GUNN DIODE MODELLING THROUGH A NEW LOAD-PULL CHARACTERIZATION METHOD

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ABSTRACT :

This paper presents a very efficient Gunn diode circuit model whose components are determined by a new method of large signal characterization which requires much less power from the generator than classical techniques. This method can be exploited through one of the two measurement setups presented according to the power provided by the power supply. This technique will be particularly interesting at millimeter-waves. The model will allow global modelling of sources such as power combiners at these frequencies.

1- INTRODUCTION :

It is necessary to master the design of amplifiers or power sources at microwaves and millimeter-waves with as little regulation as possible. This design involves the characterization of active devices. Yet, this characterization is difficult because of very small optimum impedance loads for which active devices reach their highest added power.

To reach our aim in designing and making powerful sources at 80 GHz, we have to characterize the active components we use, namely Gunn diodes. This must be done with particular accuracy for power combiners. In the latter, Gunn diodes are connected in parallel and so, the higher the number of diodes, the smaller the loads charging the diodes. Consequently, the impedance to be synthesized must be known very precisely.

Diode characterization will lead to a reliable equivalent circuit which will be used in CAD simulation software.

To reach this large signal characterization, a new method of large signal measurement has been developed. Its principle relies on pre-matching the diode and was developed on the basis of what has already been done for transistors by Bouisse *et al* (1) and Nebus *et al* (2). This technique was designed so as to be used at millimeter wavelengths.

These results will allow global modelling at microwaves and millimeter-waves in the aim of studying synchronization for power combiners.

Firstly, we worked in the X band to make it easier and more accurate to define the determining elements of the method, the measurement setup and the model.

2- AIM OF THE GUNN DIODE CHARACTERIZATION :

Gunn diodes are the components which offer the best compromise between power and phase noise at millimeter-waves as shown by Eisele and Haddad in (3). Current electrical models of these devices do not give accurate results, especially as regards impedance. Numerical and electromagnetic modelling of these components have been proposed by Lakshminarayana and Partain (4) for instance, but they require both a long computation time and perfect knowledge of the exact structure of the diode (size and doping of the material layers).

The model proposed in this paper is given in figure 1. It was designed on the basis of previous work undertaken by Friscourt (5), taking into account physical considerations about each part of the component.

While static analysis leads to the determination of resistor and I(V) equation parameter values, the aim of large signal characterization is to enable us to know the capacity and inductance values not specified by the constructor.

3- LARGE SIGNAL CHARACTERIZATION METHOD :

The principle of pre-matching relies on connecting the diode to a power supply whose internal impedance is close to the optimum load impedance of the Gunn diode. In such conditions, the optimum working point (i. e. the point for which the added power, P_{ad}, of the diode is maximum) is reached with less power from the generator (P_s) than without pre-matching. This is particularly important at millimeter-waves.
Figures 2 and 3 give the ideal (lossless) block diagrams of the measurement setup with and without pre-matching. The following equations ((1) and (2)) give the expressions of P_{ad} for each one of these setups to which we added the losses through the α coefficient (the meaning of each parameter is made clear by the figures).

$$P_{ad}=(|\rho_a|^2-1)|\alpha^2 T_1{}^2|P_s \quad (1)$$

$$P_{ad}=\left|\frac{C_2 T_1 \alpha}{1-\rho_a \alpha^2 T_1^2 T_2^2 \Gamma_{sc}}\right|^2 \left(|\rho_a|^2-1\right) P_s \quad (2)$$

With equation (1) of the classical method, we can see that the closer the optimum impedance is to the Smith chart edge, the higher P_s has to be in order to reach the maximum of P_{ad} (P_{admax}).
It is much harder to find such an easy conclusion with equation (2) of the method with pre-matching. Thus, let us define R as the ratio of equation (2) divided by equation (1) as stated in equation (3) :

$$R=\left|\frac{C_2}{1-\rho_a \alpha^2 T_1^2 T_2^2 \Gamma_{sc}}\right|^2 \quad (3)$$

Since we want R > 1, we have to find whether there is a sliding short-circuit position such that Max(R) > 1 :

$$\left|\frac{C_2}{1-|\rho_a \alpha^2 T_1^2 T_2^2 \Gamma_{sc}|}\right|^2 > 1 \quad (4)$$

This condition depends directly on the following circuit parameters :
- coupling coefficients (C_1 and C_2) ;
- losses (α).

