Short Papers

Bandwidth Properties of Rectangular T-Septum Waveguides

FRED J. GERMAN, MEMBER, IEEE, AND LLOYD S. RIGGS, MEMBER, IEEE

Abstract —**The transmission line modeling (TLM) method is applied to rectangular T-septum waveguides for the determination of the separation between the hybrid TE_{10} and hybrid TE_{20} modes. While previous analyses have predicted a wider bandwidth for this class of waveguiding structure than is available with conventional ridged waveguide, they have not been in agreement on the exact bandwidth properties. This discrepancy is resolved, and the apparent cause of error in previously published results is pointed out.**

I. Introduction

Recently there has been some interest in the use of rectangular waveguides with T-shaped septa (see Fig. 1) as an alternative to conventional ridged waveguides. These new structures provide a larger separation between the first two TE modes, thus allowing the guides to be used over a wider range of frequencies than ridged guides. Previously, rectangular waveguide fitted with a T septum on a sidewall has been investigated and found to support two modes with equal phase velocities [1]. The concept of using T-septum waveguides for operation over an increased bandwidth was arrived at intuitively by Mazumder and Saha, who analyzed rectangular waveguide with both single and double T septa [2], [3]. Their analysis applied the Ritz–Galerkin technique to the derived integral eigenvalue equations. The results of this analysis showed that the structure displays a wider bandwidth than ridged guide. Later, the same structure was analyzed by Zhang and Joines [4]. The two analyses are in excellent agreement for the first TE mode. There is a discrepancy, however, concerning the cutoff of the second mode and, hence, the bandwidth characteristics. While both analyses show an increased bandwidth over ridged guide, the results in [4] predict a substantially larger modal separation than that given in [2] and [3].

The purpose of this paper is to resolve the discrepancy in the bandwidth properties of T-septum waveguides. It is shown that the original analysis [2], [3] of the structure is correct. Further, it seems that the analysis in [4] has implemented incorrect symmetry conditions for the calculation of the cutoff of the second mode, and as a consequence the data given in [4] for modal separation are for the separation between the first and third TE modes—not the first and second.

II. Method of Analysis

For the analysis presented in this paper we have employed the transmission line modeling (TLM) method of numerical analysis. This method is well established for the characterization of waveguides of arbitrary cross section at cutoff [5], [6]. The method has been used by Shih and Hoefer to verify results for cutoff frequencies and dispersion in finline structures [7]. In order to characterize T-septum waveguides at cutoff, the two-dimensional TLM method has been used. The theory of two-dimensional TLM is well documented in the literature [8], [9]; therefore, only a brief explanation of the technique will be given here.

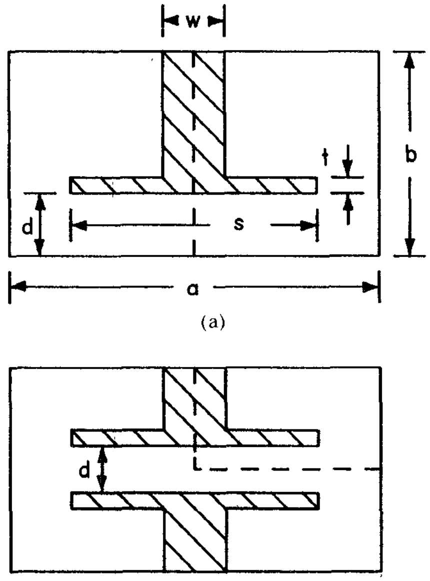

Fig. 1. Cross section of (a) single T-septum guide and (b) double T-septum guide (dimensions in (b) are the same as in (a) with the exception of *d*, as shown)

The existence of equivalent circuit models of the Maxwell equations has been known for some time [10]. The two-dimensional TLM method is based on representing the circuital equivalent of the Maxwell equations via the use of ideal, shunt (or series) connected two-wire transmission lines. The solution of the electromagnetic fields is accomplished by placing a mesh of such transmission lines in the problem space to be simulated. Boundaries are modeled by specifying the appropriate reflection coefficients in the mesh. Once the mesh has been specified, the excitation is specified by initializing ideal impulses corresponding to the desired field components at the appropriate locations in the TLM mesh. As time is advanced, these pulses are followed as they travel between nodes and scatter at the nodes. The output is obtained by saving the stream of pulses passing the output points which correspond to the desired output field quantities. This output impulse function may then be convolved with any excitation waveform to yield the response to that excitation. Alternatively, the output can be Fourier transformed to yield the steady-state response to sinusoidal excitation. In this work the output has been Fourier transformed, and the modes identified by observing the resonant peaks in the frequency spectrum.

