wave Theory Tech., vol. MTT-27, pp. 328–333, 1979.
[3] S. B. Cohn, "Microwave bandpass filters containing high-Q dielectric resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, pp. 218–227, 1968.
[4] P. Scalicky, "Direct coupling between two dielectric resonators," *Electron. Lett.*, vol. 18, pp. 332–334, Apr. 1982.
[5] J. Van Bladel, "The excitation of dielectric resonators of very high permittivity," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 208–217, 1975.
[6] J. Van Bladel, "Coupled dielectric resonators," Report 82-2 Laboratorium voor Elektromagnetisme en Acustica, 1982.
[7] J. Van Bladel, "The multipole expansion revisited," *Arch. Elek. Übertragung.*, vol. 31, pp. 407–411, 1977.
[8] R. De Smedt, "Coupled dielectric resonators of circular cylindrical shape," Laboratorium voor Elektromagnetisme en Acustica, Report 82-1, 1982. (To be published in *Arch. Elek. Übertragung.*)
[9] R. De Smedt, private communication.

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Improved Waveguide Diode Mount Circuit Model Using Post Equivalence Factor Analysis

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***Abstract*—This paper presents an improved wide-band equivalent circuit for a diode mount consisting of a gapped cylindrical post in a rectangular waveguide. The empirical round post to flat strip equivalence factor used in an earlier study by Eisenhart and Khan is replaced by one which is calculated via an accurate analysis. Results indicating the dependence of this equivalence factor on post diameter, post position, and frequency are shown, allowing a more accurate interpretation from the Eisenhart and Khan analysis.**

I. Introduction

THIS PAPER is concerned with an analytical determination of the impedance of a diode mount consisting of a cylindrical post in shunt across a rectangular waveguide. The impedance is found at both the diode package terminals on the cylindrical post and the waveguide terminal plane. Specifically, this paper substitutes a theoretical analysis to determine a factor previously approximated through measurement.

The general modeling problem of a diode mount in waveguide has been under study for many years resulting in a large number of papers on the subject. Eisenhart and Khan [1] carried out an extensive analysis, using a dyadic Green's function approach with an extension of the induced EMF method, to obtain expressions for the required impedances. The approach of Eisenhart and Khan was later applied to a two-post mount structure by El-Sayed [2], to a single-post two-gap configuration by Joshi and Cornick [3], to a waveguide diode mount having a coaxial entry by Eisenhart [4], and to a coaxial-line-waveguide junction by Eisenhart *et al.* [5]. Ogiso and Taketomi [6] used this approach to analyze iris-loaded waveguide diode mounts, while Blocker *et al.* [7] applied it to a study of the influence

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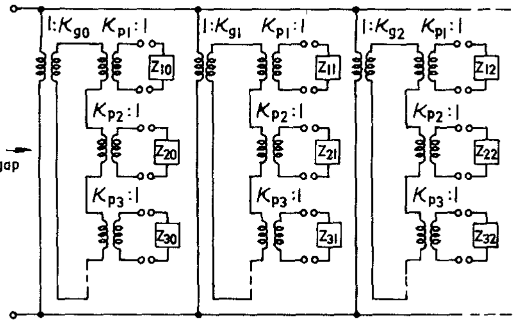


Fig. 1. Eisenhart and Khan [1] equivalent circuit for a rectangular waveguide post diode mount.

of diode package dimensions on the impedance characteristics.

A crucial feature of this analysis is its use of an equivalence between the shunt reactance of a round post and that of an infinitesimally-thin transverse flat strip in a rectangular waveguide, when the post of diameter d is replaced by a flat strip of width W; series capacitance elements were added to the flat-strip equivalent circuit to accommodate the phase changes due to the axial dimension of the round post [9]. Eisenhart and Khan used an empirically-determined factor of 1.8 for this equivalence, i.e., $W = 1.8\,d$. This value was also used by subsequent authors, although El-Sayed [10] uses a general constant having a value to be determined by experiment for the geometry and frequency range of interest. Williamson and Otto [11] have presented an analysis for mounting semiconductor devices in a rectangular waveguide without recourse to empirical factors. Although the approach of Williamson and Otto is slightly more accurate, the Eisenhart and Khan approach has the appeal of providing intuitive understanding of the components of the mount equivalent circuit and thus has been used more extensively by other research workers.

This paper reports a study carried out to determine the value of the equivalence factor analytically. Use of this analysis in conjunction with the theory of Eisenhart and Khan allows a determination of the equivalent circuit (Fig. 1) of a cylindrical-post diode mount in rectangular waveguide without recourse to empirical factors. This is of particular importance in millimeter-wave diode mounts, where the mounting-post diameter can be a significant fraction of the overall waveguide width.