We also studied the effects of $|C_2|$ and $|\alpha|$ on R for two cases :
- firstly, with an ideal coupler ;
- then with a real coupler that we used to demonstrate the validity of the measurement principle.

The curves of figures 4 and 5 give the results of these studies (for each one, we took ρ_a=1.4, as measured approximately at P_{admax}).
According to this analytical study, we are able to conclude that :
- there is an optimum position of the short circuit for which P_{admax} is reached with a minimal P_s ;
- there is an optimum value of the coupling coefficient C_2 for which P_{admax} is reached with a minimal P_s ;
- circuit losses (especially between the power supply and the measurement coupler) and C_1 have to be reduced.

We finally simulated these two measurement circuits with the *HP-MDS* CAD software. We can see the curves in figure 6 and notice that, at 10 GHz, P_{admax} is reached with about 2 dB less with the pre-matching circuit than with the classical one. This result confirms these obtained with the analytical study and clearly shows the advantages of the proposed method.

4- GUNN DIODE MODELLING AND EXPERIMENTAL RESULTS :

With the static measurement and the large signal characterization of the diode, it is possible to determine the values of all the parameters and elements of the Gunn model presented, particularly those of the I(V) relation which must take into account :

- the Gunn effect which gives the component its ability to be " active " between two DC voltages : V_0, V_{th} ;
- the Schottky effect which becomes preponderant when the DC voltage overcomes V_{th} and makes the diode resistive (as shown by Sobhy et al in (6)).

Equation (5) gives the relation between I and V which we established taking into account the previous remarks :

$$I = I_0 \times \exp\left(-a \times |V| \right) \times \tanh\left(b \times |V| + c \times |V|^3 \right) + d \times l^{((|V| - V_h)/m} \qquad (5)$$

In this equation, I_0, a, b, c, d, l, V_h and m are the parameters which have to be determined thanks to static and large signal measurements.

This characterization led to a very good correlation between simulation and measurements as can be seen in figures 7 and 8. The diode is an MA49157 working in the X band.

The small differences can be explained by :

- the temperature effect, since the diode was not " thermostatted " ;
- the harmonic components of the working frequency, for which the circuit was matched in simulation but not for measurements.

Results of the characterization with and without pre-matching are given in figure 9. Although the advantage of pre-matching is shown, the latter is partly reduced, on the one hand, by the non-optimum value of the coupling coefficient C_2, and, on the other hand, by circuit losses. Since this problem will be critical at millimeter wavelengths, a third and innovating configuration of the measurement setup is proposed. It uses a second mobile short-circuit in the exact position of the matching load of coupler 2, as shown in figure 10. Such a measurement setup was simulated with the previously presented Gunn model and very good results were obtained : the generator power necessary to reach P_{admax} was less than half that required with the pre-matching configuration of figure 2 as can be seen in figure 11.

5- CONCLUSION AND FUTURE PROSPECTS :

We have demonstrated the validity of Gunn diode characterization with a pre-matching method which makes it possible to reduce the generator power required to reach the maximum added power of the device. This will be particularly useful at millimeter-waves, especially due to the cost and availability of such sources or amplifiers. We developed a cell for diode connection in a circuit to characterize two-port active devices at millimeter wavelengths. So as to minimize losses, we are studying the development of an " integrated " measurement setup eliminating most of the connections. These developments will be presented during the conference.

Regarding modelling, we succeeded in developing an efficient Gunn diode model. It will allow the global simulation of the power combiner in the E band on which we are currently working, and consequently enable us to master the design of the latter.

REFERENCES :

(1) P. Bouysse et al, *A Novel, Accurate Load-Pull Setup Allowing the Characterization of Highly Mismatched Power Transistors*, February 1994, IEEE-Transactions on MTT, Vol. 42, pp.327-332.

(2) J.-M. Nebus et al, *Improvement of the Active Load-Pull Technique for the Optimization of High Power Communication SSPAs*, 1995, International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering, Vol. 5, N° 3, pp. 149-160.

(3) H. Eisele et Haddad, *High-Performance InP Gunn Devices for Fundamental-Mode Operation in D-Band (110-170 GHz)*, November 1995, IEEE-Microwave and Guided Wave Letters, pp.385-387.

(4) M. R. Lakshminarayana and Partain, *Numerical Simulation and Measurement of Gunn Device Dynamic Microwave Characteritics*, March 1980, IEEE-Transactions on Electron Devices, pp.546-552.

