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AN IMPROVED METHOD OF MIXER NOISE FIGURE MEASUREMENT AS APPLIED TO BEAM LEAD SCHOTTKY DIODES AT 94 GHZ.

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ABSTRACT

We present here an improved method of determining the intrinsic SSB mixer noise figure from noise measurements in single and "imperfect"balanced configurations. We describe the experimental set-up as applied to beam-lead Schottky diodes at 94GHz, and give results of NF, suppression factor and LO noise level.

INTRODUCTION

Noise figure measurement in the millimeter wave band is complicated by the significant contribution of the local oscillator AM noise. Usually,therefore, measurements are made in a balanced mixer configuration. This being an overall noise figure measurement, it is difficult to determine exactly the residual LO contribution because of the imbalance of the two mixers.

In order to characterize at 94 GHz new Schottky beam-lead diodes with an air bridge [1], recently fabricated at Thomson CSF, we have developed an original measurement method which, from noise figure measurements in single and balanced configurations, gives not only the intrinsic NF of the mixer diode under test, but also the AM noise suppression factor and the LO noise level ; furthermore, it allows an evaluation of the diode noise temperature ratio t_m.

MEASUREMENT THEORY

1. Overall measured noise figure of a single mixer.

The definition of the noise figure is

$$F=\frac{Si}{Ni}\cdot\frac{Nout}{Sout} \qquad (1)$$

Where Si and Ni are the signal and noise power at the input and Sout and Nout the signal and noise power at the output. The standard temperature adopted for determining noise figure is To=290°K, so the input noise power is

$$N_i= N_0= k\ To\ B \qquad (2)$$

where k is the Boltzmann constant and B the frequency bandwith.

Taking into account the noise temperature Tm of the mixer, the output noise power is

$$Nout= Nm=kTmB \qquad (3)$$

From the definition of the conversion loss of the mixer L, the output signal power is

$$Sout=Si/L \qquad (4)$$

Inserting (2), (3) and (4) into (1), we obtain the intrinsic noise figure

$$F_i=Lt_m\ ,\ \text{with}\ t_m=\frac{Tm}{To} \qquad (5)$$

In order to take into account the effect of the local oscillator AM noise on the noise figure measurement, we must calculate the overall noise power Nout, at the output of the mixer.

In this case, Nout is the sum of the noise power Nm generated by the mixer itself and the parasitic noise power Np due to the mixing of the fundamental power and the parasitic noise power N_{LO} existing at the signal frequency (Figure 1). Only the difference between N_{LO} and the noise floor NO is converted at the IF frequency and is divided by the conversion loss L , so the parasitic power is

$$N_P=\frac{NLO-NO}{L} \qquad (6)$$

and

$$N_{out}=N_m+\frac{NLO-NO}{L} \qquad (7)$$

Inserting (2), (4) and (7) in (1), we obtain

$$F_S=L.t_m+\left(\frac{NLO}{NO}-1\right) \qquad (8)$$

The noise figure measured in the single mixer configuration is the sum of the intrinsic noise figure given by (5) and a local oscillator AM noise dependent term. In order to suppress the large AM LO contribution, a balanced mixer configuration is commonly used.

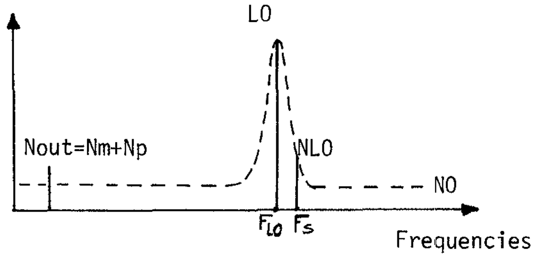

Figure 1

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2. Overall measured noise figure in a balanced mixer configuration.

To simplify the explanation of the principle of a perfect balanced mixer, we consider only the parasitic noise Np at the output of each mixer (Fig.2). At the input, the signal Si is divided into two equal parts. In the first branch, the signal is inverted before mixing. At the output of the mixer, the signal is -Si/2L, and the parasitic noise is Np. After a second inversion, the signal and noise become +Si/2L and - Np. In the other branch, at the output of the second mixer, the signal and noise are Si/2L and Np. Connecting the two branches together, the total signal output is Si/L, the total LO noise contribution is cancelled out ; thus the noise figure measured in a balanced mixer configuration is equal to the intrinsic noise figure of the mixer given by (5).