II. Equivalence Criterion

The symbols used in this paper are defined in Fig. 2. The equivalence factor f, to be determined from the subsequent analysis, is defined to be the ratio (W/d) necessary for the two structures of Fig. 2 to have identical values of shunt reactance. It is the purpose of this paper to investigate analytically the value of f and to ascertain the accuracy of the empirical value 1.8 which was used previously.

Antenna equivalence considerations [12] yield a value of 2.0 for f under free-space conditions. However, the presence of the perfectly-conducting waveguide boundary necessitates a more sophisticated equivalence criterion between the round post and flat strip.

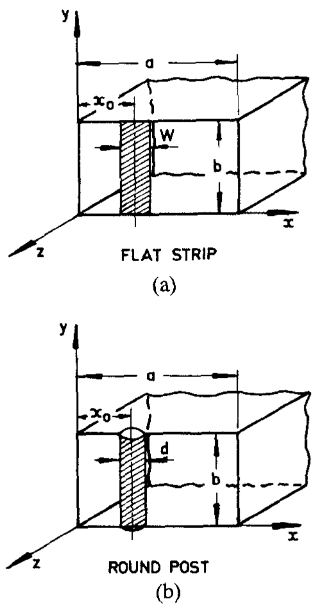


Fig. 2. Rectangular waveguide obstacles: (a) infinitesimally-thin flat strip, (b) round post.

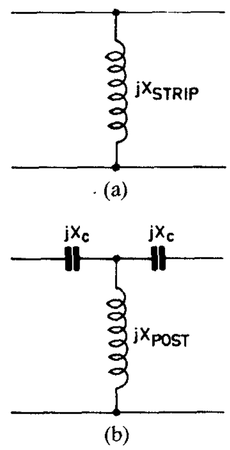


Fig. 3. Lumped-element equivalent circuits for waveguide obstacles: (a) infinitesimally-thin flat strip, (b) round post.

Referring to the simple lumped-element equivalent circuits for the obstacles shown in Fig. 3, both structures exhibit a shunt inductance; in addition, the round post, having a nonzero thickness, requires two lumped series capacitance elements to represent the phase shift. The lumped elements, which comprise the two equivalent circuits, are determined here using analyses accurate only over the frequency range for which the TE_{10} mode is dominant. However, many post waveguide circuits using solid-state devices satisfy this constraint, and thus the results of this analysis are widely applicable.

III. Round Post Analysis

Analyses of the round post in rectangular waveguide have been reported by Moschinskiy and Berezovskiy [14], Abele (centered post) [13], Fong *et al.* [15], Lewin [16], and Marcuvitz [8]. The analysis by Abele is applicable only to centered posts and the analysis by Moschinskiy and Berezovskiy is computationally tedious as it involves the solution of a doubly-infinite set of linear equations. The Lewin analysis and Fong analysis give similar results although Lewin uses an approximation for the Bessel functions. Marcuvitz in his analysis also approximates the Bessel functions. As Bessel routines are widely available on digital computers, the method of Fong was used with a generalization to remove the effect of the waveguide sliding short circuit. Although Fong assumes reduced height guide to justify uniform post current, satisfactory results are obtained in normal height guide. Experimental results provided below support this statement. Fong's approach derives a T equivalent network using variational principles along the lines of Schwinger and Saxon [17]. An outline of the approach is given below; further details may be found in [17]. The appropriate Green's function for the waveguide boundary conditions together with a y-directed uniform current source located at (x', z') is given by

$$G(x,z;x',z') = \frac{-j}{a}\sum_{m=1}^{\infty}\frac{\sin\frac{m\pi x}{a}\sin\frac{m\pi x'}{a}}{\beta_m}e^{-j\beta_m|z-z'|} \tag{1}$$

where $\beta_m = [k^2-(m\pi/a)^2]^{1/2}$ and the coordinate system is shown in Fig. 4. Even and odd excitations are incident on the post, thereby yielding two variational equations in the two unknowns Z_{11} and Z_{12}

$$Z_{11}+Z_{12} = \frac{j\beta_1 a}{2}\frac{\iint K_e(x,z)G_e(x,z;x',z')K_e(x',z')\,ds\,ds'}{\int K_e(x,z)\Psi_e(x,z)\,ds} \tag{2}$$

