VIII-3. A POWER REFLECTION TECHNIQUE FOR CHARACTERIZATION OF HIGH QUALITY VARACTOR DIODES

George D. Vendelin and Samuel A. Robinson

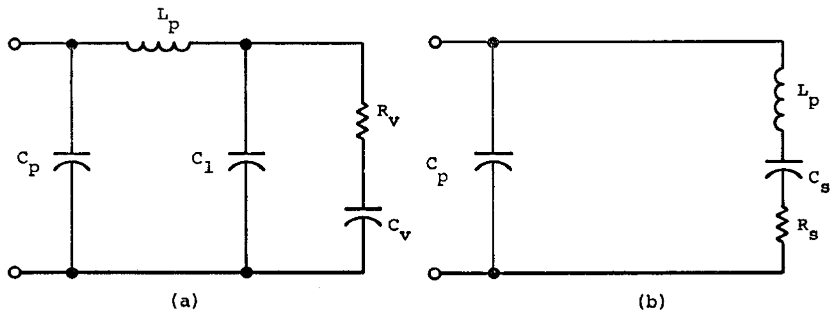
Texas Instruments, Inc., Dallas, Texas

A new method for varactor diode characterization has been developed. As the quality of microwave varactors rapidly improves, a simple and accurate means of characterization has become increasingly important. The present methods for varactor characterization consist of either a "relative impedance" or a "transmission" technique. The commonly accepted varactor equivalent circuit is shown in Figure 1.

The relative impedance method[1,2], also known as the hyperbolic method[3], requires matching the diode to a slotted line with a lossless, tunable transformer. By changing the bias voltage and measuring the VSWR, the diode quality may be calculated by assuming a resistance which does not vary with bias voltage. For high quality varactor diodes, this method requires the measurement of very high VSWR's (greater than 50). Since line loss and holder loss cause a large measurement error, the measured VSWR must be corrected for losses. In addition, the correction for losses may depend upon the bias voltage due to a shift in the position of the voltage standing wave pattern. These difficulties appear to make the relative impedance method the least attractive method for varactor characterization.

The transmission method[4,5] requires mounting the diode in reduced-height waveguide and measuring the transmitted power near the series resonant frequency. The method consists of either holding the bias fixed and varying the frequency[4] or holding the frequency fixed and varying the bias[5]. Due to the necessity of mounting the diode in waveguide, this method is limited in the range of junction capacitance and package inductance which may be resonated. Also, in a waveguide measuring system the value of characteristic impedance does not have an unambiguous value[6]. The transmission method has given higher cutoff frequencies when compared to the relative impedance method[3,6].

The new technique for varactor characterization consists of measuring the reflected power near the series resonant frequency. The measurement requires locating the varactor diode as the termination of a low impedance section of coaxial line. The measurement setup is shown in Figure 2. Since the diode resistance nearly always varies with bias voltage, the bias is fixed and the frequency is varied. The resulting VSWR is measured as a function of frequency. From a knowledge of the VSWR at series resonance and a knowledge of the 3 db frequencies, the varactor cutoff frequency may be calculated. The 3 db frequencies are defined as the frequencies where the power reflected from the diode has doubled from the resonance value. Notice the VSWR



$$C_s \cong C_v \left(1 + \frac{C_1}{C_v}\right) \qquad R_s \cong \frac{R_v}{\left(1 + \frac{C_1}{C_v}\right)^2}$$

Figure 1 - Varactor Equivalent Circuits

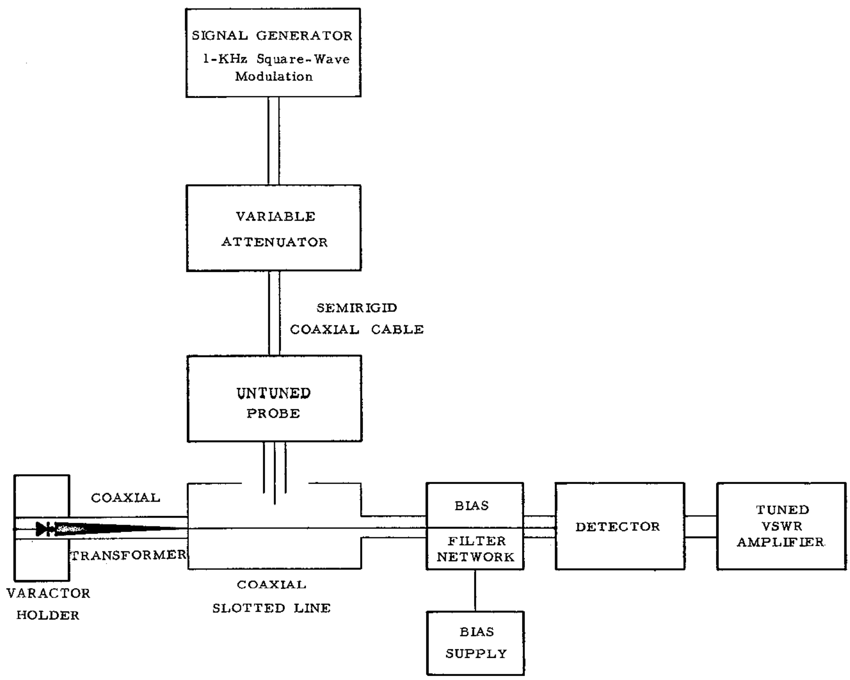


Figure 2 - Power Reflection Test Arrangement

has been reduced for better measurement accuracy by lowering the characteristic impedance at the varactor. The importance of low VSWR for the measurement of high quality varactor diodes cannot be over-emphasized.

