NON-LINEAR MODELLING AND DESIGN OF MICROWAVE MIXERS

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ABSTRACT

A non-linear model of a Schottky diode has been developed which is suitable for application in microwave mixer circuits. The entire mixer circuit was analysed using a general non linear simulation computer program. The results of the measurements prove the validity of the diode model and the accuracy of the non-linear simulation.

I. NON LINEAR SCHOTTKY DIODE MODEL

The model used in this analysis is shown in Fig. 1, and is derived from the conventional model of the Schottky diode. In this model the junction capacitance of the diode is replaced by a linear capacitor C_{Jo} and a nonlinear voltage-controlled voltage source. The junction current source I_J is given as

$$I_J = I_o \, e^{\frac{qV_J}{nkT}} - 1 \qquad (1)$$

where I_o is the reverse saturation current, n is the ideality factor, and V_J is the voltage across the junction. According to [1] a nonlinear capacitor can be modelled as a linear capacitor in series with a nonlinear voltage-controlled voltage source. Using this technique, the voltage-charge relation of the junction capacitance can be written as:

$$V_J = \frac{Q}{C_{Jo}} - \frac{Q^2}{4V_T C_{Jo}^2} \qquad (2)$$

where C_{Jo} is the capacitance of the junction at zero volt, and V_T is V_{bi}-kT/q. The first term in Eq. 2 is the voltage across a linear capacitor, with a capacitance of C_{Jo}. The second term represents a voltage-controlled voltage source, which is controlled by the voltage across C_{Jo}. Hence, the nonlinear source can be written as

$$V_n = -\frac{V_{Co}^2}{4V_T} \qquad (3)$$

where V_{Co} is the voltage across the linear capacitor C_{Jo}. The series resistance R_S is normally constant. At high microwave frequencies its magnitude might increase due to the skin effect.

II. S-PARAMETER MEASUREMENT

The validity of the model was investigated by measuring the DC, and the S-parameters of an N-type Schottky diode. The diode was a chip type HP-5082-0023. To carry out the measurements, the diode was mounted at the end of a 50Ω line as shown in Fig. 2, and was fixed onto a jig.

From the DC measurement, we found that:

$I_o = 5.8\text{x}10^{-10}$A, n = 1.089, V_{bi} = 0.64V and R_s = 5.

The one-port S-parameters of the jig were measured for different bias points from 2 to 5 GHz. Using a special de-embedding technique, the S-parameters were peeled and the one-port S-parameters of the diode were derived. These measurements show that C_{Jo} is 0.15pf.

Using a piece-wise linear technique, the small signal S-parameters of the model were calculated at each bias point, for the same range of frequencies. The calculated and the measured S-parameters are plotted on Smith charts and are shown in Figures 3, 4, 5 and 6. These plots show that there is good agreement between the predicted and the measured S-parameters.

III. MIXER CIRCUIT SIMULATION AND MEASUREMENT

The balanced mixer circuit analysis is shown in Figure 7. The entire circuit was analysed using the non-linear program ANAMIC [2,4]. This is a general program developed at Kent which is able to analyse circuits with no limitation on topology or non-linearities. The initial output from the program is in the time domain and the results can be further processed to give output power, harmonic content, frequency response, impedance levels,.. etc. The relevant parameters in our case are the powers at I.F. and R.F. frequencies measured at the I.F. port.

Case A - Variable L.O. Power

The circuit shown in Figure 7 was analysed at L.O. power levels varying from 0 to 13 dBm. The L.O. and R.F. frequencies were kept at 5 and 4.9 GHz respectively to give an I.F. frequency of

100 MHz and an up-converted frequency of 9.9 GHz. The output at 100 MHz and 9.9 GHz was calculated for various I.F. power levels.

Examples of the initial time-domain results from ANAMIC are shown in Figures 8 and 9 for L.O. power of 0 dBm and 10 dBm respectively. In both cases the results show the voltage in the time-domain at the I.F. port. The results were further analysed using the FET to obtain the power of the 100 MHz and 9.9 GHz signals. The process was repeated at different power levels and the results of the simulation compared to measured values are shown in Figure 10. These results indicate that the measured and simulated values are in very close agreement which proves the validity of both the diode model and circuit simulation.