$$\frac{1}{Z_{11}-Z_{12}} = \frac{j\beta_1 a}{2}\frac{\iint K_o(x,z)G_o(x,z;x',z')K_o(x',z')\,ds\,ds'}{\int K_o(x,z)\Psi_o(x,z)\,ds} \tag{3}$$

where the even and odd incident waves may be represented as

$$\Psi_e(x,z) = \sin\frac{\pi x}{a}\cos\beta_1 z \tag{4a}$$

$$\Psi_o(x,z) = \sin\frac{\pi x}{a}\sin\beta_1 z. \tag{4b}$$

K_e and K_o are the kernel functions, and the even and odd Green's functions are given by

$$G_e(x,z;x',z') = G(x,z;x',z')+G(x,z;x',-z') \tag{5a}$$

$$G_o(x,z;x',z') = G(x,z;x',z')-G(x,z;x',-z'). \tag{5b}$$

Assuming only first-order phase variations round the post surface are significant in the Fourier series expansion of the kernel functions, the lumped element values may be readily solved as

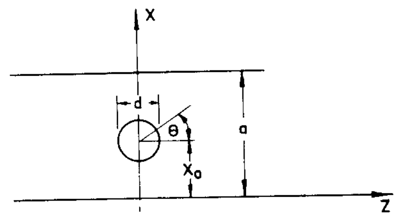


Fig. 4. Coordinate system for the round post in waveguide.

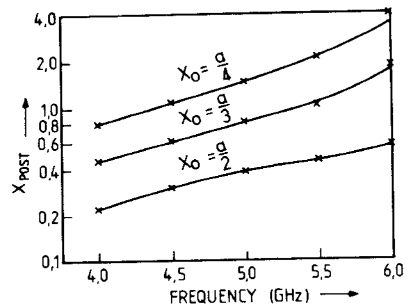


Fig. 5. Correlation between computed post reactance values and the measured Eisenhart and Khan [1] values denoted (x). Post diameter = 0.3048 cm, waveguide cross section = 4.76 cm × 2.215 cm.

$$j\frac{X_c}{Z_g} = Z_{11}-Z_{12} \tag{6a}$$

$$j\frac{X_{\text{post}}}{Z_g} = Z_{12} \tag{6b}$$

and thus

$$\frac{X_c}{Z_g} = \frac{8\beta_1 a}{(ka)^2}\frac{J_1\left(\frac{\pi d}{\lambda}\right)\sin^2\left(\frac{\pi x_o}{a}\right)}{Y_1\left(\frac{\pi d}{\lambda}\right)} \tag{7}$$

$$\frac{X_{\text{post}}}{Z_g} = \frac{\beta_1 a}{4\pi}\csc^2\left(\frac{\pi x_0}{a}\right)\left(\ln\left(\frac{4a}{\pi d}\sin\left(\frac{\pi x_o}{a}\right)\right)-2\sin^2\left(\frac{\pi x_o}{a}\right) + 1/4Y_o\left(\frac{\pi d}{\lambda}\right)\left\{1-\frac{1}{J_0\left(\frac{\pi d}{\lambda}\right)}\right\}+2S_A\right)-\frac{X_c}{2Z_g} \tag{8}$$

where

$$S_A = \sum_{m=2}^{\infty}\left(\frac{\pi}{\Gamma_m a}-\frac{1}{m}\right)\sin^2\left(\frac{m\pi x_o}{a}\right) \tag{9}$$

and

$$Z_g = 754\left(\frac{kb}{\beta_1 a}\right).$$

Applying a first-order approximation and thereby eliminating terms of order d^2 and above in (8), the values derived by Fong, for the case where the sliding short-circuit is a distance l from the post, reduce to the values obtained here as l tends to infinity. Fig. 5 shows the excellent correlation achieved between the Eisenhart and

Khan [1] measurements and the values calculated using the above formula. For the sake of comparison, the post impedance values given by Marcuvitz [8] were calculated and showed close agreement (better than 6 percent) with those given by the above analysis.

IV. Flat Strip Analysis

The reactance of a flat strip in rectangular waveguide has been studied by several authors. Lewin [16] has analyzed the thin inductive strip by using a quasi-static method. For the symmetrical case of a centered strip, Lewin has improved the solution by using the method of retention of higher order modes which adds a correction term to the TE_{30} contribution in the series. Marcuvitz [8] has also pursued the quasi-static approach in investigating the centered strip problem and has achieved a similar solution to that of Lewin involving elliptic integrals. Collin [18] applied a variational approach to the flat strip study, with the strip current distribution in the transverse direction assumed to be constant. As Fig. 6 shows, these analyses give widely varying results. Moreover, none of these analyses provided sufficiently good correlation with the measured values reported by Eisenhart and Khan [1].

