UNDERSTANDING THE WAVEGUIDE DIODE MOUNT

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Abstract

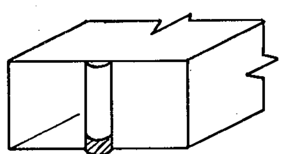
A non-mathematical discussion of the characteristics of the standard waveguide diode mount is presented, based upon an equivalent circuit which allows isolation of the effects due to the variation of the physical configuration parameters such as waveguide dimensions and post size and location.

Introduction

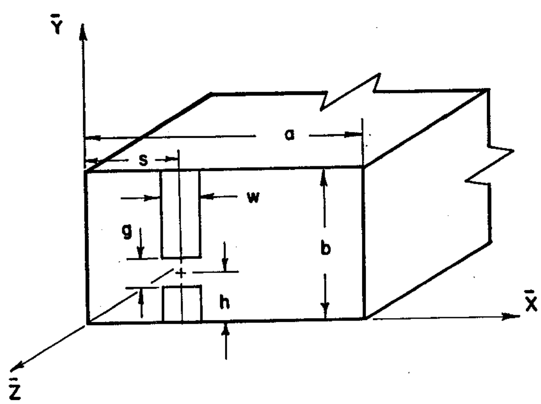
This presentation is concerned with the impedance characterization of the microwave structure shown in Figure 1a, commonly called the waveguide mount. The motivation for this discussion comes from two equally significant points:

1) this mount is widely used with practically every microwave device, and
2) the mount is at best poorly understood by most users.

For example, although many designers use reduced height waveguide to lower the impedance level seen by the diode, very few realize that when reducing the guide height from normal size the impedance initially increases greatly before decreasing.



a. Typical mount, with device located at bottom of the waveguide



b. Description of parameters for general waveguide mount

FIG. 1. WAVEGUIDE MOUNT

The main objective here is to develop an intuitive understanding of what is going on inside the waveguide, without getting lost in the mathematics. An equivalent circuit is presented, forming the basis for the discussion relating the physical parameters of the mount to their associated electrical effects. The concept is simple; i.e.; all effects within the waveguide for any mounting configuration can be explained in terms of the modes coupled to the circuit. Two things must then be determined which are dependent directly upon the configuration of interest. These are (1) the circuit topology for the various modes and (2) the coupling factor for each mode to this circuit. This information has previously been derived,[1] allowing us to concentrate on the significance of the results.

Circuit Development

General

We see in Figure 1b six (6) dimensional parameters which, together with frequency, form the set of independent variables with which we must be concerned. Our aim is not only to produce a circuit, but also to readily interpret parameter change effects upon the circuit, such as understanding the effect when reducing the waveguide height (reduce b).

Waveguide Mode Impedance

Consider first the empty waveguide defined simply by a and b. This waveguide has associated with it an infinite set of TE and TM modes described respectively by the mode characteristic impedances.[2]

$$Z_{CTE} = j\,\frac{2\eta}{a(2-\delta_o)}\frac{b}{}\left(\frac{f}{\sqrt{f_c^2 - f^2}}\right)\left(\frac{(mb)^2}{(mb)^2 + (na)^2}\right) \qquad (1a)$$

$$Z_{CTM} = -j\,\frac{2\eta}{a(2-\delta_o)}\frac{b}{}\left(\frac{\sqrt{f_c^2 - f^2}}{f}\right)\left(\frac{(na)^2}{(mb)^2 + (na)^2}\right) \qquad (1b)$$

where

η = free space impedance = 120 π ohms

m,n = mode indices with

m = field variation in the X - direction

n = field variation in the Y - direction

f_c = mode cutoff frequency = $\left[\left(\frac{mc}{2a}\right)^2 + \left(\frac{nc}{2b}\right)^2\right]^{1/2}$

c = free space velocity of propagation

$\delta_o = \begin{cases} 1, & n = 0 \\ 0, & \text{otherwise} \end{cases}$

The variations of these characteristic impedances are shown in Fig. 2. The cutoff frequency is dependent upon the mode indices m,n as well as the dimensions a,b and is identical for TE and TM modes having the same indices. Both mode types are directly proportional to guide height b and inversely to guide width a.