(5) M.-R. Friscourt, *Etude des Dispositifs à Transfert Electronique Pour la Génération de Puissance en Gamme Millimétrique*, 1985, Ph.D., University of Sciences and Techniques of Lille.

(6) M. I. Sobhy et al, *Chaotic Behaviour of Gunn Oscillators*, EMC September 1991, pp. 190-196

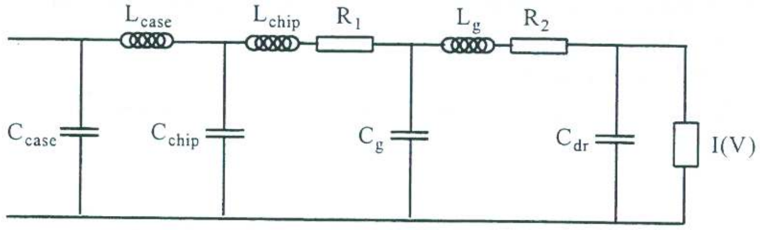

Figure 1 : Gunn diode circuit model

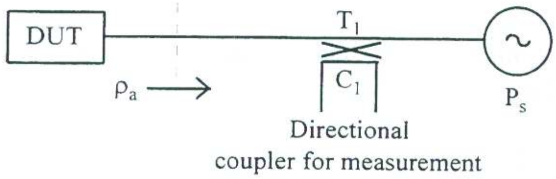

Figure 2 : Block diagram of the setup for the classical method

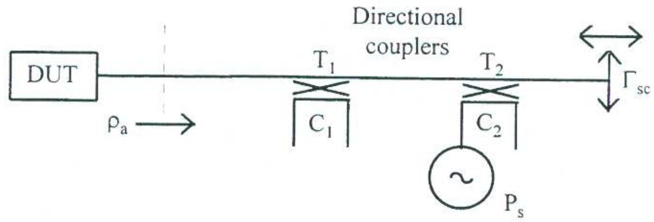

Figure 3 : Block diagram of the setup for the new method

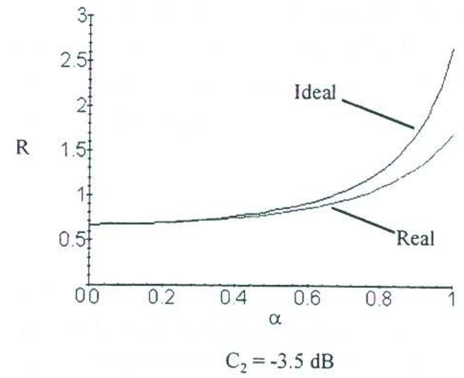

Figure 4 : Variation of the gain facteur R with losses

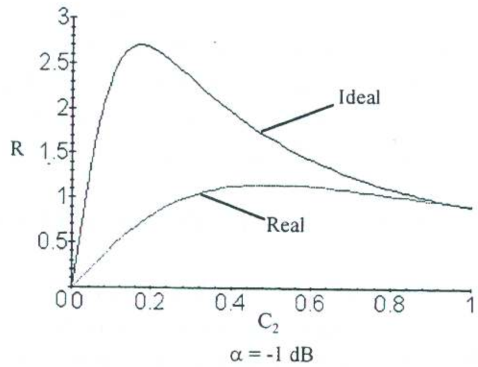

Figure 5 : Variation of the gain facteur R with the coupling coefficient

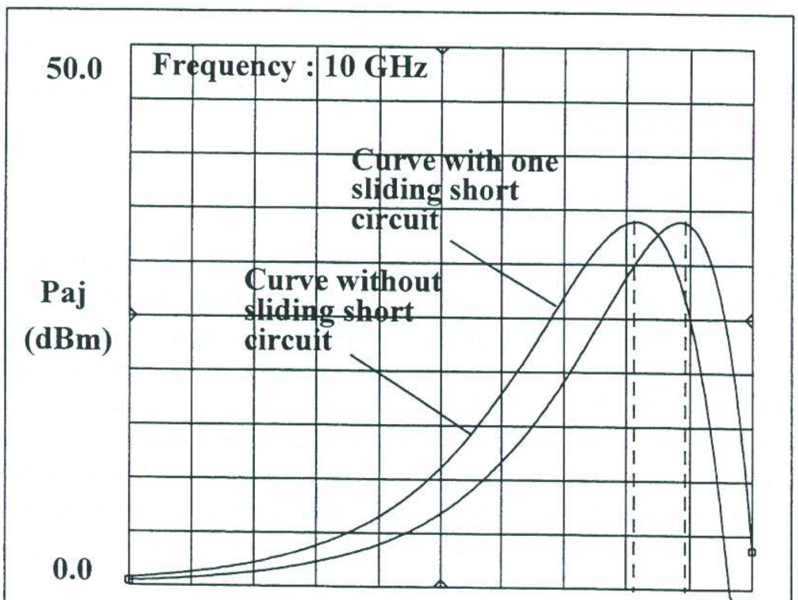

Figure 6 : Comparison between large signal characterization with and without sliding short circuit