This problem has been resolved through an extension of the Collin analysis [18] in which the strip current has a quadratic distribution in the x direction, the reactance again obtained by variational means. The details of the analysis are as follows.

The strip current surface density may generally be expressed as a Taylor series, viz:

$$J(x)=\sum_{n=0}^{\infty} C_n(x-x_0)^n \qquad \text{for } |x-x_0|\leqslant \frac{W}{2}. \quad (10)$$

Retaining only the constant term C_0 corresponds to the Collin method [18]. The approach set out here seeks to approximate $J(x)$ as a quadratic expression, viz:

$$J(x) \doteqdot \sum_{n=0}^{2} C_n(x-x_0)^n. \quad (11)$$

Collin [18] has derived the variational form for the strip reactance in terms of the general strip current $J(x)$ as

$$jX_{\text{strip}} = \frac{\Gamma_1}{2}\frac{\sum_{n=2}^{\infty}\int\int \frac{1}{\Gamma_n} J(x)\sin\left(\frac{n\pi x}{a}\right)J(x')\sin\left(\frac{n\pi x'}{a}\right)dx\,dx'}{\left[\int J(x)\sin\left(\frac{\pi x}{a}\right)dx\right]^2} \quad (12)$$

where the X_{strip} is normalized to Z_g

$$\Gamma_n=\sqrt{\left(\frac{n\pi}{a}\right)^2-k^2}$$

$$k=\omega_0\sqrt{\mu_0\epsilon_0}.$$

This reduces for the quadratic current distribution to the following:

$$jX_{\text{strip}}=\frac{\Gamma_1}{2}\frac{\sum_{n=2}^{\infty}\frac{1}{\Gamma_n}\left(x_n+\frac{C_1}{C_0}y_n+\frac{C_2}{C_0}p_n\right)^2}{\left(x_1+\frac{C_1}{C_0}y_1+\frac{C_2}{C_0}p_1\right)^2} \quad (13)$$

where

$$x_n=\frac{2a}{n\pi}\sin\left(\frac{n\pi x_o}{a}\right)\sin\left(\frac{n\pi W}{2a}\right) \quad (14)$$

$$y_n=-\frac{aW}{2\pi n}\left(2\cos\left(\frac{n\pi x_o}{a}\right)\cos\left(\frac{n\pi W}{2a}\right)\right) + \frac{a^2}{n^2\pi^2}2\cos\left(\frac{n\pi x_o}{a}\right)\sin\left(\frac{n\pi W}{2a}\right) \quad (15)$$

$$x_1=\frac{2a}{\pi}\sin\left(\frac{\pi x_o}{a}\right)\sin\left(\frac{\pi W}{2a}\right) \quad (16)$$

$$y_1=-\frac{aW}{2\pi}\left(2\cos\left(\frac{\pi x_o}{a}\right)\cos\left(\frac{\pi W}{2a}\right)\right) + \frac{a^2}{\pi^2}2\cos\left(\frac{\pi x_o}{a}\right)\sin\left(\frac{\pi W}{2a}\right) \quad (17)$$

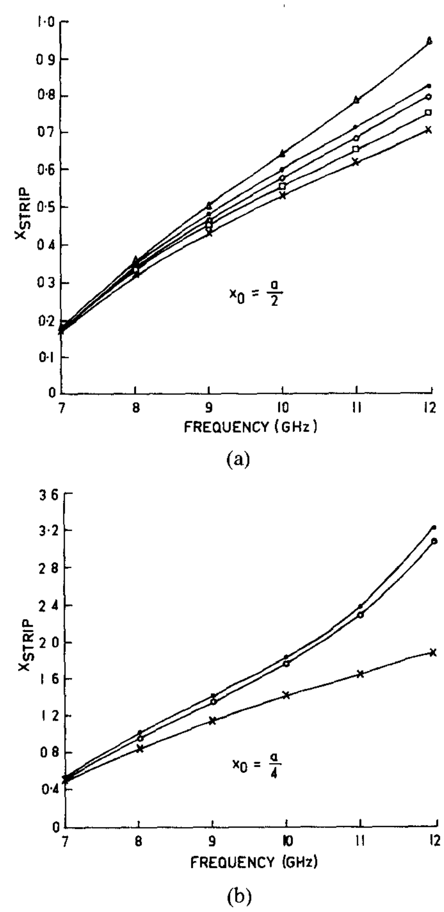


Fig. 6. Calculated values of flat strip reactance versus frequency using several methods available in the literature. The methods are denoted as follows: Collin [18] (·), Lewin [16, p. 177] (x), Lewin centered [16, p. 179] (□), Marcuvitz centered [8] (Δ), revised method of this paper (o). (a) shows the case where $x_o=1.143$ cm, $W=0.635$ mm. (b) shows the off-centered case of $x_o=0.5715$ cm, $W=0.635$ mm. Waveguide dimensions = 2.286 cm × 1.016 cm.