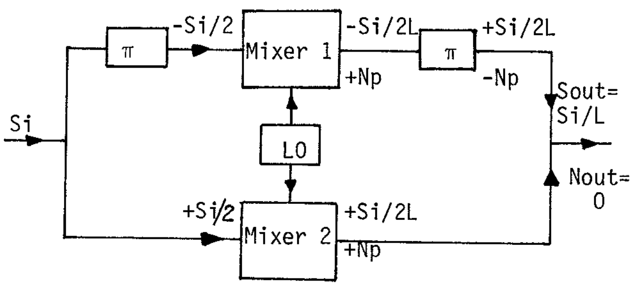

Figure 2

If the conversion losses, IF output impedances and noise temperatures of the two mixers are not identical, the total signal power at the output will depend on a contribution of the conversion losses and IF impedances of the two mixers ; the total noise power at the output will depend on the IF impedances and noise temperatures of the two mixers. So even in the case of a perfect local oscillator without AM noise, the overall noise figure measured will differ from the intrinsic one. For clarity we will first calculate the effect of asymmetry on the overall measured noise figure, first assuming a perfect LO, and then adding the effect of LO AM noise.

a) Effect of asymmetry with an ideal LO : At the output, the two mixers are connected in parallel, and the power is measured in the load R (input impedance of the IF amplifier. We will now calculate the total noise power and the total signal power available at the output of balanced mixer. Since the different noise powers are not correlated, in the case of impedance matching between the mixers and the load R, the total noise power available in R will be:

$$N_{out} = \frac{Nm1+Nm2}{2} \qquad (9)$$

If the noise temperatures of the two mixers are equal ($N_{m1}=N_{m2}$), the output power becomes :

$$N_{out} = N_m \qquad (10)$$

To calculate the total signal available in R, we take into account the conversion losses L_1 and L_2 of the two mixers. In this case, the powers available at the output of the two mixers are correlated. The equivalent circuit at the ouput of the mixers is shown Fig.3.

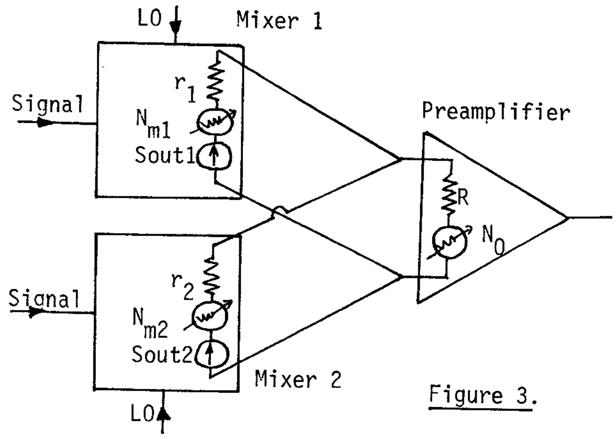

Figure 3.

Then, the total output power available in R is

$$S_{out} = \frac{V^2}{R} \qquad (11)$$

with $$V = \frac{R}{(Rr_1+Rr_2+r_1r_2)^2}\,(V_1r_1+V_2r_2) \qquad (12)$$

The maximum signal output power from mixer 1 is

$$S_{out1} = \frac{Si}{2L_1} = \frac{V_1^{\,2}}{4r_1}, \text{ so } V_1 = \left(2\,\frac{Sir_1}{L_1}\right)^{1/2} \qquad (13)$$

and for mixer 2 :

$$S_{out2} = \frac{Si}{2L_2} = \frac{V_2^{\,2}}{4r_2}, \text{ so } V_2 = \left(2\,\frac{Sir_2}{L_2}\right)^{1/2} \qquad (14)$$

Inserting (12), (13) and (14) into (11), we obtain:

$$S_{out} = \frac{2R\,Si}{(Rr_1+Rr_2+r_1r_2)^2}\left(\left(\frac{r_1}{L_1}\right)^{1/2} r_2 + \left(\frac{r_2}{L_2}\right)^{1/2} r_1\right)^2 \qquad (15)$$

If the output IF impedances of the two mixers are equal and matched with the load ($r_1=r_2=2R$), we obtain :

$$S_{out} = \frac{Si}{4}\left(\frac{1}{\sqrt{L_1}}+\frac{1}{\sqrt{L_2}}\right)^2 \qquad (16)$$

Combining (10) and (16) in the definition of the noise figure given by (1), we obtain the noise figure in the imperfect balanced configuration with a perfect LO.

