A Useful Equivalence for a Coaxial-Waveguide Junction

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Abstract—**The junction formed by a coaxial line entering the broad wall of a rectangular waveguide is commonly used, but has not been accurately analyzed due to the electromagnetic-field complexity. An excellent correlation has been established between this complex structure and a similar one which has already been thoroughly characterized. This close correlation permits use of the equivalent circuit of the previously characterized structure as a representation for the coax-waveguide junction as well. This usage is made possible by study of the relationship which exists between the two configurations, thus allowing accurate circuit analysis of components utilizing the coax-waveguide junction.**

INTRODUCTION

THE JUNCTION formed by a coaxial line entering the broad wall of a waveguide is encountered in a variety of microwave circuits. It has been studied extensively [1]–[3], but the most successful use has been based upon empirically determined knowledge rather than on theoretical analysis. Despite this difficulty the junction is still used, often providing the only solution to a designer's mounting or coupling problem. In particular, the coupling of microwave solid-state diodes to rectangular waveguides is a frequent requirement in the design of microwave oscillators, amplifiers, detectors, and control devices. This is normally accomplished by placing the device within a gap in a post which is mounted across the waveguide parallel to the E-field of the propagating mode. (See Fig. 1(a).) It is, however, often either necessary or convenient to shift the device location from the waveguide proper to a point within a coaxial line which couples into the waveguide as shown in Fig. 1(b). This coaxial-waveguide configuration has not been adequately characterized by analysis, limiting its application by circuit designers. Obviously an accurate representation of the junction would be very useful allowing determination of the impedance presented to the semiconductor device by this complex mounting structure.

This knowledge would simplify designs using Gunn, IMPATT, and varactor diodes whose operation is strongly dependent on this impedance.

This paper proposes the use of an equivalent circuit developed as a representation for a similar configuration. Through the use of an "effective gap" G_e, a relationship between the two configurations is determined which allows use of the theoretical characterization for the coaxial-waveguide junction.

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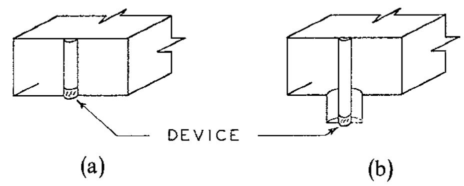

Fig. 1. Device coupling to a waveguide. (a) Broad wall mounting. (b) Coax mounting.

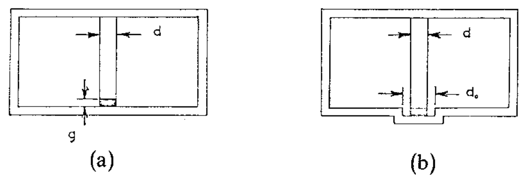

Fig. 2. Waveguide cross-section for (a) loaded post gap and (b) loaded coaxial gap.

DISCUSSION AND PROCEDURE

Consider a load in a very small gap in a post across a waveguide as shown in Fig. 2(a). Similarly, consider a load in the coax configuration shown in Fig. 2(b). It is reasonable to expect that these two configurations would have virtually identical effects on a wave propagating in the waveguide, since the apparent aperture of the load material is practically identical and the orientation/position shift is very slight. All of the current at the base of the post flows equally through both loads, and the electromagnetic fields in the waveguide will be similar for both types. Conversely, looking out from the gaps into the waveguide should present equivalent conditions to the observer. This concept is not new and has even been used as the basis for some analysis [1], [3]. There are two questions which must be addressed if this equivalence can be and is to be established. First, a relationship must be determined between the inside diameter d_0 of the coaxial line outer conductor and g of the post gap, for a given post size d. Secondly, experimental evidence must be obtained to provide a feeling for the dimensions at which there is a breakdown in the equivalence, as the gaps grow in size relative to the surrounding waveguide.

These questions were addressed by carrying out a series of impedance measurements Z_M which were compared to theoretical calculations Z_R [4] for the impedance seen from the post gap (see Fig. 3). A wide range of coaxial configurations varying the characteristic impedance Z_0 and the outer diameter d_0 were measured in two different size

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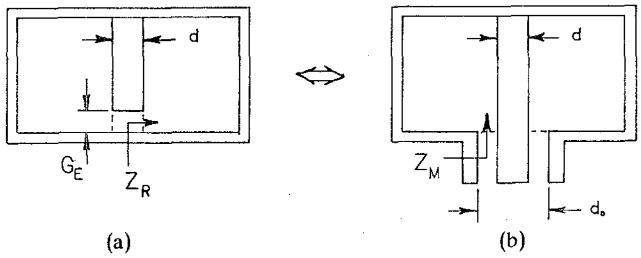

Fig. 3. Configurations being compared. (a) Post gap. $Z_R \equiv$ calculated impedance from theoretical analysis looking out of the gap. (b) Coax gap. $Z_M \equiv$ measured impedance at coax-waveguide interface. (Not Z_0 which is the characteristic impedance of the coaxial line.)

