A NEW MICROWAVE MEASUREMENT TECHNIQUE TO CHARACTERIZE DIODES AND AN 800 GC CUTOFF FREQUENCY VARACTOR AT ZERO VOLTS BIAS

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The equivalent circuit of a diode in a waveguide is difficult to determine because it is embeded in the circuit of supporting devices such as dielectric spacers and posts. The influence of these supporting devices can be eliminated by fabricating the diode directly in reduced height waveguide. Diodes in cartridges can also be made to approximate this situation.

Consider the cartridge of Fig. 1 developed by W. M. Sharpless. If it is mounted transversely through the centers of the broad walls of reduced height rectangular waveguide, 0.900" x 0.050", so that the end caps become in effect a part of the waveguide wall, there is no post inductance and the shunting cartridge capacity is greatly reduced, because now only capacity in excess of the normal distributed waveguide capacity effectively shunts the catwhisker-crystal combination. For this cartridge this is much less than the "empty" cartridge capacity of 4×10^{-14} farad as determined on an audio frequency bridge. Thus we have in effect only the catwhisker-crystal combination connected between the centers of the broad walls of the waveguide.

Transmission loss measurements on a typical variable capacitance diode in a Sharpless cartridge mounted in reduced height (0.900" x 0.050") rectangular waveguide with well matched tapers to full height waveguide (0.900" x 0.400") on either side are presented in Fig. 2. The different curves are obtained at different bias voltages with negligible D.C. current flowing through the diode i.e. less than 1×10^{-7} Amp.

The simplest equivalent circuit connected across a transmission line capable of yielding these curves is a series resonant L, C, R_s combination.

That this circuit is a very good approximation may be seen as follows. Labeling the characteristic impedance (assumed constant) of the transmission line Z_o, the transmission loss ratio (magnitude) at resonance T, and the two frequencies at which the transmission loss is T/2, f_1 and f_2; T, f_1, and f_2, can be related to R_s, C, and L by:

$$R_s = \frac{Z_o}{2} \quad \frac{1}{\sqrt{T} - 1} \qquad\qquad L = \frac{1}{4\pi^2 f_1 f_2 C}$$

$$C = \frac{f_1 - f_2}{\pi Z_o f_1 f_2} (\sqrt{T} - 1) \left(1 - \frac{2}{T}\right)^{\frac{1}{2}}$$

Z_o is actually frequency dependent in a rectangular waveguide but its variation is slow enough with frequency that the use of its value at resonance in the above equations is accurate to two significant figures for the curves of Fig. 2. We can thus calculate values of R_s, C, and L for each of the 6 transmission curves of Fig. 2. Plots of R_s and C so obtained are presented in Fig. 3. Included in Fig. 3 for comparison is the junction capacity curve obtained on a 100 KC bridge. The agreement between these two curves is quite remarkable. (Agreement is not generally found when appreciable current is flowing.) R_s is seen to exhibit a slight increase with reverse bias which also unavoidably corresponds to an increased frequency of measurement. L was observed to increase from 1.3 to 1.4 nanohenries from 8.6 to 11.9 Gc. This change in L is small enough that our simple L, C, R_s, equivalent circuit is an excellent approximation as is indicated by the correlation between the 100 KC and X-band capacity measurements.

Though the L, C, R_s equivalent circuit was deduced for a varactor diode it is felt that all diode types representable by this series circuit with C shunted by some resistance R, including Esaki, backward, detector and converter diodes, can be accurately measured by this technique provided there exists a bias voltage at which R is large compared to the reactance of C at the frequency of measurement (as was the case for the varactor). This technique has in fact already been utilized to measure both backward and Esaki diodes.

A much cleaner circuit than that employed for Fig. 2 is obtained when a diode is fabricated directly in a piece of waveguide. This is almost a "must" at high microwave frequencies and the transmission method enables one to measure diodes so assembled. Transmission curves obtained on such a diode, mounted in reduced height M-band waveguide, 0.148" x 0.010", are shown in Fig. 4. This diode was an electrically formed .003 Ω cm GaAs crystal with a Zn contacting element. It had a reverse bias breakdown voltage of approximately 7 volts and was fairly rugged mechanically and electrically. The R_s, C, and L values obtained from these curves are presented below. It is to be noted that the cutoff frequency at zero bias, defined as the reciprocal of $\omega R_s C$, is approximately 800 Gc.

Bias Voltage	R_s Ω	C picofarads	L nanohenries
+ 0.65	13.5	.022	.40
+ 0.25	12.1	.018	.41
0.00	12.0	.016-.017*	.41-.42*

*Estimated

Unfortunately, these diodes cannot be removed for low frequency bridge comparisons. Their electrical superiority over standard types has been confirmed however by comparison measurements. This type of diode "likes" to form with even less capacity than that shown in Table I and its use should therefore extend the range of parametric devices well into the millimeter region.

The transmission method of measurement has proved to be an accurate and relatively simple way to obtain diode parameters. It is applicable at high microwave frequencies and for extremely small capacitances. Its absolute accuracy in determining R_s increases as R_s decreases thus making it a useful way to measure high Q diodes.