Case B - Variable L.O. and R.F. Frequencies (constant I.F. frequency)

The same procedure was repeated to obtain the variation of the conversion loss with L.O. frequency. The L.O. power was kept at 10 dBm and both the L.O. frequency and the R.F. frequency were varied to keep the I.F.frequency at 100 MHz. Figure 11 shows the results of the simulation and measurements. Again these results confirm the accuracy of the entire procedure.

Case C - Variable I.F. Frequency

In this case the L.O. power was kept at 10 dBm and the L.O. frequency at 5 GHz. The RF frequency was varied and the predicted and measured conversion loss values are shown in Figure 12.

IV. NOISE FIGURE MEASUREMENTS

The noise figure of the designed circuit was measured as a function of L.O. frequency and the results are shown in Figure 13. No simulation results are available.

V. CONCLUSIONS

A non-linear model for Schottky diodes has been developed and the model was used in the design of a microwave balanced mixer. The mixer circuit was first analysed using a general non-linear circuit simulation program. The results of the simulation and measurements are in very close agreement which indicates the validity of the diode model and the accuracy of the simulation program.

The designed mixer has a conversion loss of 6 dB and a noise figure of 6 dB.

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[4] M. I. Sobhy, A. K. Jastrzebski, R. S. Pengelly, J. Jenkins and J. Swift, "The design of microwave monolithic voltage controlled oscillators", 15th European Microwave Conference, pp. 925-930, September 1985.

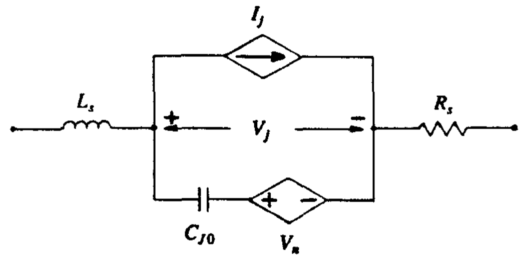


Fig-1 Equivalent model of the Schottky diode

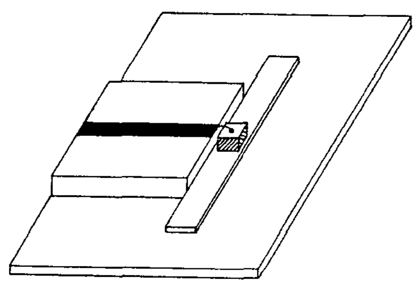
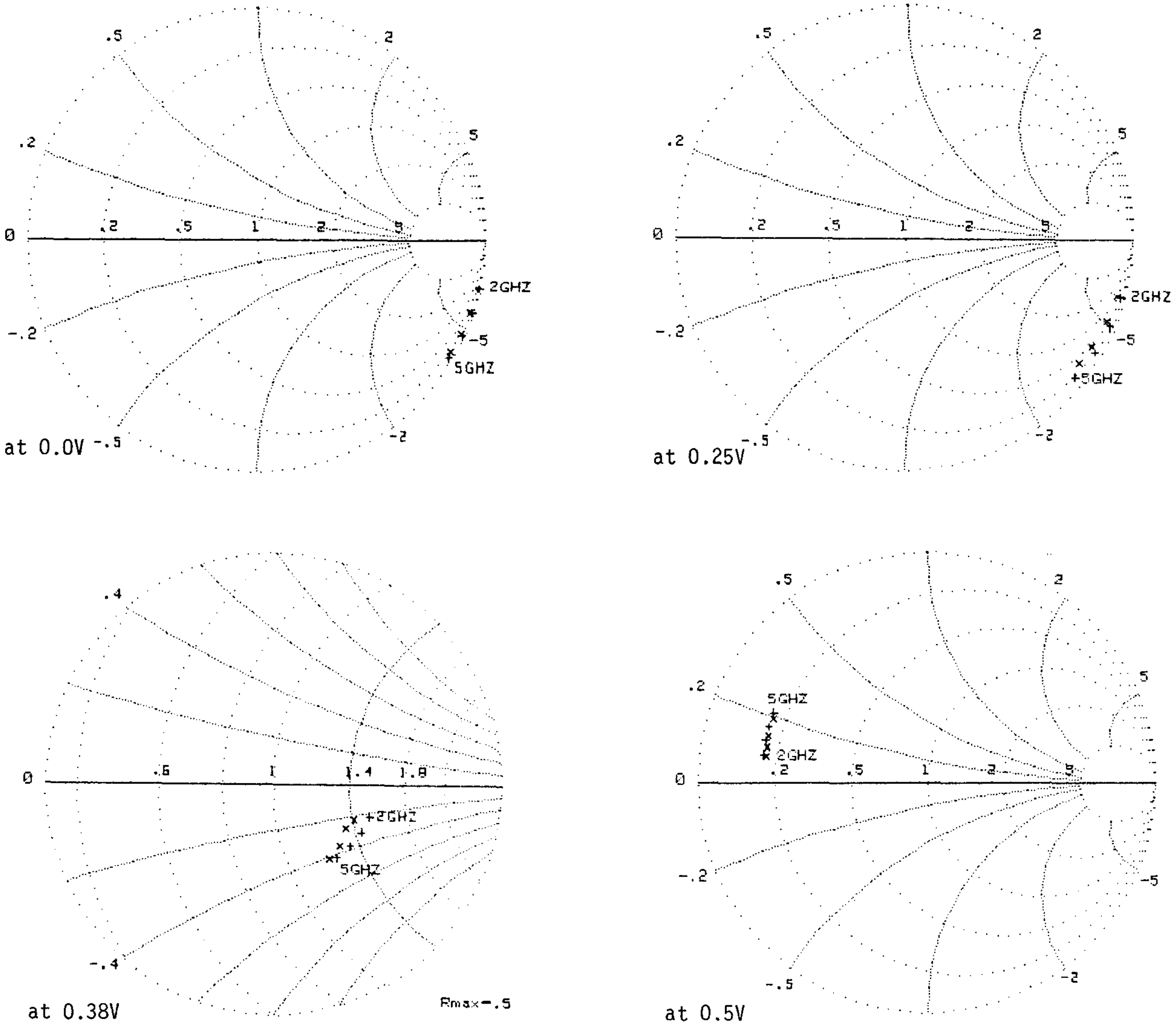