$$F = L_1 t_m \frac{4}{\left(\sqrt{\frac{L_1}{L_2}}+1\right)^2} \qquad (17)$$

b) Effect of asymmetry with LO AM noise. In this case, we must take into account the local oscillator parasitic noise. At the output of each different mixer, the parasitic noise already given by (6) becomes :

$$N_{P1}=\frac{N_{LO}-N_0}{L_1}\ ; \qquad N_{P2}=\frac{N_{LO}-N_0}{L_2}$$

These parasitic noises being correlated together, the calculation previously made for the total signal output power can be applied. So, after replacing S_{out1} and S_{out2} by N_{P1} and N_{P2} in eq.(11) to (16), and taking account that these correlated noise signals are out of phase, the total power given with a perfect LO by (10) becomes :

$$N_{out}=N_m+(N_{LO}-N_0)\left(\sqrt{\frac{1}{L_1}}-\sqrt{\frac{1}{L_2}}\right)^2 \qquad (18)$$

Combining (16) and (18) in the definition of noise figure (1), we obtain the overall noise figure in the imperfect balanced configuration.

$$F_B=L_1 tm\frac{4}{\left[\sqrt{\frac{L_2}{L_1}}+1\right]^2}+2\left(\frac{N_{LO}}{N_0}-1\right)\left[\frac{\sqrt{\frac{L_2}{L_1}}-1}{\sqrt{\frac{L_2}{L_1}}+1}\right]^2 \qquad (19)$$

Given the predominance in the measurement error of the second term in (19), (that dealing with the LO AM noise power), (19) can then be rewritten as :

$$F_B=F_i+2\left(\frac{NLO}{NO}-1\right)S$$

Figure 4 shows F_B as a function of N_{LO} for several values of suppression factor S defined as :

$$S=\left(\frac{\sqrt{\frac{L2}{L1}}-1}{\sqrt{\frac{L2}{L1}}+1}\right)^2$$

In practice, the suppression factor and the local oscillator AM noise are not known ; the discrepancy between the intrinsic and measured noise figure in the balanced configuration may be significant. From the previous results, we have developed a measurement method which, from noise figure measurement in single and balanced configurations, gives not only the intrinsic noise figure of the mixer diode under test, but also the AM noise suppression factor, and the LO AM noise level.

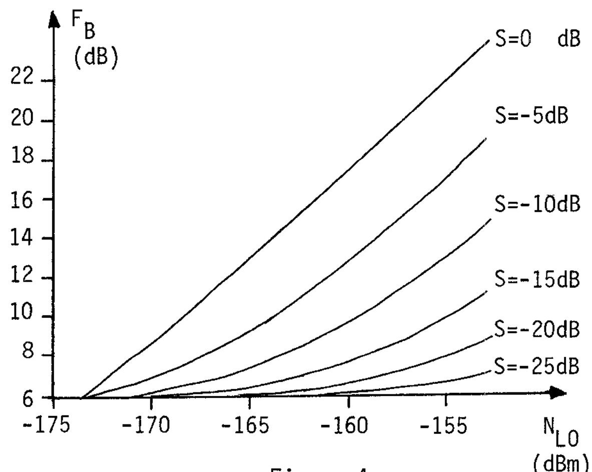

Figure 4

Overall noise figure as function of N_{LO} for several values of S, with F_i=6dB.

3. Improved method for intrinsic noise figure measurement.

The principal of our method is based on the fact that the suppression factor is independant of the LO AM noise level. So, for two LO with different AM noise levels, F_B will be equal to :

$$F_{B1}=F_i+2\left(\frac{N_{LO1}}{N_0}-1\right).\ S \qquad (20)$$

$$F_{B2}=F_i+2\left(\frac{N_{LO2}}{N_0}-1\right).\ S \qquad (21)$$

Disconnecting one of the two mixers, the unknown suppression factor S becomes equal to 1 (as in the single mixer configuration) and, using two LO with differing noise powers, equations (20) and (21) can be rewritten as :

$$F_{S1}=F_i+2\left(\frac{N_{LO1}}{N_0}-1\right) \qquad (22)$$

$$F_{S2}=F_i+2\left(\frac{N_{LO2}}{NO}-1\right) \qquad (23)$$

From (20), (21), (22) and (23) we obtain :

$$S=\frac{FB1-Fi}{FS1-Fi}=\frac{FB2-Fi}{FS2-Fi} \qquad (24)$$

and

$$F_i=\frac{FB1.FS2-FB2.FS1}{FS2+FB1-FS1-FB2}$$

Furthermore, having calculated Fi, we can calculate S from (24), N_{LO1} and N_{LO2} from (22) and (23).

The advantage of this original method is that, in order to measure the intrinsic noise figure of a mixer, it is unnecessary to know either the LO AM noise power, or any of the elements of the asymmetry of the branches of the balanced mixer.

