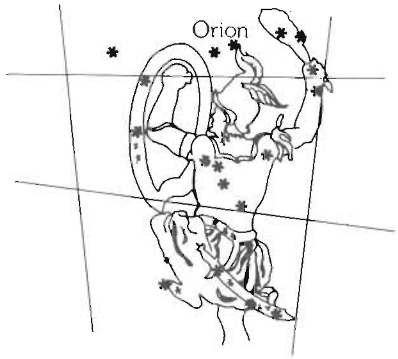
Although an SSB, single response noise figure can be approximated with F_{DSB} + 3dB, to be accurate one should measure noise figures of the Mixer/Filter combination.

Mixer
Noise Figure Depends On Application

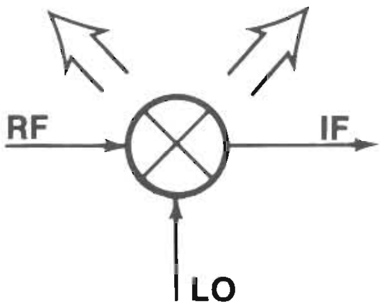
Inexpensive Radar

$F_{SSB} = 6.5dB$

Radio Astronomy

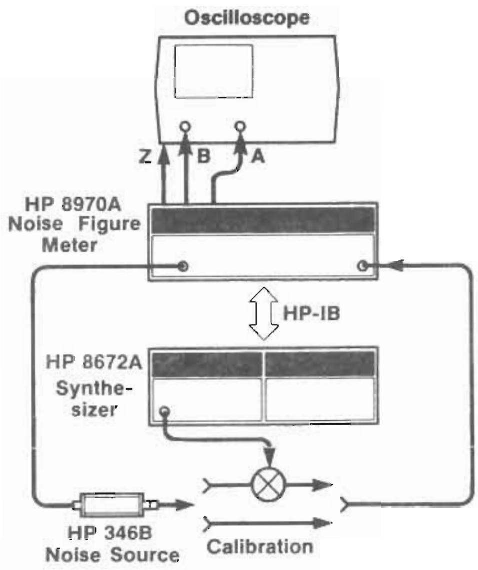


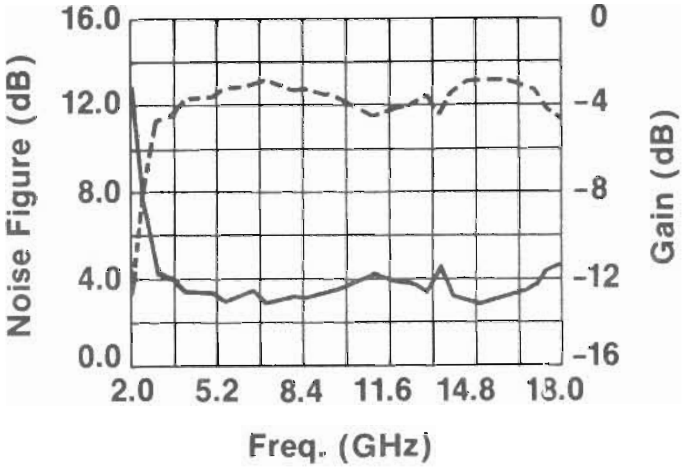
$F_{DSB} = 3.5dB$



The mixer noise figure is undefined unless a particular application is also specified. In radio astronomy, the desired signal is located in both the upper and lower sidebands. In an inexpensive radar, the signal is located in only one sideband and there is no preselector to filter out the downconverted image noise. The noise figure of the radar mixer should illustrate its noise figure degradation due to image noise. In the above example, the upper sideband conversion loss is assumed equal to the lower sideband C.L., therefore, the noise figure is shown to be 3dB worse than the radio astronomy (DSB) case.

Mixer Noise Figure Measurement (Function of RF)