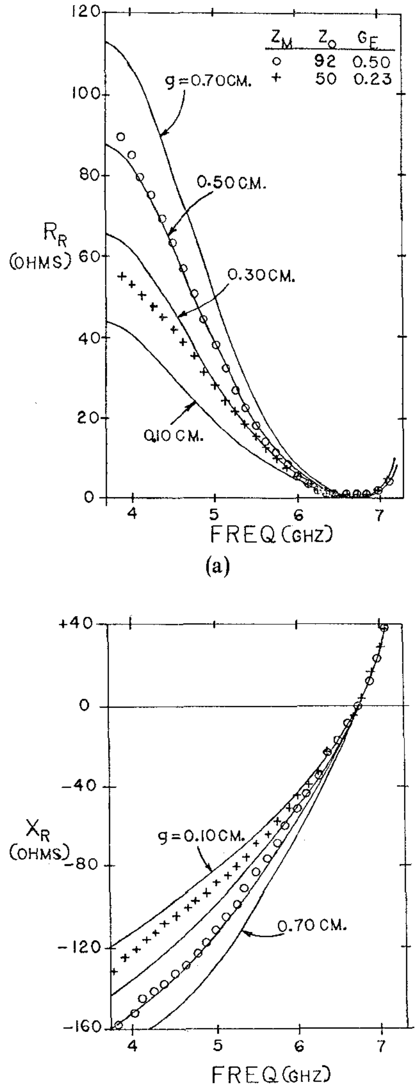

Fig. 4. Z_R plot for C-band waveguide with $d = 0.3$ cm and $g = 0.1, 0.3, 0.5, 0.7$ cm. ($a = 4.755$ cm, $b = 2.215$ cm.) Data shows excellent correlation. (a) Real part. (b) Reactive part.

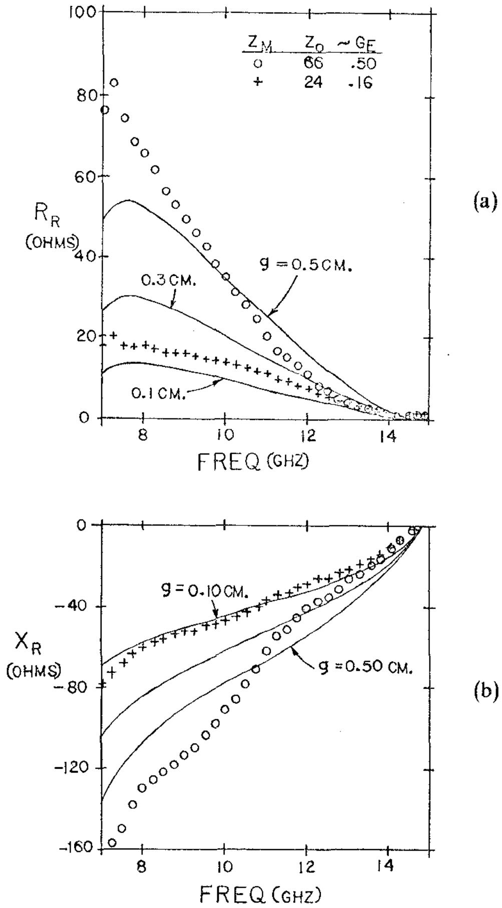

Fig. 5. Z_R plot for X-band waveguide with $d = 0.475$ cm and $g = 0.1, 0.3, 0.5$ cm. ($a = 2.286$ cm, $b = 1.016$ cm.) Data shows deteriorating correlation. (a) Real part. (b) Reactive part.

waveguides. Comparisons were made by varying the gap parameter g in the calculations in the hope of finding a value which produced an impedance plot Z_R closely comparable with the measured data Z_M. Once found, this gap value was specified as the equivalent gap G_e for that coax configuration. No other parameters were altered for this comparison and the equivalent gap position is considered to be at the waveguide bottom, i.e., $h = 0$. The comparison results varied from excellent to poor, slowly degrading as the gap size grew relative to the wavelengths involved.

