LEAKAGE PROPERTIES OF A STUB-LOADED RIDGE-RECTANGULAR WAVEGUIDE

Mikio TSUJI and Hiroshi SHIGESAWA
Department of Electronics, Doshisha University
Kyotanabe, Kyoto 610-0321, Japan
E-mail mtsuji@mail.doshisha.ac.jp

1. Introduction

A leaky-wave line-source antenna is basically an open waveguide that supports a leaky mode (instead of a bound mode) and that therefore radiates all along its length. For use at millimeter wavelengths, various novel leaky-wave antennas were proposed, analyzed, and measured based on some low loss open waveguide designed specifically. Since these waveguides are already open, a physical cut to produce leakage is not meaningful and new mechanisms were tried for permitting the initially bound dominant mode to leak, the most common of which was the introduction of asymmetry. One of the most widely used of these open waveguides for antenna purposes is the stub-loaded rectangular waveguide, proposed by us[1-4] and consisting of a rectangular waveguide with an asymmetrically located stub guide. This guide can be fed by an ordinary rectangular waveguide source, radiate in a single polarization (with negligible cross polarization at all scan angles), possess flexibility in beamwidth and permit one to change the beamwidth without affecting the angle of maximum radiation. The only problem of this guide is that one must take more than a half wavelength in the width of a rectangular waveguide. This means that for use of a scanning array antenna, extra main beam due to a grating lobe is not avoided. Therefore, the width of the guide needs to be reduced to less than a half wavelength and then we have done it by using a ridge waveguide(see Fig. 1) , as D. Y. Kim and R. S. Elliott had introduced it for planar array of slots[5]. In this paper, we have investigated the effect of ridging stub-loaded rectangular waveguides, theoretically and experimentally. The waveguide structure proposed here is very complicated and includes many conductor edges at which the fields diverge. So it is hard to analysis it by the ordinary mode-matching technique due to slow convergence. To overcome this difficulty, we have proposed a new analytical method based on the efficient mode-matching technique developed by us[6][7], in which the singular aperture fields are assumed.

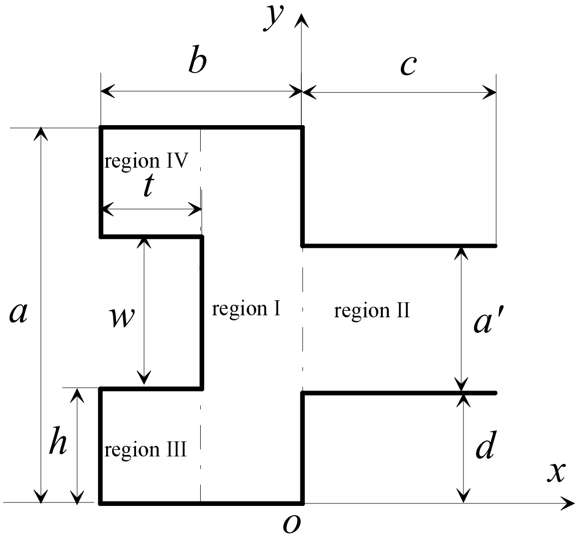

Fig. 1. Cross-section view of a stub-loaded ridge-rectangular waveguide. The stub guide is located asymmetrically to produce a vertically electric field component that propagates as a TEM wave at an angle in the stub guide and radiates power from the open end.

2. Numerical Approach

Here we consider a stub-loaded ridge-rectangular waveguide which installs a ridge into the conventional stub-loaded rectangular waveguide[1], as shown in Fig. 1. Numerical-analysis method used here is the modified mode-matching method developed by us [2], in which the singular aperture functions, expressing the field behavior at the corners of conductors, are incorporated to accelerate the convergence of solutions. Then, we divide the guide cross section vertically divided into four regions, I, II, III, and IV, as shown in Fig. 1. The electric and magnetic field components E_u^i and H_u^i (where $u = x, y, z$ and I = I, II, III, IV) in each region are expanded in terms of both fields of TM and TE constituent waves to the y direction; these components fulfill the boundary conditions on the xz planes of the conductors. For example, E_y^I and H_y^I in the region I are expressed as follows:

$$E_y^I = \sum_{n=1}^{N} \left\{ V_{1n}^I \frac{\sin \bar{k}_{xn}^I x}{\sin \bar{k}_{xn}^I (t-b)} - V_{2n}^I \frac{\sin \bar{k}_{xn}^I (x-t+b)}{\sin \bar{k}_{xn}^I (t-b)} \right\} \cos\left\{ \frac{(n-1)\pi}{a} y \right\} \tag{1}$$

$$H_y^I = -\sum_{n=1}^{N} \left\{ I_{1n}^I \frac{\sin k_{xn}^I x}{\sin k_{xn}^I (t-b)} - I_{2n}^I \frac{\sin k_{xn}^I (x-t+b)}{\sin k_{xn}^I (t-b)} \right\} \sin\left(\frac{n\pi}{a} y \right) \tag{2}$$

In these equations, V_{jn}^I and I_{jn}^I (j=1, 2) are the unknown modal amplitudes, and k_{xn}^I is the wavenumber in the x direction. The overbar is used to denote quantities for the TM_y constituent wave.