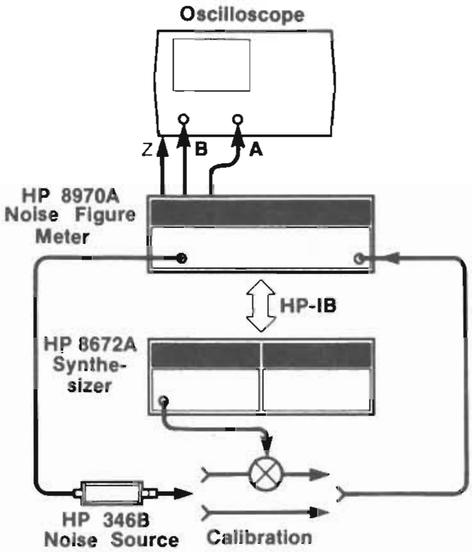


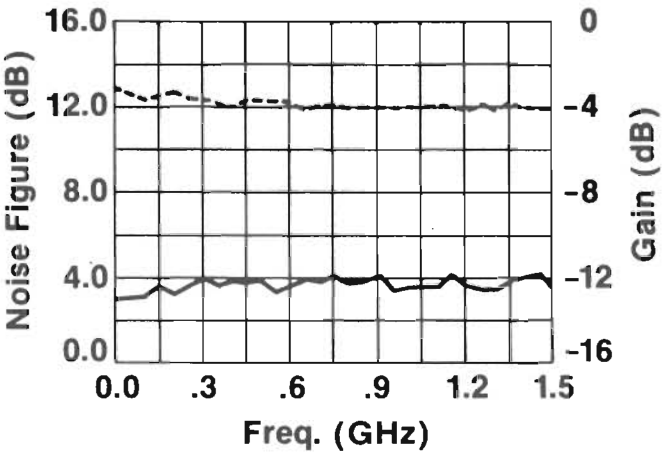
Illustrated here is a typical result from a mixer noise figure measurement. The measurement can be summarized as follows:

1) Set up 8970 (Select appropriate measurement mode, start & stop frequency for sweep, IF frequency, etc.)
2) Calibrate (Connect noise source to 8970 & push calibrate key)
3) Make Measurement (Connect noise source to mixer & push single sweep key)

Noise figure will be different for different IF's. Measure your mixer at the IF frequency at which it will be used. (The measurement illustrated is DSB.)

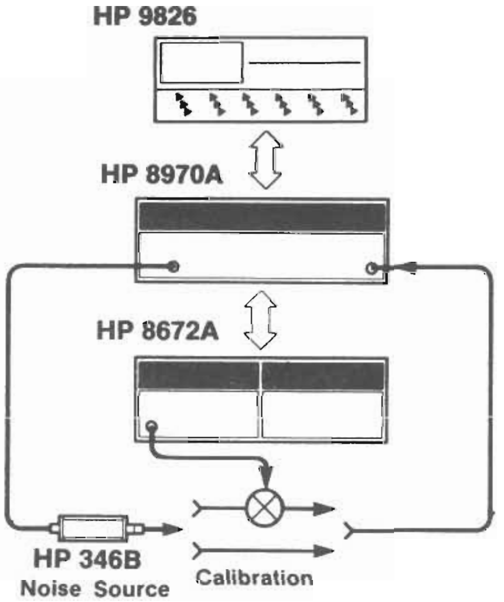
Mixer Noise Figure Measurement (Function of IF)

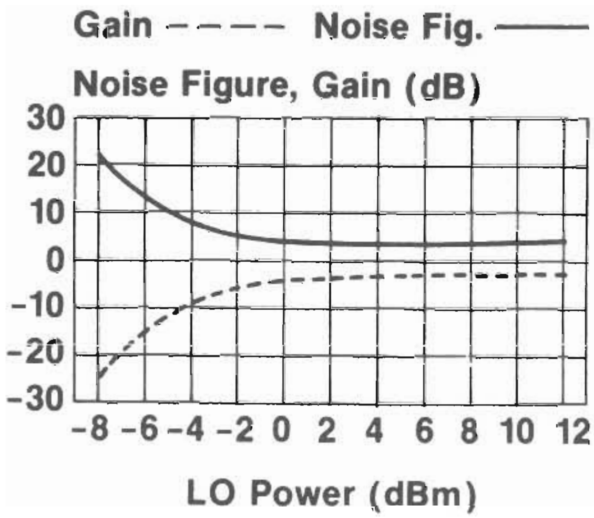




Here is an example of a typical swept IF noise figure measurement of a mixer. The three measurement steps are the same a the RF measurement (SET UP, CALIBRATE, MEASUREMENT) with a few changes in the SET UP step.