This procedure is demonstrated in Fig. 4 which shows two sets of measured data plotted on a family of Z_R curves. R and X are plotted separately. These two examples show the excellent correlation for nominal coax-impedance levels and hole size.

Fig. 5 shows two of the weaker correlations, giving an idea of the magnitude of error if the equivalence is taken too far. In the first case for $Z_0 = 24\,\Omega$, the hole size is over 30 percent of the guide width. For $Z_0 = 66\,\Omega$, the hole has increased to over 60 percent of the guide width, with the obvious deterioration of results. Actually, it is surprising to see any correlation for such an extreme physical distortion, but even this case gives "ball-park" results.

Results and Conclusions

Comparisons for all the data taken were consolidated resulting in Fig. 6, representing the gap-coax relationship for two different waveguide aspect ratios (a/b). These effects are relative to the guide size so that the results can be used

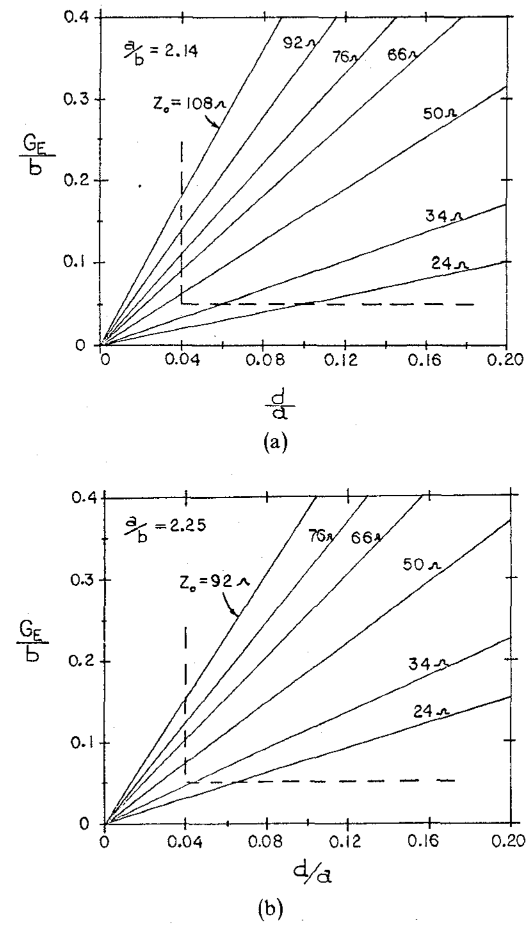

Fig. 6. Plot of normalized equivalent gap versus normalized post diameter with coax characteristic impedance as a parameter. (a) Aspect ratio $a/b = 2.14$ as used for C-band waveguide. (b) Aspect ratio $a/b = 2.25$ as used for X-band waveguide.

independently of frequency. The aspect ratio for standard waveguide sizes does vary depending on the band so that in other cases some estimation will be required. Fortunately the ratios do not vary greatly. Values of G_e and d for the area off the chart or outside the dashed lines will result in reduced accuracy as shown in Fig. 5. These boundaries are not sharp but represent the values where the equivalence begins to deteriorate. Generally the maximum values for d/a and G_E/b come about from the coax entry becoming large relative to the waveguide. For example, the 24-Ω case of Fig. 5 has a d/a of 0.208 and the correlation is still close. The 66-Ω case, however, exceeds both limits with the expected lack of correlation.

The dashed line lower limits come from analytical rather than physical restrictions and are present to indicate a loss of resolution due to the crowding of the values. For very small post diameters and gap sizes, the theoretical analysis requires the summation of a great number of higher order waveguide mode effects and use of the equivalent circuit becomes impractical for high precision. Here again, however, good approximation in these areas is still available from Fig. 6 sufficient for many applications.

It is concluded that the coax-waveguide junction can be represented by a post with a gap for nominal values of post and coax size relative to the waveguide. The relationship establishing the equivalent gap G_e is given for two different waveguide aspect ratios and can be used for any frequency waveguide for the dominant mode range. The equivalent circuit developed for the post with a gap [4] is general enough to represent the junction independent of the waveguide or gap loading. This then allows direct circuit design to be applied to configurations using the coax-waveguide junction.

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