MEASUREMENT OF THE LARGE SIGNAL CHARACTERISTICS OF MICROWAVE SOLID STATE DEVICES USING AN INJECTION LOCKING TECHNIQUE

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Abstract

The device under test is operated as an injection-locked oscillator. The dynamic conductance and susceptance of the device are obtained from the phase and amplitude response of the system.

Introduction

Solid-state devices used for the generation and subsequent amplification of power at microwave frequencies are usually operated under large signal conditions, in order that reasonable power outputs may be achieved. The proper design of the circuits associated with such a device requires that the large signal device parameters be known.

Conventional test equipments, such as network analysers may be used to make large signal measurements, however,with certain diode types, particularly the transferred electron type, it may be difficult to suppress oscillation while making the measurement.

The injection-locking technique proposed allows the diode to be operated in a cavity under typical operating conditions, while the measurements are carried out.

Theory

Fig.1. shows a typical injection-locking system with the locking and output signals separated by a circulator. The conditions for locking in such a system have been considered by Quine[1] who used the equivalent circuit of Fig.2. Here the active device is represented by a voltage dependent conductance in parallel with a fixed susceptance due to Co. The cavity and its coupling system are represented by the inductance and transformer. When locking occurs only one frequency can exist and thus the impedance presented to the load by the diode and cavity via the coupling system must satisfy the normal transmission line voltage equations. The admittance presented by the diode and its resonant circuit must satisfy the equation

$$G_{IN} + jB_{IN} = \frac{G_0}{n^2}\left[\frac{1-a^2}{1+a^2+2a\cos\theta}\right] + j\frac{G_0}{n^2}\left[\frac{2a\sin\theta}{1+a^2+2a\cos\theta}\right]$$

taking the imaginary part of this equation and assuming $\omega \approx \omega o$ (so that a simplified expression may be used for the change of susceptance with frequency) yields[2]

$$\frac{G_0}{n^2}\left[\frac{2a\sin\theta}{1+a^2+2a\cos\theta}\right] = -2\omega_o \frac{C_o\Delta\omega}{\omega_o}$$

where $\Delta\omega = \omega_L - \omega_o = 2(F_L - F_0)\pi$

In most conventional injection locking systems, the locking power is very small compared with the free running output power and hence a $\ll$ 1.0. Quine uses this assumption to obtain the expression

$$\theta \simeq \sin^{-1}\left[-Q\frac{\Delta\omega}{\omega_o}\cdot\frac{1}{a}\right] \quad (3)$$

where $Q = \frac{\omega_o C_o n^2}{G_o}$

which is very similar to that obtained by Adler[3] for a feedback oscillator. In this case, 'a' may take values up to unity (locking signal power = output power) and an exact solution then yields[2]

$$\theta = \sin^{-1}\left[\frac{K}{\sqrt{1+K^2}}\cdot\frac{1}{a}\right] + \sin^{-1}\left[\frac{K}{\sqrt{1+K^2}}\right]$$

where $K = \frac{2C_o n^2\Delta\omega}{G_o}$

$= 2.Q.\frac{\Delta\omega}{\omega_o}$

The curves of θ against 'a' can be more conveniently expressed as versus power gain in dB, and for the large signal case, take the form shown in Fig.3. The small signal curves are similar but the maximum value of θ is restricted to ±90. For both large and small signals the theoretical curves are symmetrical and their shape is independent of the sign of ΔF.

The r.f. voltage across the diode terminals will increase, as the magnitude of the locking signal is increased from a low value until, in the limit, when the locking gain becomes zero, the diode presents zero conductance to the circuit and contributes no power to the output. Observations of the oscillator output power as the locking power is being varied, and also the phase and gain of the system enables the relative change in r.f. voltage across the device to be evaluated. The change in the diode conductance may be found from the real part of Eq(1).

In practice, the change in the r.f.voltage across the diode also produces a change in the diode susceptance. The change in the total circuit susceptance (that of diode +

cavity) may be found from the imaginary part of Eq(1).

The result of the susceptance change is to make the large signal phase-gain curves highly assymetrical. This assymetry is noticeable even in most small-signal locking experiments.

Measurement techniques

Measurements are made using the equipment shown in Fig.4. A circulator is used to separate the locking and output signals, and a network analyser is used to compare their amplitudes and phases. The locking power is varied and the power output of the system together with the phase-amplitude characteristics recorded. This is repeated for a number of locking frequencies close to the natural frequency of the oscillator. The measured values are substituted into Equation (1) to give the normalised conductances (or susceptances) as a function of normalised R.F. voltage.

