A NEW TECHNIQUE FOR NOISE FIGURE MEASUREMENTS OF MILLIMETRE-WAVE MIXERS

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ABSTRACT

A novel noise measurement method for mixers which exploits mixer noise figure variation with LO power is reported. The method allows for the first time high noise figures, e.g. at the maximum conversion gain point of millimetre wave mixers, to be found. With the technique proposed, noise figures as high as 20 dB can be accurately measured. The suggested method and its advantage over the conventional hot/cold noise measurement are demonstrated for a 65 GHz millimetre-wave GaAs MMIC down converter. For the mixer under test, the measured noise figures obtained were 9.3 dB with 7 dBm LO power and 15.1 dB with 13 dBm LO power, and the respective conversion gains were –1 dB (low noise point) and +3 dB (maximum conversion gain point).

THE PROBLEM OF MEASURING HIGH NOISE FIGURES

The noise specification for millimetre-wave mixers operated close to their point of maximum conversion gain often cannot be performed. In the literature, one finds publications which either do not state the noise figure at all (e.g. [1],[2], and [3]); or state it for a different LO power level than that which yields maximum conversion gain, e.g. [4]. This approach is of course of limited use in a practical situation.

The reason is that conventionally, the noise figure of the device under test is obtained by measuring two different output noise powers, P_1 and P_2, resulting from two different applied input noise temperatures, T_1 and T_0. The overall noise figure n_{Fmeas} can then be calculated according to [5] as

$$n_{Fmeas} = \frac{y \cdot \left(1 - \frac{T_1}{T_0}\right)}{y - 1}, \qquad \text{with } y = \frac{P_1}{P_2} \tag{1}$$

n_{Fmeas} again consists of the noise figure of the device under test, n_{F2}, and its RF and IF port embedding networks, n_{F1} and n_{F3}, Figure 1. The wanted mixer noise figure, n_{F2}, Figure 1, has to be de-embedded using Friis' formula for noise in cascaded networks [6]. Solving this equation for the mixer's noise figure, finally results in

$$n_{F2} = 1 + g_1 \cdot \left(n_{Fmeas} - \frac{n_{F3} - 1}{g_1 \cdot g_2} - n_{F1} \right) \tag{2}$$

where g_n is the gain of the n^th element of the network, Figure 1.

To show the impact of extraction of large noise figures, equation (1) is rearranged in terms of y, resulting in

$$y = \frac{-n_F}{1 - \frac{T_1}{T_0} - n_F} = \frac{-1}{\frac{1 - T_1/T_0}{n_F} - 1} \qquad \text{with } 0 < T_1/T_0 < 1 \tag{3}$$

It can be seen that, irrespective of the values of T_1 and T_0 used, for high noise figures the term n_F dominates and the power ratio y tends towards 1, i.e. the difference between the two measured noise power levels P_1 and P_2 becomes very small. As a consequence, the measurement error of the noise meter becomes dominant and may even completely mask the difference to be measured; hence measurements of the high noise figures normally associated with the maximum conversion gain point of millimetre-wave mixer are either very inaccurate or indeed impossible.

The overall noise figure n_{Fmeas} of the measurement set-up in Figure 1 was calculated using Friis' formula [6] to be 17.9 dB; this would result in a y factor of 1.006, equation (3). Hence, the difference in noise power output level between the hot and cold source for the measurement set-up used would just be 0.026 dB, while the jitter of the HP 8970 B noise power density meter used is specified to be 0.02 dB. Consequently, the limitations in short-term stability of the noise meter would mask the actual measurement results.

NOISE FIGURE ESTIMATION AT MAXIMUM CONVERSION GAIN

First we assume that the passive networks surrounding the mixer do not change their performance as a function of noise or LO power. The linear expression for the noise output power n_o is by definition [5]

$$n_o = n_{Fmeas} \cdot g \cdot n_i \tag{4}$$

where g is the gain and n_i is the input noise signal. By using equation (4) for each of the building blocks in Figure 1, and making use of the fact that the output signal n_o of each individual block is the input signal n_i of the following block, equation (5) can be derived for the measurement with low LO power (indicated by the index l). Here, $n_{o,l}$ is the overall output noise power measured by the noise meter, while n_i is the noise power created by the noise source.