EXPERIMENTAL SET-UP

The different noise figures are obtained from Y factor measurements [2]. In practice, we use a gas discharge tube in series with a ferrite modulator controlled by the automatic noise figure meter. The test set up (Fig.5) consists of a 3dB rat-race coupler and two single-ended mixers whose diodes are in opposite senses with respect to one another. The signal is divided into two equal parts which arrive in phase at the mixers, whilst the LO is divided into two parts which arrive out of phase at the mixers. The diodes are individually biased and individually RF power matched with the waveguide short-circuits. The IF outputs are extracted via SMA coaxial ports and connected in parallel. A WR 75 guide switch for the signal input and a coaxial switch for the IF output allow conversion loss measurements to be made under the same conditions and with the same adjustment (biasing, RF matching, LO level), as for mixer noise figure measurements.

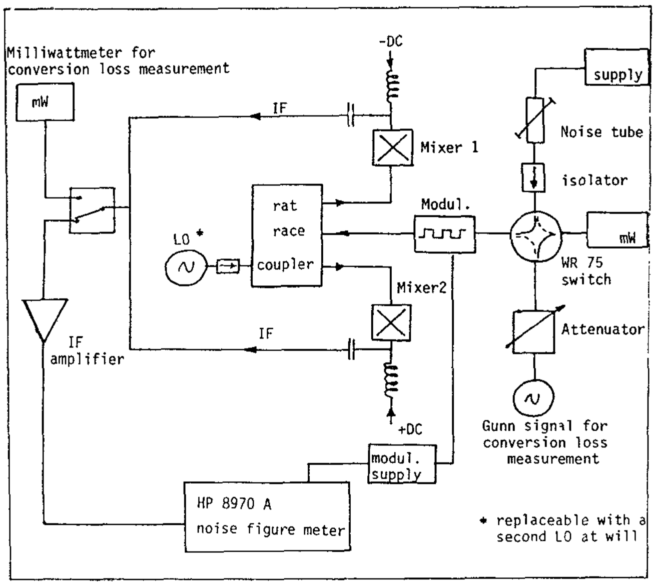

Figure 5

Each mixer consists of a WR 75 guide terminated in an adjustable short-circuit. The substrate, perpendicular to the waveguide, is fabricated from fused silica 0.12 in thick. The waveguide-to-microstrip transition consists of an electric probe inserted into the waveguide. A lowpass filter is required, to pass the IF frequency and reject LO and RF signals. The diode is biased through the IF port by a bias network. The DC return is obtained by a line of length $\lambda/4$ terminated in a short-circuit connected to the RF line.

RESULTS

Using this method, Schottky beam-lead diodes APX 377, recently fabricated at Thomson CSF, have been measured. Some examples of results obtained are given in table I.

Typically, we find a very good intrinsic noise figure of 7.2dB (SSB) including N_{IF}=1.2dB, and convertion loss of 6.0dB. There is therefore a very good correlation between the conversion loss and the noise figure of the mixer ; and thus the temperature t_m of the Schottky diode measured at 94GHz is close to 1. The comparison between the intrinsic noisefigure F_i and balanced noise figure measurements F_{B1} and F_{B2} shows the efficacy of our method, in imperfect balanced conditions.

	MEASUREMENTS (dB)					CALCULATIONS			
						(dB)		(dBm)	
Nb	F_{B1}	F_{S1}	F_{B2}	F_{S2}	L	Fi	S	B_{OL1}	B_{OL2}
1	6.5	16	6.7	20	6.3	6.4	-25	-161	-157
2	7.3	17	8.5	20.5	6.1	6.1	-16	-160	-157
3	9.0	17	10.9	20	5.9	5.9	-11	-160	-157
4	6.0	16.5	6.1	21	6.0	6.0	-30	-161	-156

Table I

CONCLUSION

After taking into account the effects of imperfect balance in the calculation of overall noise figure in balanced configuration, we have developed a method for the measurement of the intrinsic noise figure of the mixer diode in an imperfect balanced configuration. Applied to beam-lead Schottky diodes this method gives a good correlation between conversion loss and noise figure.

AKNOWLEDGEMENTS

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[1] K.MILLS,F.AZAN, "Glass reinforced GaAs beam-lead Schottky diode with airbridge for millimeter wavelengths", Elec.Lett, Sep 84, Vol 20 N°19, pp 787-788.

[2] HEWLETT-PACKARD Application Note 57-1 "Fundamentals of RF and Microwave Noise Figure Measurements".