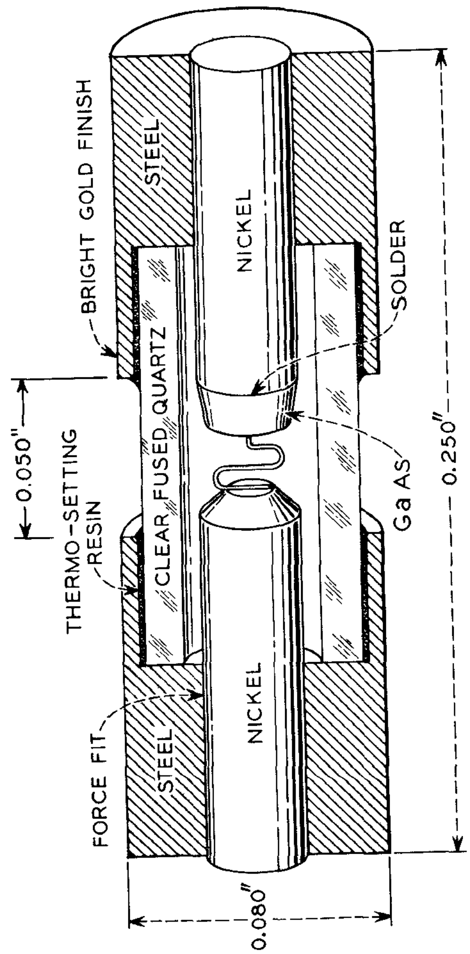

Fig. 1 - Microwave crystal in cartridge designed by W. M. Sharpless.

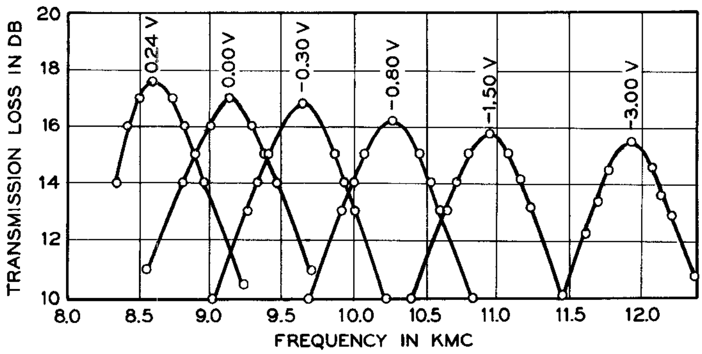

Fig. 2 - Transmission characteristics of a varactor diode in a Sharpless cartridge in reduced height X-band waveguide.

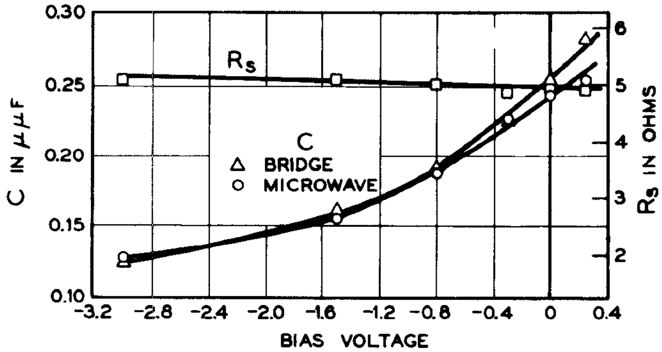

Fig. 3 - R_s and C (both microwave and 100 KC bridge measurements) as functions of bias voltage.

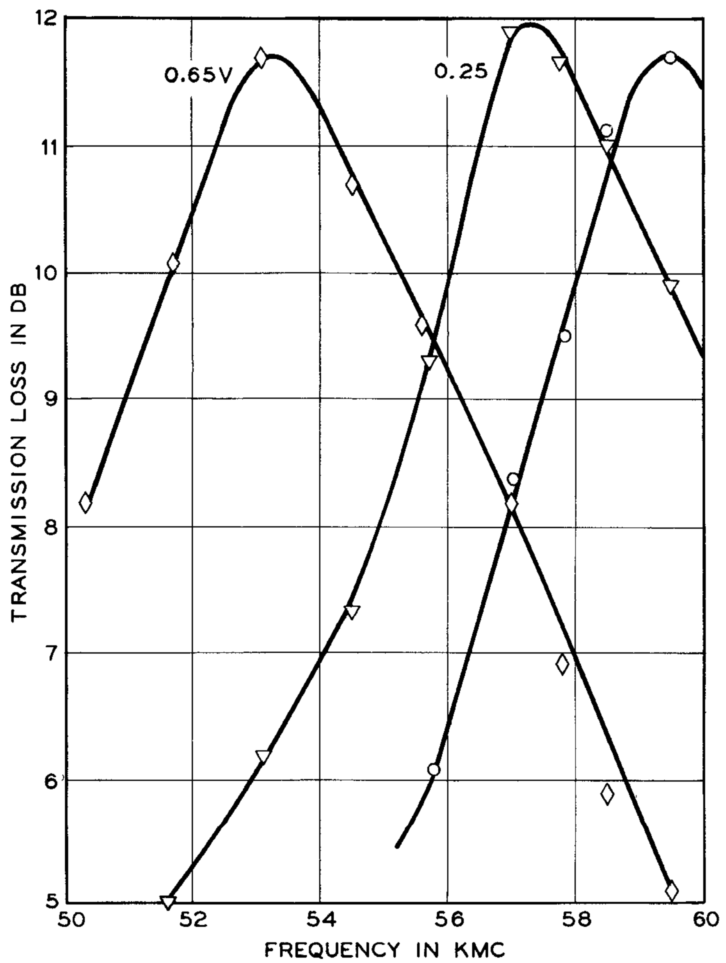

Fig. 4 - Transmission characteristics of a varactor diode mounted directly in reduced height M-band waveguide.

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