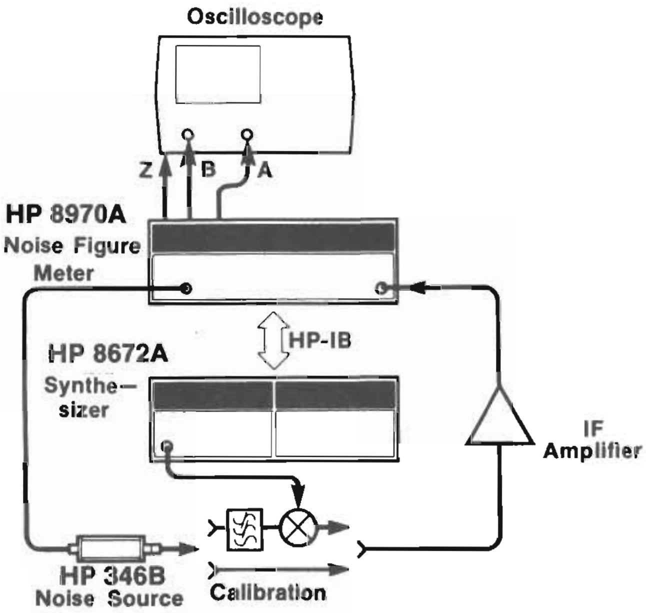
Noise Figure As A Function Of LO Power

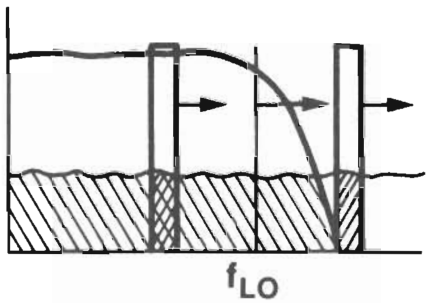




In order to find the LO power required for optimum noise figure or conversion loss, noise figure measurements can be made at specified LO and IF frequencies, the LO power varied and the results interpreted for optimum performance.

SSB Measurement
(Single Response Devices)





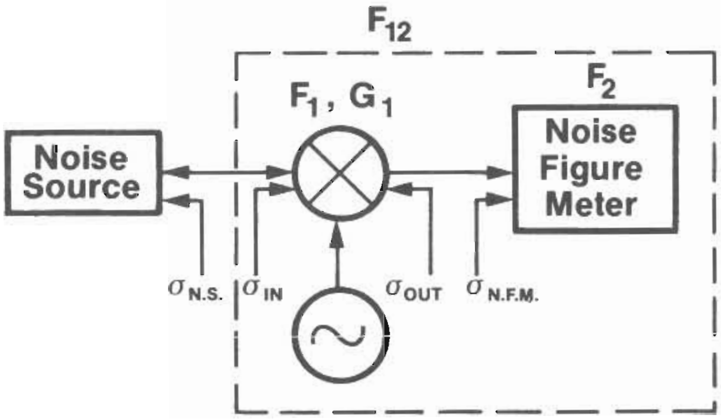
RF Measurement
(Swept LO, Fixed IF)

For SSB measurements with a preselection filter, a swept RF measurement range of no more than 2 IF can be made in order to keep the desired sideband in and the unwanted sideband out of the passband of the preselector. Due to filter skirts, the practical range is usually much less.

Accuracy

$$\Delta NF_1\,(dB) = \frac{F_{12}}{F_1}\,\Delta NF_{12}\,(dB) - \frac{F_2}{F_1 G_1}\,\Delta NF_2(dB) + \frac{F_2 - 1}{F_1 G_1}\,\Delta G_1\,(dB)$$

$$-\left(\frac{F_{12}}{F_1} - \frac{F_2 - 1}{F_1 G_1}\right)\Delta M\,(\sigma_{N.S.}\ \text{vs.}\ \sigma_{IN}) + \left(\frac{F_2}{F_1 G_1} - \frac{F_2 - 1}{F_1 G_1}\right)\Delta M\,(\sigma_{N.S.}\ \text{vs.}\ \sigma_{N.F.M.})$$



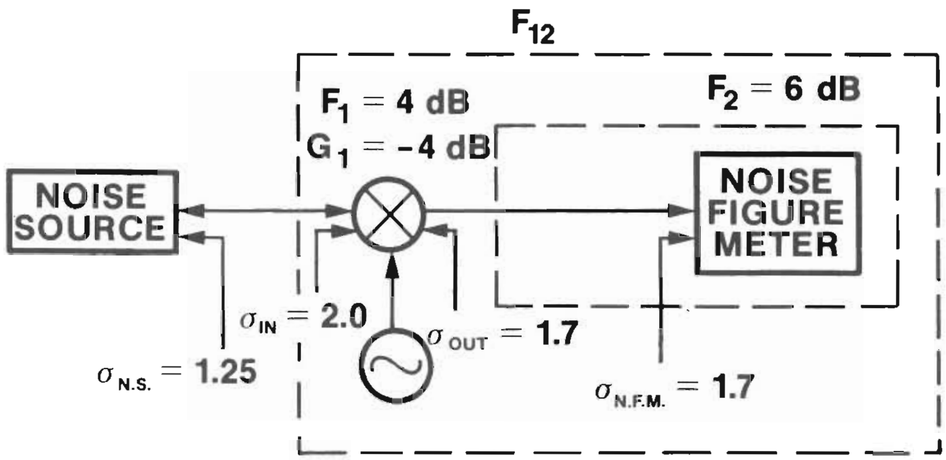
Total Noise Figure Uncertainty Is A Function Of F_1, G_1, And F_2

According to the noise figure uncertainty equation, overall noise figure uncertainty is dependent on F_1, G_1, and F_2. (F_{12} also depends on F_1, G_1, and F_2).