For the work presented in this paper, a two-dimensional TLM program utilizing a shunt-connected mesh has been implemented. In order to obtain increased modeling resolution and more efficiently utilize computer resources, a graded mesh has also been implemented. This allows the use of rectangularly shaped transmission line elements, which permits the mesh to be made most

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The authors are with the Department of Electrical Engineering, Auburn University, Auburn, AL 38630-3501.

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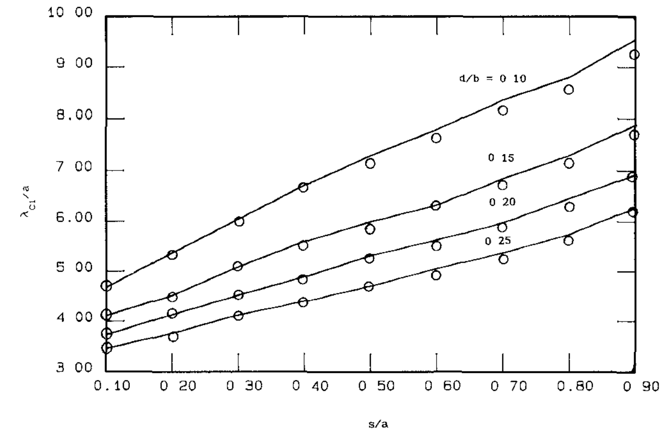

Fig. 2. Normalized cutoff wavelength of fundamental mode in STSG ($b/a = 0.45$, $w/a = 0.10$, $t/b = 0.05$). ○ Mazumder and Saha; —— TLM.

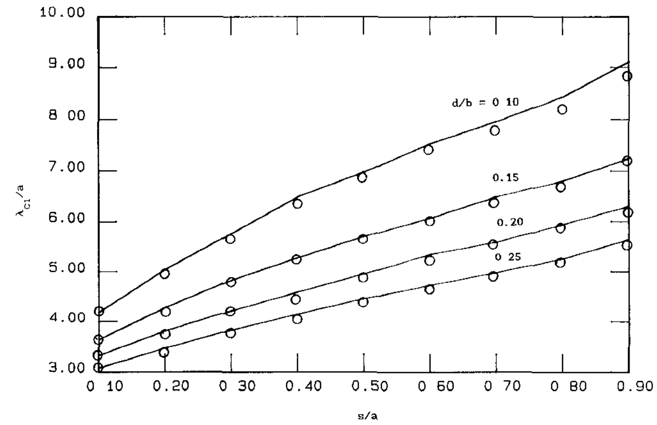

Fig 3. Normalized cutoff wavelength of fundamental mode in DTSG ($b/a = 0.50$, $w/a = 0.10$, $t/b = 0.05$) ○ Mazumder and Saha; —— TLM.

dense in areas where the fields are changing rapidly. The particular method used to grade the mesh is based on the hybrid matrix technique of Al-Mukhtar and Sitch [9].

The cross sections of the structures of interest are shown in Fig. 1. Fig. 1(a) is the single T-septum guide (STSG) and Fig. 1(b) is the double T-septum guide (DTSG). Note that for the DTSG only the symmetrical septum case is considered here. Computational efficiency and suppression of undesired modes can be greatly enhanced by the use of appropriate symmetry boundary conditions. For the STSG only half of the structure must be considered, while only one quarter of the DTSG must be analyzed. The sections of the STSG and DTSG analyzed are indicated in Fig. 1 by the dashed lines.

In this study we are concerned only with the hybrid TE_{10} and hybrid TE_{20} modes. For calculation of the hybrid TE_{10} mode, the vertical symmetry plane should be a perfect magnetic conductor, and for the hybrid TE_{20} mode it should be a perfect electric conductor. For the DTSG, the horizontal symmetry plane is a perfect electric conductor.

III. Numerical Results

An analysis of the STSG and DTSG has been performed using TLM, as described in the previous section. The waveguides were excited by initializing the H_z field component along a vertical line at various positions directly beneath the T septum. The output was also the H_z field component taken beneath the septum. The TLM mesh was graded such that the highest density of nodes was located at the edges of the "T".

Results for the cutoff wavelength of the hybrid TE_{10} mode for the STSG and DTSG are shown in Figs. 2 and 3, respectively; the dimensions used are given in the figures. These results are in very good agreement with the same data as calculated in [2], [3], and [4], thus providing further confirmation of these results.

To determine the cutoff wavelengths for the hybrid TE_{20} mode, the vertical symmetry plane was changed to a perfect electric conductor for both STSG and DTSG. The results obtained by the TLM simulation are shown in Figs. 4 and 5. These results agree very well with those obtained by Mazumder and Saha [2], [3]. This indicates that the results for the hybrid TE_{20} mode given in [4], which predict a larger bandwidth, are in error.