$$n_{o,l} = n_{F3} \cdot g_3 \cdot n_{F2,l} \cdot g_{2,l} \cdot n_{F1} \cdot g_1 \cdot n_i \tag{5}$$

g_3 and g_1 are the resistive losses of the corresponding waveguide structures, and consequently smaller than 1. Building up a similar equation for the high conversion efficiency operating point (indicated by the index h), results in equation (6)

$$n_{o.h} = n_{o.l} \cdot f = n_{F3} \cdot g_3 \cdot n_{F2,h} \cdot g_{2,h} \cdot n_{F1} \cdot g_1 \cdot n_i \tag{6}$$

Here, f represents the increase in system noise floor due to the increased LO power. It is the noise power ratio for low noise and maximum conversion gain operation, and measured in the same manner as y. The advantage of using f rather than y is that f is normally several dB, while y is normally only a fraction of a dB, and hence, much more difficult to measure.

Next, equation (6) is divided by equation (5) and solved for the noise figure of the mixer at the high conversion gain operating point, $n_{F2,h}$:

$$n_{F2,h} = f \cdot n_{F2,l} \cdot \frac{g_{2,l}}{g_{2,h}} \tag{7}$$

This final formula allows us to accurately calculate the normally difficult or impossible to obtain noise figure of a mixer at the high conversion gain operating point using readily measurable conversion gain $g_{2,h}$ at this point, and the more easily measured mixer noise figure $n_{F2,l}$ and the conversion gain $g_{2,l}$ at a low noise operating point.

VALIDATION OF TECHNIQUE

Figure 1 shows the noise measurement set-up. The mixer is a Philips D01PH GaAs MMIC (RF = 65.5 GHz, LO = 64 GHz, IF = 1.5 GHz) probed on a Cascade Summit 12000 probe station with three GSG coplanar waveguide probes. The LO power level can be varied between 0 dBm and 20 dBm using a variable waveguide attenuator connected to the output port of an IMPATT LO signal source.

First, the noise figure was measured at a predicted operating point of the mixer, where a reasonable compromise between noise figure and conversion gain is expected from mixer theory. This operating point is defined by 7 dBm LO power, $V_{gs} = -0.7$ V, and $V_{ds} = 3$ V. A noise figure of approximately 9.3 dB was measured for the down converter at this operating point.

Next, a noise measurement with identical DC bias, but an increased LO power level of 13 dBm was carried out. These conditions result in an optimum mixer conversion gain of 3 dB, but result in the output noise power level being raised by 9.8 dB. On applying equation (7), the resulting noise figure for the mixer at its high conversion gain operating point was found to be 15.1 dB.

CONCLUSION

A novel noise measurement method for accurately measuring the high noise figures associated with millimetre-wave mixer circuits when operated for optimum conversion gain is presented. The new method circumvents accuracy problems experienced with the conventional method. Existing and new theories were implemented and compared for a noise figure measurement on a GaAs millimetre-wave MMIC down converter. Thereby the limitations of the conventional method, and the superiority of the new method presented here, which allows for the first time the measurement of noise figure in regions where high noise figure is to be expected, e.g. at the maximum conversion gain operating condition, were established.

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FIGURES

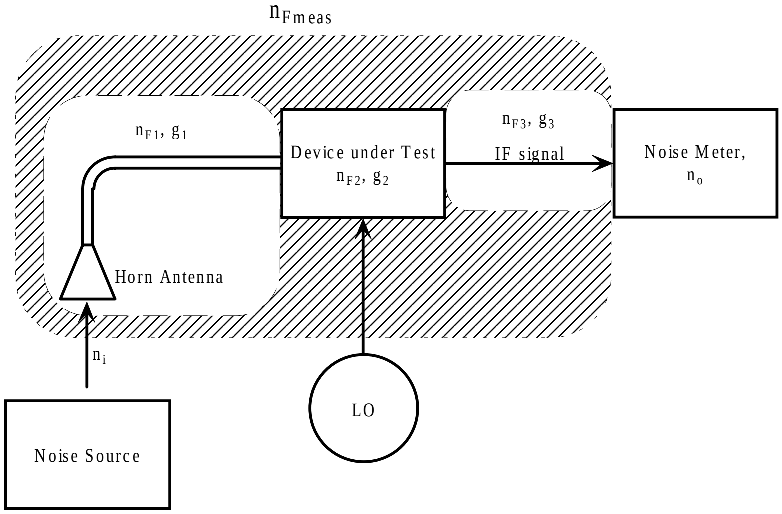

Figure 1: Measurement Set-up

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