The normalising factor for each parameter is the relevant free-running value. The information may be put in absolute terms if one point on the normalised graph is fixed. In the present case the diode conductance and susceptance are measured for the oscillator. in the free-running condition. The oscillator cavity is made with a detachable diode mount which takes the form of a precision 7 mm connector.

The diode under test is located at the mating plane of the connector and the admittance measured at this point, looking into the cavity is the complex-conjugate of the free-running admittance of the diode.

This method of diode characterisation may be automated to a reasonable degree. A data-logger is used to record the information which is then processed by a simple computer program to give directly plots of diode conductance and susceptance as functions of R.F. voltage swing.

Results

Typical results obtained for both Gunn and Impatt diodes are shown in Figs. 5 and 6.

The Gunn diode was operated at 9.2 GHz and the coupling to the diode was adjusted for the maximum power output of 25mw. The results refer to the semiconductor chip having been corrected for the effects of the package using the model due to Owens and Cawsey.

The Impatt diode is a commercial low power device capable of an output of some 100 mW in X-band. The results shown are for an output of 30 mw at 8.3 GHz and include the effect of the package.

Fig.7. shows the effect on the normalised conductance of a Gunn diode produced by a change in the D.C. bias to the device. The general trend is similar to that predicted theoretically.

The accuracy of this method of diode characterisation is affected by several factors, the more important being

.Inaccuracies in the measurement of the free-running diode admittance. These are due to the physical disturbance of the cavity, required to make the measurement, and to the subsequent alteration of the electric field near the diode site.

.Errors in the relative measurement of conductance against voltage (and susceptance against voltage). These are mainly due to difficulty in estimating a line of symmetry, for the phase-gain curves, which is required for the 0^{o} phase reference.

.Changes produced in the voltage and current wave-forms at the diode, due to the presence of the large locking signal.

.The distributed nature of the coupling circuit between the diode and the load. The coupling ratio is dependent on the actual diode admittance and not fixed at the free-running value.

The overall measurement accuracy is estimated to be better than $\pm$ 20%

Conclusions

This method of device characterisation has several advantages over other methods.

The device under test is operated as an oscillator near its normal working point.This eliminates problems of device stabilisation which is encountered with some other methods. The method is relatively fast and amenable to automation.

A limitation of the method is that results can only be obtained over a restricted range of diode R.F. voltage. However,this range is in the region in which the diode is usually operated.

Acknowledgments

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References

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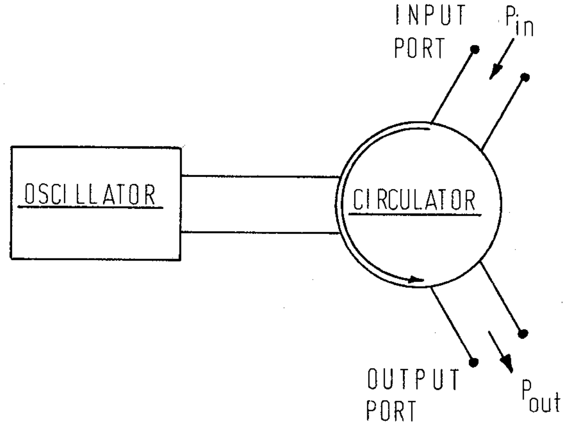

F_0 = Free-running frequency of oscillator

F_L = Frequency of locking signal

$\Delta F = F_L - F_0$ Gain = $\frac{P_{out}}{P_{in}}$

Fig.1. Injection locking circuit

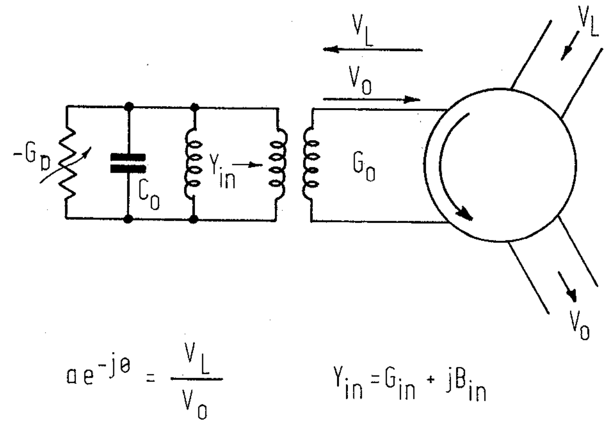

Fig.2. Quine equivalent circuit.