Fig-2 The carrier used to measure the parameters of the diode



Figs. 3-6 The S-parameters of the Schottky diode HP-5082-0023. The measured data x and predicted data +

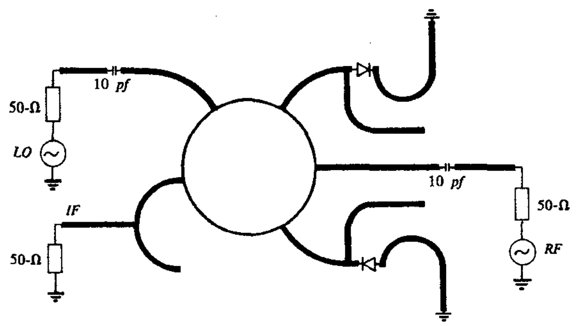


Fig. 7 5 GHz microstrip ratrace mixer

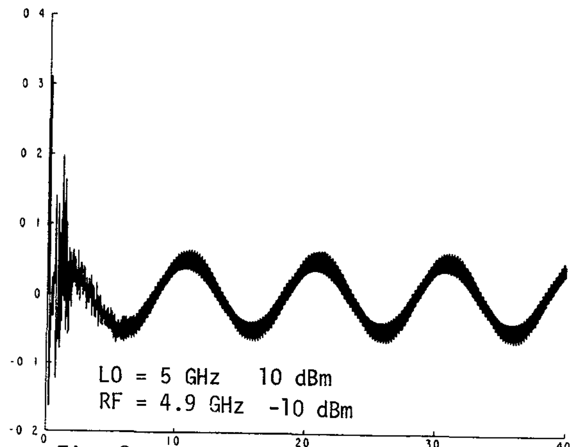


Fig. 8

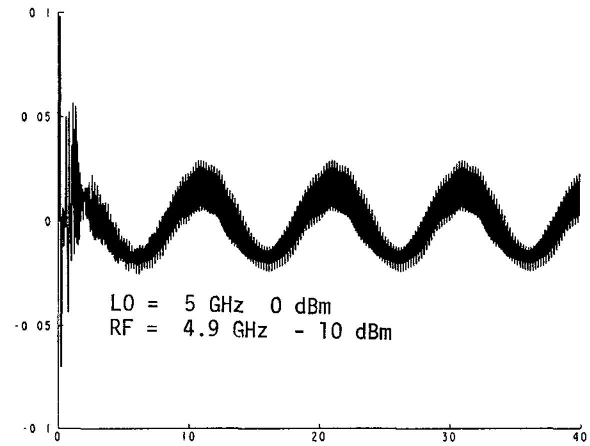


Fig. 9

Figs. 8 - 9: Voltage at the 50Ω load.