The varactor parameters may be calculated from the following equations. The coupling of the line may be determined by observing the shift of the voltage minimum when the diode is at the resonant frequency compared to an open circuited line.

Overcoupled Line $R_s < Z_o$		Undercoupled Line $R_s > Z_o$	
$R_s = Z_o/S_o$	(1)	$R_s = Z_o S_o$	(2)
$C_s = \frac{(f_2 - f_1)S_o}{2\pi f_1 f_2 Z_o V(S_o)}$	(3)	$C_s = \frac{(f_2 - f_1)}{2\pi f_1 f_2 Z_o V(S_o)}$	(4)
$f_{co} = V(S_o) \frac{f_1 f_2}{f_2 - f_1}$	(5)	$f_{co} = \frac{V(S_o)}{S_o} \frac{f_1 f_2}{f_2 - f_1}$	(6)

$$L_p = \frac{1}{4\pi^2 f_1 f_2 C_s} \quad (7)$$

$$V(S_o) = \frac{S_o^2 - 1}{(-S_o^2 + 6S_o - 1)^{1/2}} \quad (8)$$

$$S_{1,2} = \frac{S_o + 1 + \sqrt{2}\,(S_o - 1)}{S_o + 1 - \sqrt{2}\,(S_o - 1)} \quad (9)$$

Z_o = characteristic impedance at the varactor

S_o = VSWR at the resonant frequency

f_1, f_2 = 3 db frequencies

$S_{1,2}$ = VSWR at the 3 db frequencies

The functions $S_{1,2}$ and $V(S_o)$ have been plotted versus S_o in Figure 3. Since the function $V(S_o)$ has real values for $S_o < 5.82$, the method must be modified for values of R_s less than $Z_o/5.82$. The influence of the package capacitance has been neglected since $1/\omega C_p \gg R_s$ for most packaged varactor diodes.

Typical data taken for silicon and gallium arsenide varactor diodes are given in Figure 4. Since these diodes were overcoupled, the cutoff frequency was calculated from (5). This calculation was not corrected for system losses.

A low impedance (about 17 ohms) slotted line is currently being developed and will permit even more accuracy for the reflection technique since the losses of the transformer section will be eliminated. The present transformer consists of a tapered section which transforms 50 ohms to approximately 7.2 ohms over a distance of 3.5 inches. The losses were reasonably small since

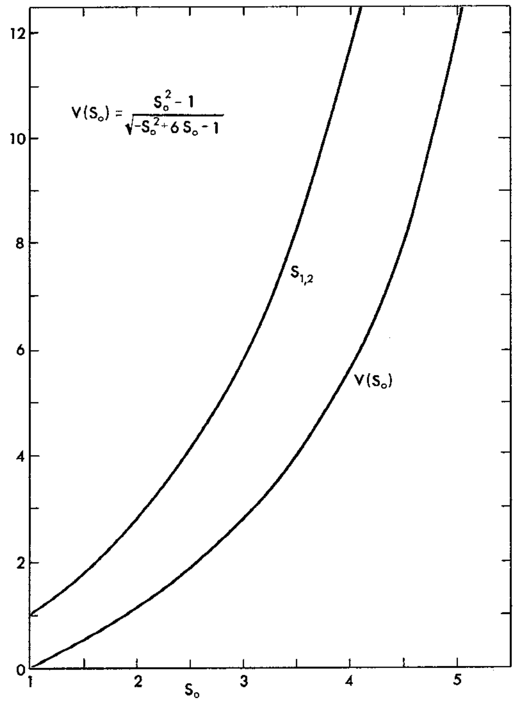
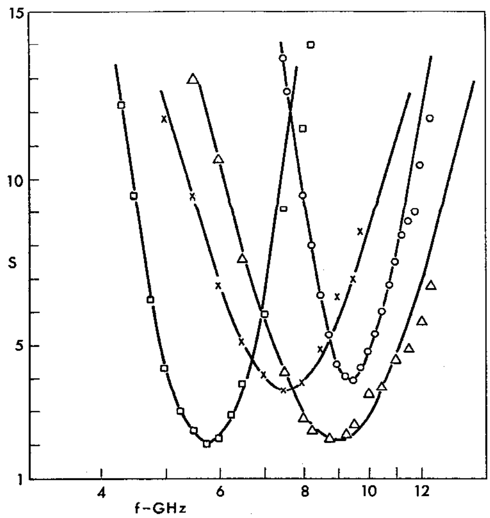


Figure 3 - VSWR at 3 db Frequency and $V(S_o)$ versus S_o



	Type	Bias Volts	V_B Volts	f_{co} GHz
○	GaAs Schot.	0	9.3	110
x	GaAs Mesa	0	12.2	56
△	Si Mesa	-6	112	53
□	Si Schot.	0	33	41

Figure 4 - Varactor Data

the VSWR of a short circuit was greater than 35. The transformation consisted of a linear taper on the center conductor and an exponential taper on the outer conductor. All parts were gold plated for low microwave loss.

The accuracy of the power reflection method will be limited by the high VSWR's of high quality varactor diodes. The primary sources of error are the losses in the transformer section (which can be eliminated with a low impedance slotted line), the repeatability of the VSWR measurement, and possible losses in the varactor holder. The present technique is estimated to have an accuracy at least as good as any other method.

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