CHARACTERIZATION OF PACKAGED VARACTOR DIODES*

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Summary

A method is presented for determining true junction capacitance and resistance, and all package equivalent circuit element values of varactor diodes from measurements of total capacitance and microwave impedance with bias.

Introduction

This paper describes an advanced technique for evaluating the equivalent circuit element values of packaged varactor diodes.

All package and junction equivalent circuit elements are determined from low-frequency capacitance and microwave-frequency impedance measurements made only on the diode under evaluation. The total effect of the diode mount and the measuring circuit is eliminated by determining the transformation[1] between the measuring port and the packaged diode terminal surface. Package loss is accommodated by conductance in parallel with the package capacitance. True junction capacitance is separated from all other capacitances. The evaluation program is capable of testing for that type of junction resistance variation predicted for abrupt-junction varactors. Both fixed and variable parts of junction resistance can be determined.

Diode Circuit Model

A typical encapsulated microwave diode shown in Fig. 1(a) has an equivalent lumped circuit of Fig. 1(b). The overall configuration of the diode junction, its package, and the measuring circuit is modeled by the block diagram of Fig. 2. The networks are defined by the complex transformation constants which are the ordinary ABCD matrices of passive, linear, two-port networks.

The junction capacitance measured at a low frequency includes a constant error, C_X. The model is altered to that shown in Fig. 3.

Theory of Procedure

The junction capacitance is measured at a number of bias points and microwave impedance is measured at the same bias points. These data are processed to yield the transformation, $A'_2B'_2C'_2D'_2$, of the overall network. Standard known impedances are inserted in the diode holder to evaluate the $A_1B_1C_1D_1$ between the reference plane of measurement and the terminal surface[2] of the packaged diode. The transformation constants, $A'_3B'_3C'_3D'_3$, are then calculated.

If $C_X = 0$, the $A_3B_3C_3D_3$ matrix is formed as follows:

$$\begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ G_p + j\omega C_A & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & j\omega L_D \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j\omega C_B & 1 \end{bmatrix} \begin{bmatrix} 1 & R_J \\ 0 & 1 \end{bmatrix} \tag{1}$$

The package element values are then calculated as

$$\begin{aligned} R_J &= \mathrm{Re}B_3/A_3 \\ G_p &= \mathrm{Re}C_3/A_3 \\ L_D &= \mathrm{Im}B_3/\omega \\ C_B &= (1 - A_3)/\omega \cdot \mathrm{Im}B_3 \\ C_A &= [\mathrm{Im}C_3/A_3 + 1/\mathrm{Im}B_3 - 1/(A_3 \cdot \mathrm{Im}B_3)]/\omega \end{aligned} \tag{2}$$

However, the available package transformation, $A'_3B'_3C'_3D'_3$, which is determined experimentally, includes the fixed error, C_X. The matrix multiplication leads to

$$\begin{aligned} A'_3 &= A_3 - j\omega C_X B_3 \\ B'_3 &= B_3 \\ C'_3 &= C_3 - j\omega C_X D_3 \\ D'_3 &= D_3 \end{aligned} \tag{3}$$

Since A_3 must be pure real, it follows that

$$C_x = -\mathrm{Im}A'_3/\omega \mathrm{Re}B'_3 \tag{4}$$

Thus, it is possible to solve for A_3, B_3, C_3, D_3, using the value found in Eq. (4).

The major assumption of the above analysis is that R_J is constant with bias voltage. The modifications which would be necessary to accommodate voltage variable, R_J, for abrupt-junction varactors are, however, possible, and will be described in the oral presentation.

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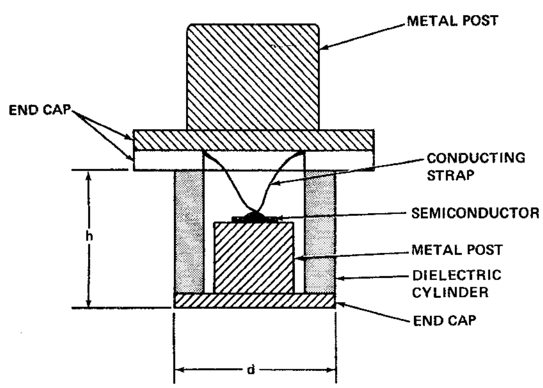
Experimental

A high degree of measurement accuracy is required for the present numerical method. The microwave measurement setup is a standard slotted section arrangement, in which the signal is fed through the probe. The microwave source is phase-locked to provide frequency stability of within ±200 Hz at 10 GHz. The diode is mounted in a reduced-height, X-band, rectangular waveguide. Standard impedances used are: (1) a solid dummy short, (2) a number of inductive posts, and (3) a capacitor gap.

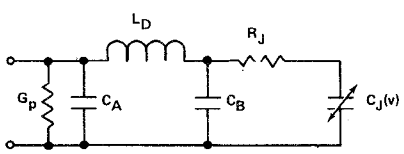
The procedure is handled by computer, once the measurements and the values of the standard impedances have been entered. The data processing to find the transformation ABCD matrices is done by Kajfez's least square error technique.[3] The computer outputs are the values of junction capacitance (corrected by C_X), the diode resistance, the package element values, static cutoff frequency, and, when appropriate, dynamic cutoff frequency.

Conclusion

The prime advantages of the present method are: (1) complete characterization of microwave diode packages, (2) accurate diode junction capacitance evaluation, and (3) the possibility of ultimate automation of microwave diode characterization.



(a) TYPICAL PACKAGED DIODE.



(b) EQUIVALENT LUMPED CIRCUIT.

Figure 1. Typical Packaged Diode and Equivalent Circuit

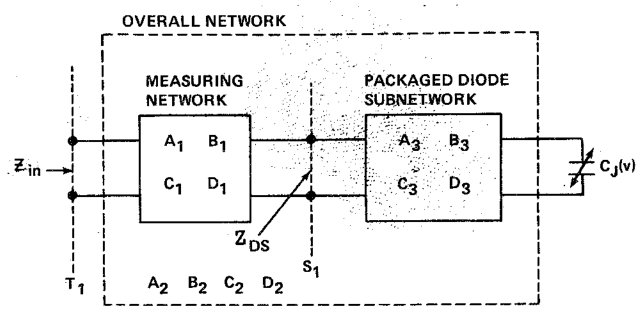


Figure 2. Block Diagram of the Diode Measurement Circuit

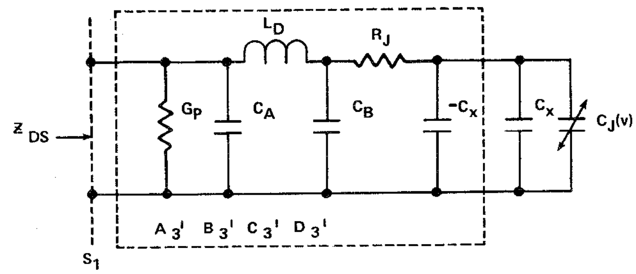


Figure 3. Packaged Diode Circuit Model with Junction Capacitance Correction

References

[1]C. N. Dunn and J. E. Dalley, "Computer-Aided Small Signal Characterization of Impatt Diodes," IEEE Trans. on MTT, Vol. MTT-17, September 1969, pp. 691-695.

[2]W. J. Getsinger, "Mounted Diode Equivalent Circuits," IEEE Trans. on MTT, Vol. MTT-15, November 1967, pp. 650-651.

[3]D. Kajfez, "Numerical Data Processing of Reflection Coefficient Circle," IEEE Trans. on MTT, Vol. MTT-18, February 1970, pp. 96-100.