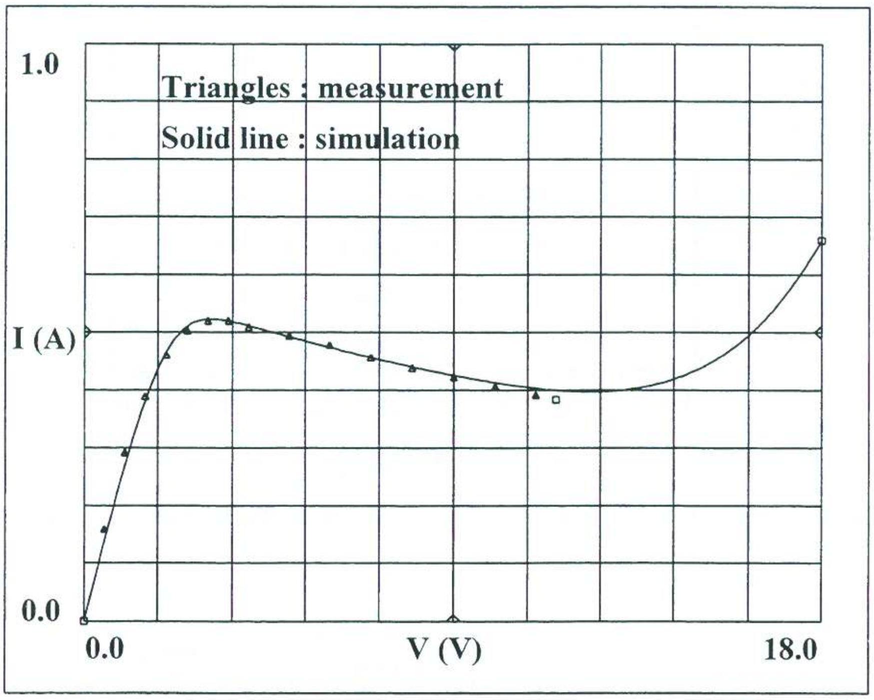

Figure 7 : Comparison between static measurement and simulation

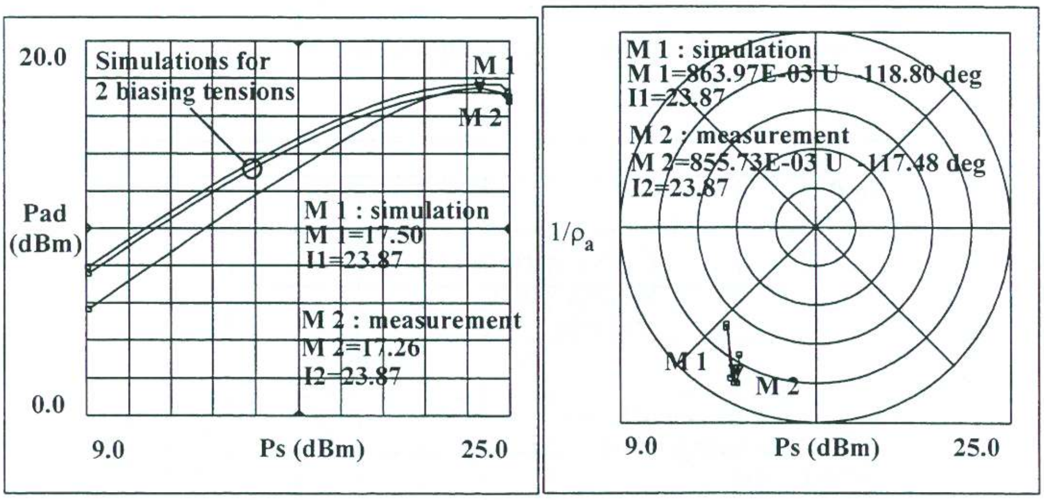

Figure 8 : Measurement and modelling results of the Gunn diode

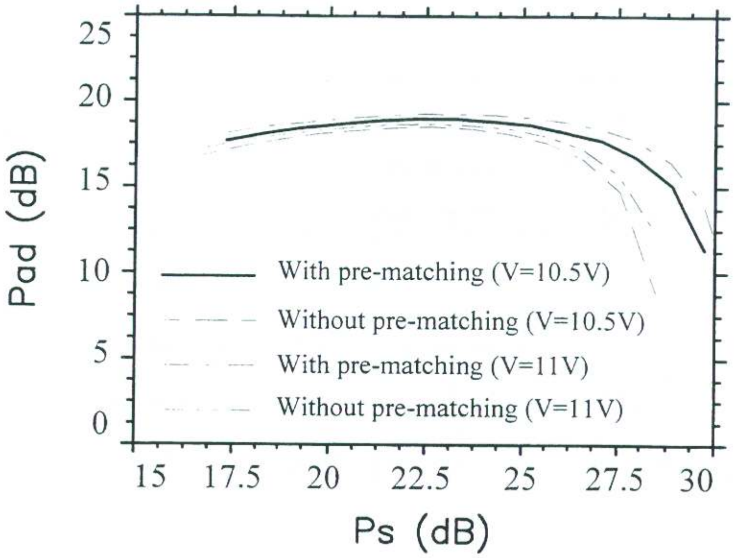

Figure 9 : Curves of $P_{ad}(P_s)$ for two bias voltages with and without pre-matching