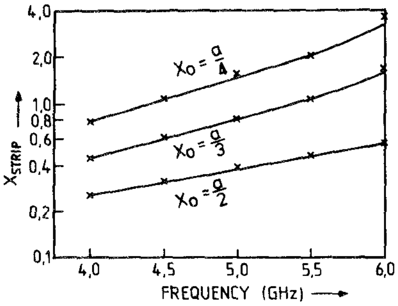


Fig. 7. Correlation between computed strip reactance values and the measured Eisenhart and Khan [1] values denoted (x). Strip width = 0.549 cm, waveguide dimensions = 4.76 cm × 2.215 cm.

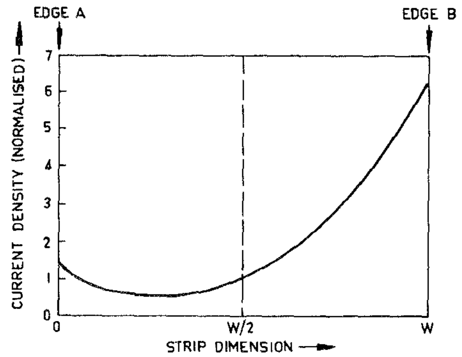


Fig. 8. Variation of calculated surface current density along the strip as a function of the x-coordinate. $x_o = 1.19$ cm, $a = 4.76$ cm, $W = 0.93$ cm. Edge A is closer to the waveguide walls than edge B.

$$p_n = \frac{a}{n\pi}\frac{W^2}{4}\left\{2\sin\left(\frac{n\pi x_o}{a}\right)\sin\left(\frac{n\pi W}{2a}\right)\right\} + \left(\frac{a}{n\pi}\right)^2 W\left\{2\sin\left(\frac{n\pi x_o}{a}\right)\cos\left(\frac{n\pi W}{2a}\right)\right\} - 2\left(\frac{a}{n\pi}\right)^3\left\{2\sin\left(\frac{n\pi x_o}{a}\right)\sin\left(\frac{n\pi W}{2a}\right)\right\}. \tag{18}$$

$$p_1 = \frac{a}{\pi}\frac{W^2}{4}\left\{2\sin\left(\frac{\pi x_o}{a}\right)\sin\left(\frac{\pi W}{2a}\right)\right\} + \left(\frac{a}{\pi}\right)^2 W\left\{2\sin\left(\frac{\pi x_0}{a}\right)\cos\left(\frac{\pi W}{2a}\right)\right\} - 2\left(\frac{a}{\pi}\right)^3\left[2\sin\left(\frac{\pi x_0}{a}\right)\sin\left(\frac{\pi W}{2a}\right)\right]. \tag{19}$$

As the above equation is in variational form, the variables C_1/C_0 and C_2/C_0 may be found by a Rayleigh–Ritz approach, putting

$$\frac{\partial jX_{\text{strip}}}{\partial\left(\dfrac{C_1}{C_0}\right)} = 0 \tag{20}$$

and

$$\frac{\partial jX_{\text{strip}}}{\partial\left(\dfrac{C_2}{C_0}\right)} = 0. \tag{21}$$

The differentiation leads to the following two simultaneous equations:

$$\left(x_1 + \frac{C_1}{C_0}y_1 + \frac{C_2}{C_0}p_1\right)\sum_{n=2}^{\infty}\frac{1}{\Gamma_n}\left(x_n + \frac{C_1}{C_0}y_n + \frac{C_2}{C_0}p_n\right)y_n = \sum_{n=2}^{\infty}\frac{1}{\Gamma_n}\left(x_n + \frac{C_1}{C_0}y_n + \frac{C_2}{C_0}p_n\right)^2 y_1 \tag{22}$$

$$\left(x_1 + \frac{C_1}{C_0}y_1 + \frac{C_2}{C_0}p_1\right)\sum_{n=2}^{\infty}\frac{1}{\Gamma_n}\left(x_n + \frac{C_1}{C_0}y_n + \frac{C_2}{C_0}p_n\right)p_n = \sum_{n=2}^{\infty}\frac{1}{\Gamma_n}\left(x_n + \frac{C_1}{C_0}y_n + \frac{C_2}{C_0}p_n\right)^2 p_1. \tag{23}$$