Mode Combination

When energy is contained in any given mode in a lossless, straight, unobstructed waveguide, it will remain in that mode, for no means of coupling to any other mode is present. However, by putting an obstacle in the waveguide we provide a means of cross-modal coupling, where the coupling characteristics are strongly dependent upon the shape of the obstacle. When the obstacle is a solid post, the equivalent coupling effect is that the TE and TM modes for a given

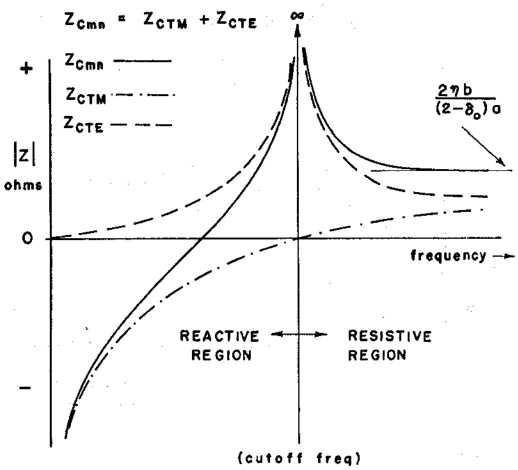


FIG. 2. MODE CHARACTERISTIC IMPEDANCE PLOTS

m,n set combine directly as a series pair as indicated by the solid curve of Figure 2. This curve shows a resonant zero which is dependent only on the index n, mathematically described in equation 2.

$$Z_{Cmn} = -j\,\frac{2\eta\, b\lambda_c}{a(2-\delta_o)}\left[\frac{\left(\frac{n\lambda}{2b}\right)^2 - 1}{\left(\lambda^2 - \lambda_c^2\right)^{1/2}}\right] \qquad (2)$$

Note that $Z_{Cmn} = 0$ for $\lambda/2 = b/n$, $n = 0,1,2 \ldots \infty$.

Solid Post Coupling

Because the post is a discontinuity in the X-direction (across the guide), it establishes coupling between the modes as m varies, for fixed n, in the form of a series combination. At this stage coupling still does not exist between modes with different values of n. It is important to mention that the mode impedance effects are weighted by a convergence factor which is determined by the post size w normalized to the guide width a. These weighted values are then coupled to the series combination by a factor which is dependent on the post positions relative to the sidewall.

Gap Coupling

By placing a gap or break in the post we introduce the Y-direction discontinuity which provides coupling between the series sets which have previously been developed. The result is a parallel combination of the series sets, all tied together at the gap terminals. This time the series sets are weighted by a convergence factor dependent upon the gap size g normalized to the guide height b, and coupled through a factor dependent upon the gap position h.

Total Effect

The resulting total equivalent circuit is shown in Figure 3, representing the combination of a doubly infinite set of modes to the gap terminals. Let us now interpret the significance of this network configuration and relate it to the mount parameters. First note the matrix-like appearance where each row is for a fixed value of m and each column for a fixed value of n. The boundaries or limits on this matrix relate directly to the convergence factors previously mentioned. More specifically, the number of rows of practical importance is determined by the width of the post; the smaller the post the greater number required. This relationship is best understood if we consider the post