In an effort to identify the source of error in [4], the DTSG data using a perfect magnetic conductor for the vertical symmetry plane were reexamined. The second resonance under these symmetry conditions corresponds to the second mode which has a nonzero E_y field component along the vertical center of the guide. The results for the modal separation between this mode

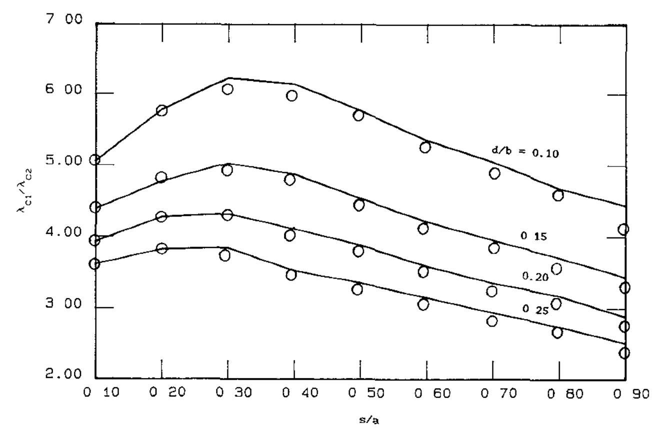

Fig. 4. Bandwidth characteristic of STSG ($b/a = 0.45$, $w/a = 0.10$, $t/b = 0.05$) ○ Mazumder and Saha; —— TLM.

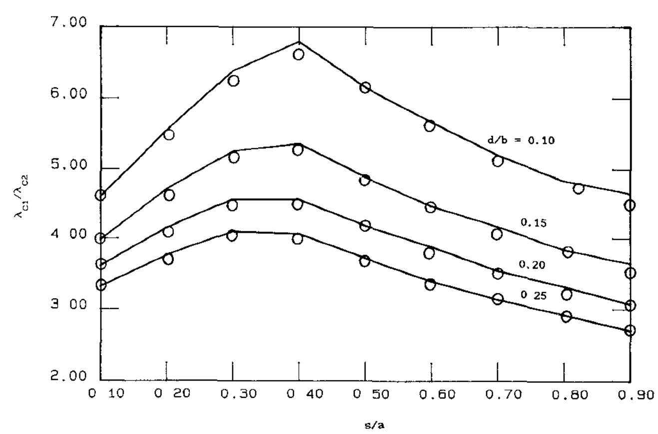

Fig 5. Bandwidth characteristics of DTSG ($b/a = 0.50$, $w/a = 0.10$, $t/b = 0.05$). ○ Mazumder and Saha; —— TLM.

and the hybrid TE_{10} mode are given in Fig. 6 for two different values of d/b. Values obtained by Zhang and Joines in [4] for separation between the hybrid TE_{10} and hybrid TE_{20} modes are indicated in this figure by O's. The level of agreement shown in Fig. 6 would seem to indicate that incorrect symmetry conditions were implemented in [4] for calculation of the hybrid TE_{20} mode. The curves given in [4] actually appear to describe the separation between the first and second waveguide modes with nonzero E_y along the vertical center of the waveguide.

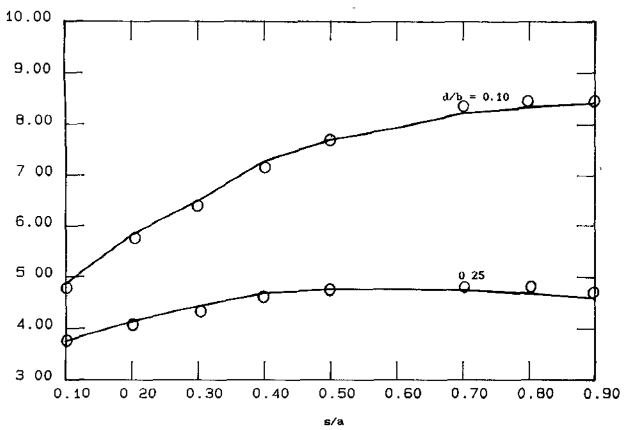

Fig. 6. Comparison of third mode from TLM analysis and second mode from analysis in [4] for DTSG ($b/a = 0.50$, $w/a = 0.10$, $t/b = 0.50$) O Mazumder and Saha; —— TLM.

IV. Conclusions

The bandwidth characteristics of rectangular waveguide with both single and double T-shaped septa have been investigated. The numerical analysis was performed using the well-established TLM method. Results for the cutoff waveguide of the dominant mode have been calculated for various dimensions of the structure and have been found to be in very good agreement with previously calculated results. Previously, there was disagreement in the correct results for the bandwidth characteristics of the guides. Using the TLM simulation, we have calculated the bandwidth for both the STSG and the DTSG. Our results are shown to agree with those originally given by Mazumder and Saha [2], [3]. It has also been observed that the results for bandwidth calculated by Zhang and Joines [4] appear to actually be the separation between the first and third TE modes.