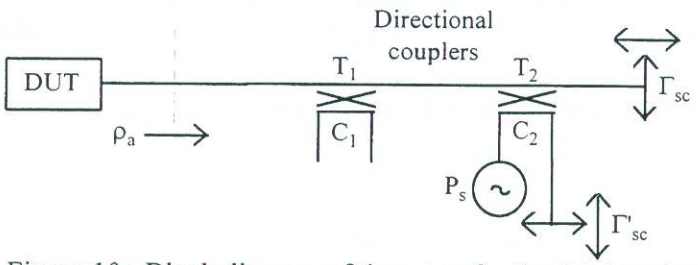

Figure 10 : Block diagram of the setup for the third method

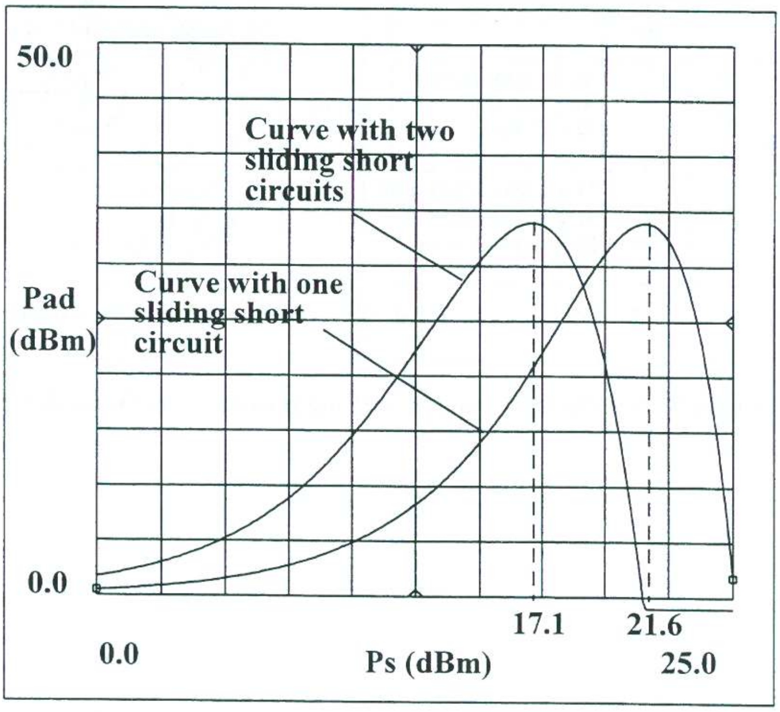

Figure 11 : Comparison between the necessary power from the generator for setups with one and two sliding short circuits