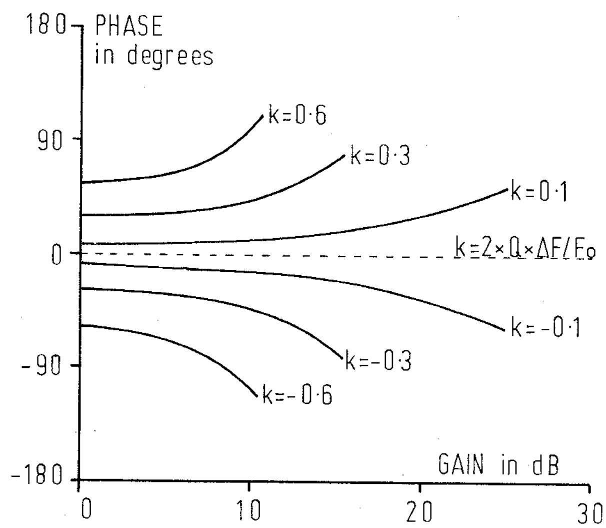

Fig.3. Theoretical phase-gain curves

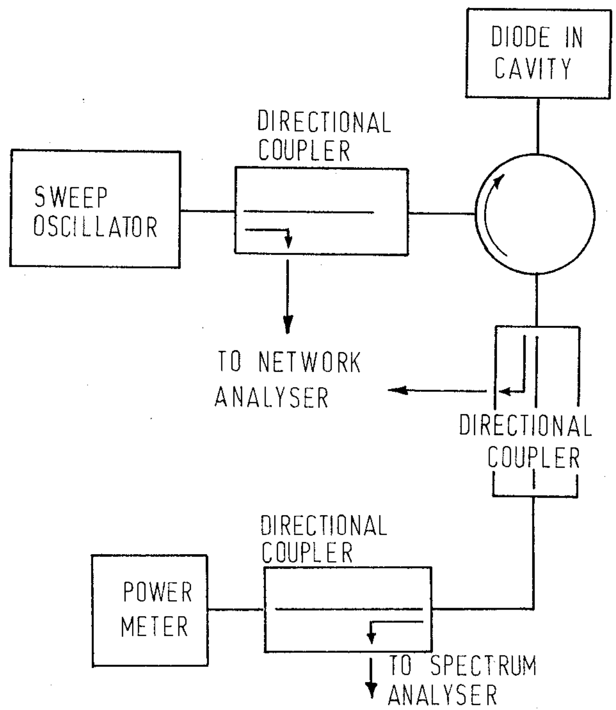

Fig.4. Block diagram of test circuit.

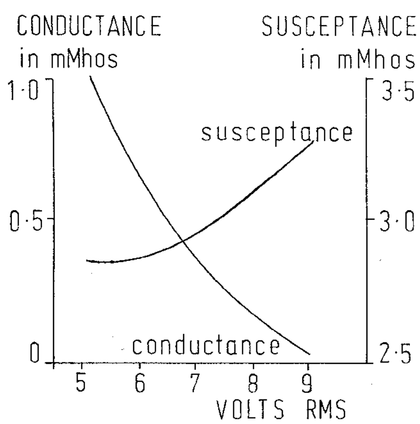

Fig.5. Gunn diode results

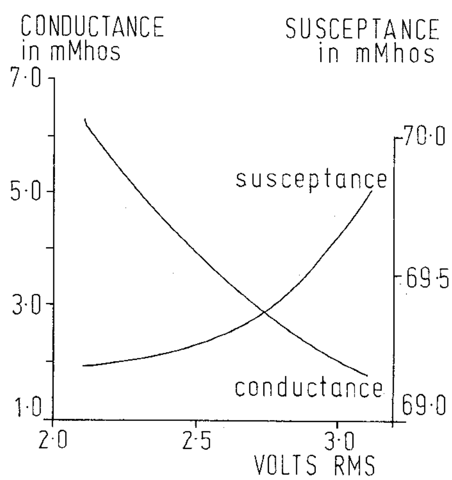

Fig.6. Impatt diode results

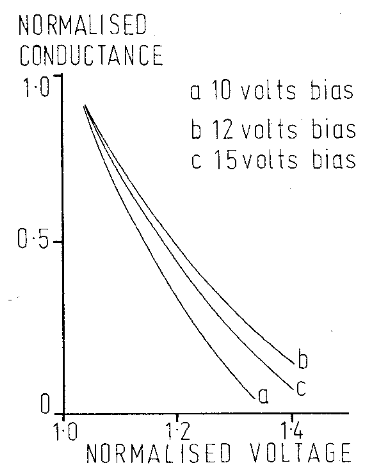

Fig.7.7. Gunn diode results