Considering the agreement of the results obtained using the Ritz–Galerkin technique and the TLM method, it is felt that a great deal of confidence may be placed in the results of this and previous investigations.

References

[1] R. S. Elliott, "Two-mode waveguide for equal mode velocities," *IEEE Trans. Microwave Theory Tech.*, vol MTT-16, pp. 282–286, May 1968.

[2] G. G. Mazumder and P. K. Saha, "A novel waveguide with double T-septums," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, pp. 1235–1238, Nov. 1985.

[3] G. G. Mazumder and P. K. Saha, "Rectangular waveguide with T-shaped septa," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-35, pp. 201–204, Feb. 1987.

[4] Y. Zhang and W. T. Joines, "Some properties of T-septum waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-35, pp 769–775, Aug. 1987.

[5] P. B. Johns, "Application of the transmission-line-matrix method to homogeneous waveguides of arbitrary cross-section," *Proc. Inst Elec Eng.*, vol. 119, pp. 1086-1091, Aug. 1972.

[6] P. B. Johns, "The solution of inhomogeneous waveguide problems using a transmission-line matrix," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp 209–215, Mar. 1974.

[7] Y. C. Shih and W. J. R Hoefer, "Dominant and second-order mode cutoff frequencies in fin lines calculated with a two-dimensional TLM program," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, pp. 1443-1448, Dec. 1980

[8] P. B. Johns and R. L. Beurle, "Numerical solution of 2-dimensional scattering problems using a transmission-line matrix," *Proc Inst. Elec Eng.*, vol 118, pp. 1203–1208, Sept. 1971.

[9] D. A. Al-Mukhtar and J E Sitch, "Transmission-line matrix method with irregularly graded space," *Proc. Inst. Elec. Eng.*, vol 128, pt H, pp 299–305, Dec. 1981

[10] G. Kron, "Equivalent circuit for the field equations of Maxwell—I," *Proc. IRE*, vol. 32, pp. 289–299, May 1944.

On the Bandwidth of T-Septum Waveguide

B. E. PAUPLIS AND D. C. POWER

***Abstract*—There is some degree of confusion in the recent literature concerning the bandwidth properties of T-septum waveguide. Two analyses, using the same Rayleigh–Ritz–Galerkin technique, disagree significantly. We present another analysis of the T-septum guide, using an alternative formulation of the method, which supports the original analysis of Mazumder and Saha. A possible source of the disagreement is found and illustrated. The history of the T-septum waveguide is discussed and several additional references are provided.**

I. Introduction

The history of the T-septum waveguide is long and interesting. This type of waveguide seems to have appeared first in the literature in 1968, when Elliott [1] proposed and analyzed it as an example of a waveguide having two modes which can be made to propagate at a common phase velocity. The proposed application was to slotted guide antennas having variable polarization. Although Elliott was particularly interested in a configuration with a single T septum attached to the sidewall of rectangular waveguide, his analysis did not depend on whether the septum was attached to the narrow or to the broad wall. An additional analysis of the configuration was presented by Silvester [2] as an example of the use of a finite element analysis program for general waveguide cross sections. The T-septum guide also was analyzed by Alexopoulos and Armstrong [3] and by Lyon [4]. The primary interest of all of these authors in the structure was as a two-mode waveguide with equal mode velocities, but the wide-band possibilities of the configuration were understood [1], [4].

Recently, Mazumder and Saha [5], [6] generalized the waveguide cross section to include double T-septum guide. They reported the analysis of the cutoff frequencies and bandwidths of various geometries, with the principal motivation being the optimization of bandwidth. They discovered that the waveguide could be designed to have slightly broader bandwidths than standard single- or dual-ridged guide. The most recent work concerning T-septum guide was that of Zhang and Joines [7], [8], who reported that [5] and [6] had incorrectly identified the second mode eigenvalue and therefore the waveguide was significantly broader in bandwidth than had been believed. The reported discrepancy is significant; the differences between the analyses approach 75 percent in some cases. Both groups used the Rayleigh–Ritz–Galerkin procedure originally described by Montgomery [9] and subdivided the waveguide cross section as shown in Fig. 1(a).

This paper reports the results of our analysis of the T-septum waveguide. We also use the Rayleigh–Ritz–Galerkin procedure, but we subdivide the waveguide cross section as shown in Fig. 1(b). We find that our results agree very closely with the original analyses in [1]–[6] and with the new results of German and Riggs [10], but disagree significantly with the results in [7]. We indicate what we believe to be the error in [7] by reproducing their results using our analysis. We further show that the usual practice of naming the modes of reentrant waveguide, such as the T-septum and ridged guide, with the standard nomenclature of rectangular waveguide (TE_{mn}) is misleading.

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The authors are with the Missile Systems Division, Raytheon Company, 50 Apple Hill Drive, Tewksbury, MA 01876.

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