These equations are nonlinear in (C_1/C_0) and (C_2/C_0) and therefore require iterative solution; Newton's method [19] in two dimensions was used successfully for this purpose. As Fig. 7 shows, excellent agreement is obtained between the calculated and measured data reported by Eisenhart and Khan [1]. Fig. 8 shows the theoretical surface current density distribution along the strip as a function of the x-coordinate, as calculated by the variational method.

V. Factor Calculation and Experimental Verification

Using the theoretical values for the reactance of a round post and a flat strip, the equivalence factor defined in Section II above was computed for a variety of conditions of geometry and excitation.

The variation of the equivalence factor with post position and frequency was first explored. Fig. 9 shows the factor for the post in the centered position of C-band waveguide. The effect of off-centering the post over the same frequency range is also shown in Fig. 9. It is clear from an inspection of the curves that the factor is more sensitive to frequency when the posts are off-centered; this dependence may be attributed to the coupling capacitance between the post and the walls of the waveguide. Fig. 10 shows there is also a relatively strong dependence of the equivalence factor on post diameter. This effect is more predominant in the off-centered case where again the coupling capacitance between the post and the walls of the waveguide is significant.

Values above 2 in Fig. 9 are due to the implicit errors in the approximations used in the variational approaches. The sensitivity of the equivalence factor to both the post and strip impedance calculations leads to the factor climbing slightly above the theoretical value of 2. Fig. 11 shows a useful chart (for the common centered post) of equivalence factor versus frequency, normalized to cutoff and plotted for a family of post diameters. The fundamental limitation in the Eisenhart and Khan [1] approach of $(W/a) < 0.35$ limits the values of the parameter (d/a) to $(d/a) < 0.20$ in this graph.

The equivalent circuit of Eisenhart and Khan [1] may be revised now to remove its empirical factor by replacement with the equivalence factor calculated by the method de-

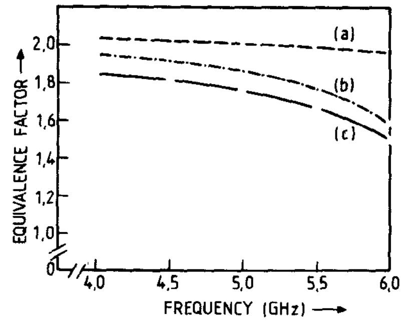


Fig. 9. Variation of the calculated equivalence factor with frequency for: (a) centered post, (b) $x_o = 1.5867$ cm, (c) $x_o = 1.19$ cm. Post diameter = 0.3048 cm, waveguide cross section = 4.76 cm×2.215 cm.

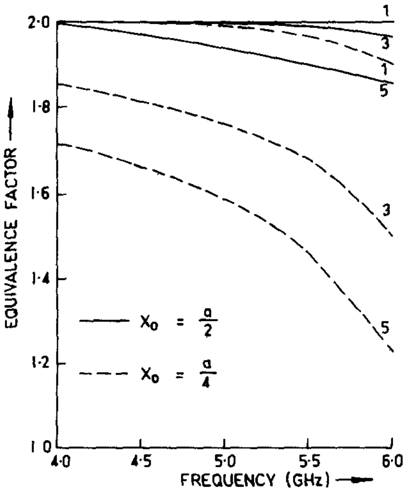


Fig. 10. Variation of the calculated equivalence factor with the frequency for post diameters 1 mm, 3 mm, and 5 mm. The calculations are done both for the centered case and an off-centered case ($x_o = 0.25a$). Waveguide cross section = 4.76 cm×2.215 cm.

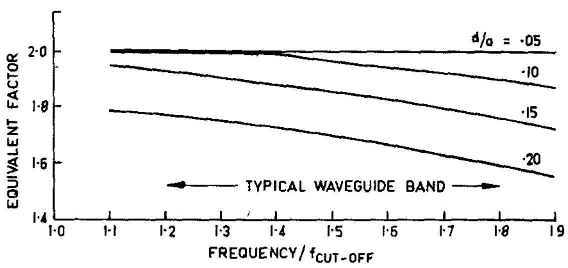


Fig. 11. Variation of the equivalence factor versus frequency, normalized to the waveguide cutoff frequency for a number of post diameters.