Accuracy Example

$$\Delta NF_1\,(dB) = \frac{F_{12}}{F_1}\,\Delta NF_{12}\,(dB) - \frac{F_2}{F_1 G_1}\,\Delta NF_2(dB) + \frac{F_2 - 1}{F_1 G_1}\,\Delta G_1\,(dB)$$

$$- \left(\frac{F_{12}}{F_1} - \frac{F_2 - 1}{F_1 G_1}\right)\Delta M\,(\sigma_{N.S.}\ \text{vs.}\ \sigma_{IN}) + \left(\frac{F_2}{F_1 G_1} - \frac{F_2 - 1}{F_1 G_1}\right)\Delta M\,(\sigma_{N.S.}\ \text{vs.}\ \sigma_{N.F.M.})$$



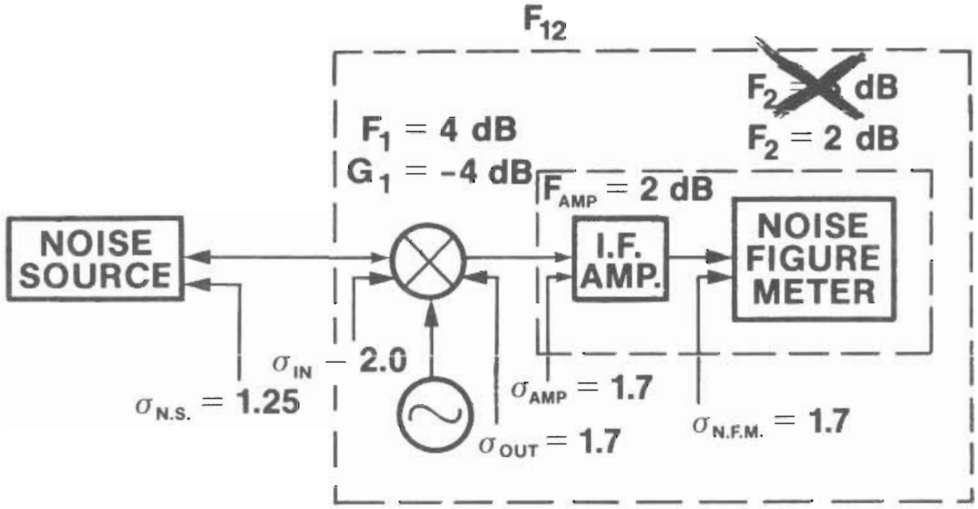
$\Delta NF_1\,(dB) = 2.02\ dB\ (RSS)$

Mixers, being low gain (G_1) devices, have a high uncertainty in measuring their noise figure (the lower G_1 is, the higher ΔNF_1 is) but....

Accuracy Example (cont.)

$$\Delta NF_1\,(dB) = \frac{F_{12}}{F_1}\,\Delta NF_{12}\,(dB) - \frac{F_2}{F_1 G_1}\,\Delta NF_2(dB) + \frac{F_2 - 1}{F_1 G_1}\,\Delta G_1\,(dB)$$

$$-\left(\frac{F_{12}}{F_1} - \frac{F_2 - 1}{F_1 G_1}\right)\Delta M(\sigma_{N.S.}\ \text{vs.}\ \sigma_{IN}) + \left(\frac{F_2}{F_1 G_1} - \frac{F_2 - 1}{F_1 G_1}\right)\Delta M(\sigma_{N.S.}\ \text{vs.}\ \sigma_{N.F.M.})$$



$\Delta NF_1 (dB) =$ [illegible] (RSS)

$\Delta NF_1 (dB) = 0.62$ dB (RSS) With Preamplifier

...by adding a high gain, low noise preamplifier to the measurement setup (reducing second stage noise figure), uncertainty can be reduced considerably.

If the mixer is to be used with an IF amplifier in the final system, uncertainty can be reduced by measuring the mixer/amplifier combination (the higher G_1 is, the lower ΔNF_1 is).