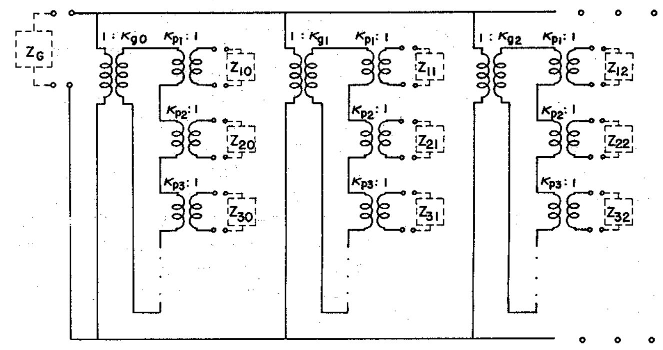


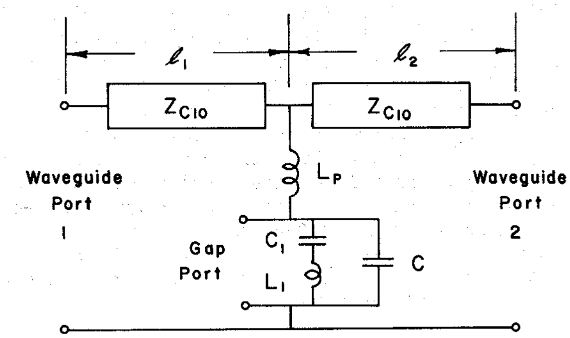
FIG. 3. EQUIVALENT CIRCUIT OF POST MOUNT

as a spatial pulse of width w in domain a. The narrower the pulse, the greater the number of spatial harmonics necessary to accurately reconstruct the pulse when represented by a summation of spatial harmonics (i.e., modes). Quite independent, but following the same concept, is the determination of the number of columns to be considered. Here we consider Y-directed spatial harmonics which are determined by gap size g in domain b, again requiring more columns as g gets smaller.

The parameters s and h establish coupling factors between the modes and the gap terminals, accounting for the relative position of the post and gap to the peaks and nulls of the mode fields.

Circuit Simplifications

The circuit of Figure 3 can be simplified for restricted frequency ranges. The combination and rearrangement of many elements results in Figure 4 which considers the range where only the TE_{10} is the propagating mode. Referring to this circuit let us consider some typical parameter variations. Suppose we increase the post width w. This increases the convergence rate for m values so that fewer modes are included in the summations. This reduces the values of L_p, L_1 and increases C_1 and C with no change to Z_{C10}.



C_1 = Capacitance due to TM_{m1}

L_1 = Inductance due to TE_{m1}

C = Combined capacitive effect of all TE and TM modes for $n > 1$.

L_p = Post inductance due to TE_{m0} modes for $m > 1$.

Z_{C10} = Characteristic impedance for TE_{10} mode = $240\,\pi\,(b\lambda_g/a\,\lambda)$

ℓ_1, ℓ_2 = Lengths of waveguide to ports

FIG. 4. SIMPLIFIED WAVEGUIDE MOUNT

More significant is the variation of the gap position along the post. At the bottom of the guide, coupling is maximized to all higher order modes, resulting in a maximum of C_1 and C with minimum value for L_1. As we move up along the post, however, this coupling decreases resulting in $L_1 \rightarrow \infty$, $C_1 \rightarrow 0$ at the mid-point and C becoming smaller. The combined effect on the gap driving point impedance is shown in Figure 5. Note the increase in the resistive part of greater than 6:1 over the range. Diodes, particularly sources, are usually mounted at the bottom of the waveguide for heat sinking purposes, and to take advantage of the low impedance matching conditions.

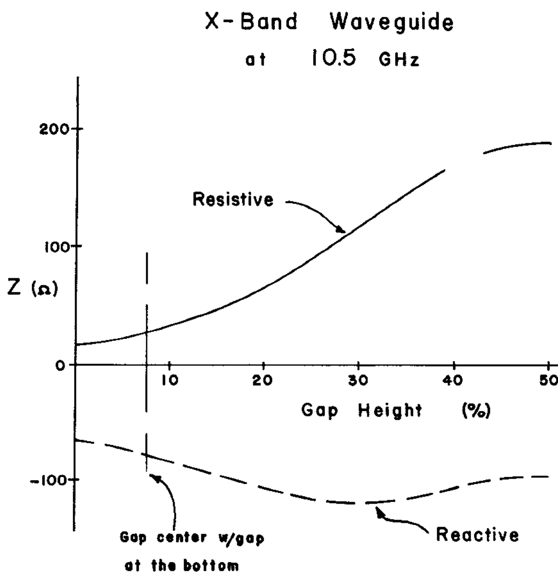


FIG. 5. DRIVING POINT IMPEDANCE VERSUS GAP POSITION FOR CENTERED POST OF 0.120" DIAMETER, WITH 0.060" GAP APPROPRIATE FOR PILL DIODES