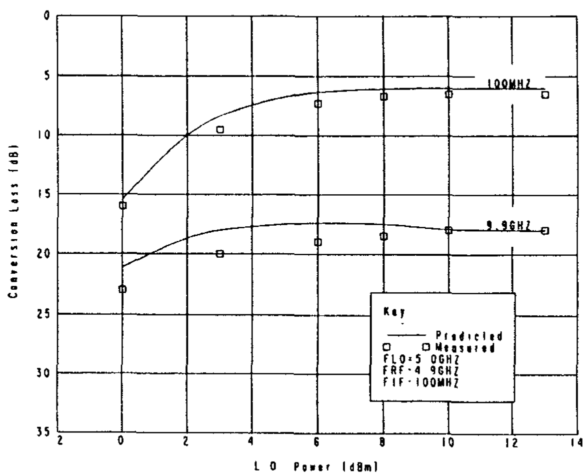


Fig-10 The predicted, and the measured conversion loss of the mixer for different power levels. Data are shown for 100 MHz IF and 9.9 GHz up-converted frequencies

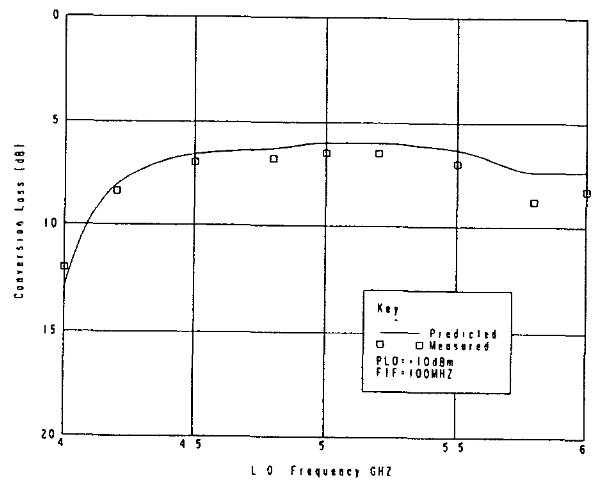


Fig-11 The predicted, and the measured conversion loss of the mixer for different LO frequencies.

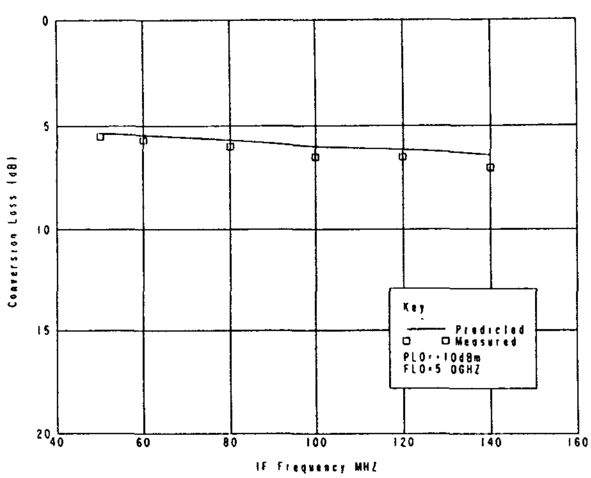


Fig-12 The predicted, and the measured conversion loss of the mixer for different IF frequencies.

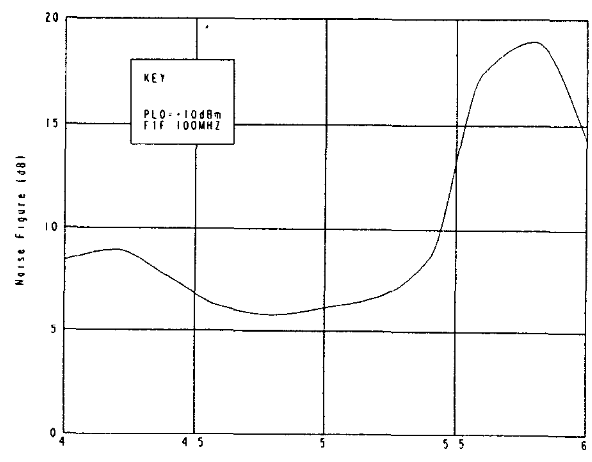


Fig-13 The measured noise figure of the mixer for different LO frequencies.