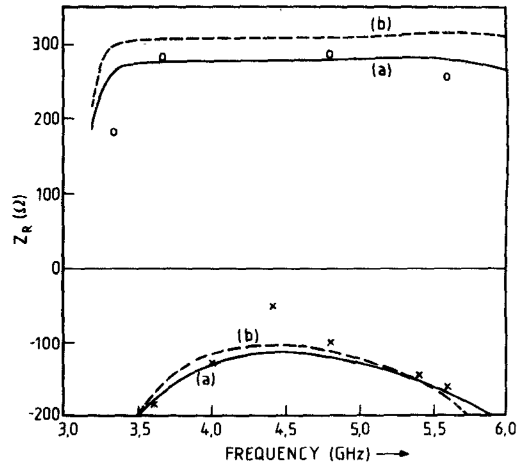


Fig. 12. Correlation between the measured driving point impedances of Eisenhart and Khan [1] and: (a) revised method of this paper, and (b) calculations from [1]. Using the notation of [1], $s' = 0.500$, $h' = 0.500$, and $d = 0.3048$ cm. (o = measured resistance, x = measured reactance). Waveguide dimensions = 4.76 cm×2.215 cm.

scribed above, together with the addition of the series capacitance elements representing the axial phase shift along the post. A comparison between the revised theoretical values, the original calculated results, and the experimental driving point impedances of Eisenhart and Khan is shown in Fig. 12. There is slightly improved correlation between theory and experiment through use of the calculated factor.

From an examination of the above results, it is clear why Eisenhart and Khan [1] chose the figure of 1.8 for the equivalence factor. Their original analysis excluded the use of the series post capacitances. Thus, for off-centered posts, where this capacitance is relatively small, Fig. 9 shows 1.8 is a reasonable average value to choose. However, for centered posts the empirical value of 1.8 without series capacitance elements as per the original Eisenhart and Khan paper [1] gives similar results to the calculated value of approximately 2.0 with the series capacitance elements explicitly dealt with separately.

No account has been taken of the effect of the gap in the post during the calculation of the equivalence factor. El-Sayed [2] found for small diameters almost perfect agreement was obtained between theory and experiment by using the Eisenhart and Khan [1] empirical factor of 1.8 together with an equivalent circuit impedance multiplicative factor of $(1 - W/2a)$. The additional multiplicative factor reflects the nonuniform current distribution across the post and is clearly independent of the gap size. Such good agreement was found for gap sizes up to the order of $b/4$. On this basis, the analyses used above, which clearly take into account the nonuniform current distribution, should be applicable for gap sizes up to the order of $b/4$.

VI. Approximate Factor Analysis for Centered Posts

For small post diameter mounts centered in the waveguide, an approximate formula may be derived for the equivalence factor. Marcuvitz [8, p. 227–229] has derived an approximation for small centered strips, viz:

$$X_{\text{strip}} \doteqdot \frac{a}{2\lambda_g}\left[\ln\left(\frac{8a}{\pi e^2 W}\right) + \frac{4}{27}\left(\frac{a}{\lambda}\right)^2\right] \text{ for } W \ll a. \quad (24)$$

This formulation has been derived by the quasi-static method in considering the static obstacle current produced by the TE_{10} mode and thereby permitting the reactance to be calculated. This approximation was used in preference to a modification of the revised Collin analysis set out above, due to the difficulty in approximating this analysis. The Marcuvitz approximation given above was found to be sufficiently accurate for the centered diode mount situation under investigation.

It remains now to approximate the post-analysis formula for the centered case. For small diameters, terms of order d^2 may be ignored, which thereby excludes further consideration of X_c. The term $Y_0(\pi d/\lambda)[1-1/J_0(\pi d/\lambda)]$ also tends to zero by this reasoning. Then

$$\frac{jX_{\text{post}}}{Z_g} \doteq j\frac{\beta_1 a}{4\pi}\left\{\ln\left(\frac{4a}{\pi e^2 d}\right)+2S_A\right\}. \tag{25}$$

Remembering X_{strip} is already normalized, equating X_{post}/Z_g and X_{strip} to determine the equivalence factor yields in the centered case

$$W = 2(1+\epsilon)d \tag{26}$$

where $1+\epsilon$ is a perturbation from the free-space value of 2.0 and is given as

$$1+\epsilon = \exp\left[2S_A - \frac{4}{27}\left(\frac{a}{\lambda}\right)^2\right]. \tag{27}$$

One may clearly expect this formula to be valid only for small diameters ($d/a < 0.075$) and for low frequencies near cutoff where the quasi-static method applies. The benefits of such an approximate factor are two-fold. Firstly, it indicates quantitatively the parameters which affect the equivalence factor most significantly. Secondly, for regions where the approximations are valid, the factor may easily be incorporated into an already existing program to calculate diode mount parameters using the method of Eisenhart and Khan. Otherwise, the complex iterative procedure described earlier must necessarily be used.