The last example to be discussed is probably the most interesting, that of reducing the waveguide height b. This will proportionately reduce the magnitude of all circuit elements; however, the initial major effect is to increase the resonant frequency of $C_1 - L_1$, thereby removing their strong shunting effect. This results in much stronger coupling between the gap and the propagating mode, greatly increasing the resistive part of the gap input impedance. Eventually all values approach zero as b but not until the height has been substantially reduced. Referring to Figure 6 we see that it would be necessary to use a guide height of less than 0.060" to see a resistive part less than that seen for normal height waveguide in X-band.

The erroneous "constant current" assumption for the post current distribution, still often used in analyses of this mount, is probably the primary factor in maintaining the confusion long associated with this mount. This assumption in effect neglects C, C_1 and L_1 thereby significantly altering the equivalent circuit. Figures 5 and 6 show clearly the strong influence of these circuit elements. In fact it is the series resonance of $C_1 - L_1$ that establishes the tuning saturation reported in the literature.[3]

Summary and Conclusions

The following list summarizes the major effects that each of the six configuration parameters has on the characteristics of the waveguide mount.

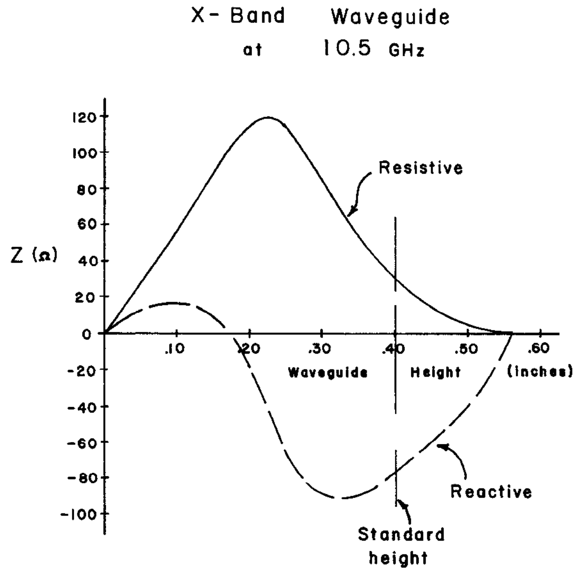


FIG. 6. DRIVING POINT IMPEDANCE VERSUS WAVEGUIDE HEIGHT FOR CENTERED POST OF 0.120" DIAMETER WITH 0.060" GAP SET AT BOTTOM OF THE GUIDE

1. 'a' Guide width - Primary parameter, establishes the frequency range for the dominant mode.
2. 'b' Guide height - Directly scales the magnitude of all mode impedances; inversely sets the zeros of the parallel sets; and is a factor in higher order mode cutoff frequency determination.
3. 'w' Post width - Normalized to 'a' determines the m index convergence.
4. 'g' Gap size - Normalized to 'b' determines the n index convergence.
5. 's' Post position - Determines coupling between the post and the modes.
6. 'h' Gap position - Determines coupling between the gap and the modes.

We can conclude that understanding the operation of the waveguide mount is simplified considerably by development of an equivalent circuit which, when separated out into its basic elements, allows isolation of the various parameter effects.

References

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3. B. C. Taylor, S. J. Fray and S. E. Gibbs, "Frequency Saturation Effects in Transferred Electron Oscillators," IEEE Trans. on Microwave Theory & Tech., Vol. MTT-18, Nov. 1970, pp. 799-807.