VII. Conclusions

This paper has outlined an analytical method whereby the equivalence factor for round post to flat strip conversion may be calculated for a waveguide environment. A slight improvement in the correlation between calculated and measured driving point impedance is obtained by using the above method in preference to the previously used empirical value of 1.8. The analysis not only allows the sensitivity of the factor to various post geometry dimensions to be ascertained, but also yields an approximate expression for the equivalence factor for small-diameter centered posts at frequencies just above the dominant-mode cutoff frequency where the quasi-static method applies best.

References

[1] R. L. Eisenhart and P. J. Khan, "Theoretical and experimental analysis of a waveguide mounting structure," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 706–719, Aug. 1971.

[2] O. L. El-Sayed, "Impedance characterization of a two post mounting structure for varactor-tuned Gunn oscillators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 769–776, Aug. 1974.

[3] J. S. Joshi and J. A. F. Cornick, "Analysis of a waveguide mounting configuration for electronically-tuned transferred-electron-device oscillators and its circuit applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 573–584, Sept. 1976.

[4] R. L. Eisenhart, "Comments on a 2-gap waveguide mount," in *Proc. 1976 IEEE MTT-S Internat. Microwave Symp.*, pp. 60–62.

[5] R. L. Eisenhart, P. T. Greiling, L. K. Roberts, and R. S. Robertson, "A useful equivalence for a coaxial-waveguide junction," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp. 172–174, Mar. 1978.

[6] K. Ogiso and D. Taketomi, "A design of X-band pulsed Gunn diode oscillators using measured pulsed Gunn diode admittance," in *Proc. 6th Cornell Electrical Engineering Conf.*, Aug. 1977, pp. 113–121.

[7] T. G. Blocker, D. N. McQuiddy, T. E. Hasty, and D. W. Shaw, "Device-package-circuit optimization of Gunn devices at millimeter wave frequencies," in *Proc. 4th Biennial Cornell Electrical Engineering Conf.*, Aug. 1973, pp. 155–164.

[8] N. Marcuvitz, *Waveguide Handbook.* New York: McGraw-Hill, 1951.

[9] R. L. Eisenhart and P. J. Khan, "Some tuning characteristics and oscillation conditions of a waveguide-mounted transferred electron diode oscillator," *IEEE Trans. Electron. Devices*, vol. ED-19, pp. 1050–1055, Sept. 1972.

[10] O. El-Sayed, "Generalized analysis of parallel two-post mounting structures in waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp. 24–33, Jan. 1977.

[11] A. G. Williamson and D. V. Otto, "Analysis of a waveguide mounting structure," in *Proc. I.R.E.E., Australian Electronics Communications*, Apr. 1973, pp. 95–97.

[12] H. Jasik, Ed., *Antenna Engineering Handbook.* New York: McGraw-Hill, 1961.

[13] T. A. Abele, "Inductive post arrays in rectangular waveguide," *Bell Syst. Tech. J.*, vol. 57, pp. 577–594, Mar. 1978.

[14] A. V. Moschinskiy and V. K. Berezovskiy, "An exact solution of the problem of scattering of the H_{10} mode on a circular cylindrical inhomogeneity in a rectangular waveguide," *Radio Eng. Electron. Phys.*, vol. 22, pp. 18–22, July, 1977.

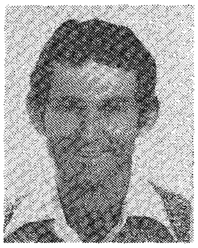
[15] T. T. Fong, K. P. Weller, and D. L. English, "Circuit characterization of V-band IMPATT oscillators and amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 752–758, Nov. 1976.

[16] L. Lewin, *Theory of Waveguides.* London: Newnes–Butterworths, 1975.

[17] J. Schwinger and D. S. Saxon, *Discontinuities in Waveguides.* New York: Gordon & Breach, 1968.

[18] R. E. Collin, *Field Theory of Guided Waves.* New York: McGraw-Hill, 1960.

[19] L. W. Johnson and R. D. Riess, *Numerical Analysis.* London: Addison–Wesley, 1977.



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