Instead of applying the field matching directly to the fields on the yz planes at $x = 0$ and t-b, we first satisfy the y-component continuity on these planes through unknown aperture fields E_{yja} and H_{yja} (j = 1, 2). These aperture fields are expanded into functions that present the singular behavior of fields at conductor edges with right angle and fulfill the boundary condition on the xz plane of the conductors. For example, the singular aperture fields at x =0 are given as follows:

$$E_{y2a} = \begin{cases} 0 & (0 < y < d) \\ \displaystyle\sum_{q=1}^{Q} A_{1q} \frac{\cos\{(q-1)\pi(y-d)/a'\}}{\{1-y/(d+a')\}^{1/3} (y/d-1)^{1/3}} & (d < y < d+a') \\ 0 & (d+a' < y < a) \end{cases} \tag{3}$$

$$H_{y2a} = \begin{cases} \displaystyle\sum_{q=1}^{Q} B_{1q} \frac{\sin\{(2q-1)\pi y/2d\}}{\{1-(y/d)^2\}^{1/3}} & (0 < y < d) \\ \displaystyle\sum_{q=1}^{Q} B_{2q} \frac{\cos\{(q-1)\pi(y-d)/a'\}}{\{1-y/(d+a')\}^{1/3} (y/d-1)^{1/3}} & (d < y < d+a') \\ \displaystyle\sum_{q=1}^{Q} B_{3q} \frac{\sin\{(2q-1)\pi(a-y)/2(a-d-a')\}}{\left[1-\{(a-y)/(a-d-a'\}^2\right]^{1/3}} & (d+a' < y < a) \end{cases} \tag{4}$$

where A_{mq} and B_{mq} are the unknown coefficients of the qth singular function. On the other hand, the singular aperture fields at $x = t$-b are easily obtained in the same way.

Then equating these singular-aperture fields to the y component of the modal functions in Eqs. (1) and (2) at both x = 0 and t-b, applying the orthogonal relations of the modal function, and using an integral formula, the modal amplitudes V_{jn}^i and I_{jn}^i in each region can be expressed in terms of the unknown coefficients of the singular-aperture functions. Finally, we introduce the remaining continuity condition of the z component fields on the yz planes at at x = 0 and t-b in the usual mode-matching sense and obtain the eigenvalue equation for the complex propagation constant of the guide. It is obvious from the above description that the matrix size to be solved depends not on the number N of modal functions, but only on the number Q of unknown coefficients expressing aperture fields.

Since the stub guide shown in Fig. 1 produces a vertically electric field component that propagates as a TEM wave at an angle in it and radiates power from the open end, we assume that it is terminated by the admittance $Y_R/Y_0 = G_R/Y_0 + jB_R/Y_0$ for a TEM wave (TM_{y0}^{II} wave). The expressions of the admittance are approximately given as the follows[3]:

$$\frac{G_R}{Y_0} = \bar{k}_{x0}^{II}\,\frac{a'}{2} - \frac{(\bar{k}_{x0}^{II} a')^3}{48} \qquad (5)$$

$$\frac{B_R}{Y_0} = \bar{k}_{x0}^{II}\,\frac{a'}{\pi} \ln\left[\frac{e}{\gamma}\,\frac{\pi}{\bar{k}_{x0}^{II} a'}\right] \qquad (6)$$

where e = 2.718 and γ = 1.781.

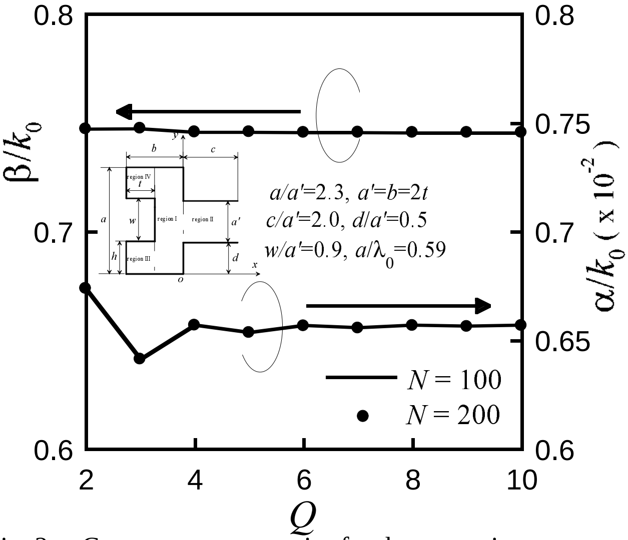

Fig. 2. Convergence properties for the expansion terms.

3. Numerical Results

Figure 2 shows a typical example of the convergence properties for the complex propagation constant at a/λ_0 = 0.59, when the guide dimensions are assumed to be a/a' = 2.3, a' = b = 2t = 2d = 0.5c, and w/a' = 0.9. It is found from this figure that both the phase constant β/k_0 and the attenuation constant α/k_0 almost converge when we take N = 100 and Q = 6. We perform the numerical calculations by taking N = 200 and Q = 8 hereafter.

Figure 3 shows the dispersion characteristics of the normalized phase constant β/k_0 and the attenuation constant α/k_0. For comparison, the results for the stub-loaded rectangular waveguide with t/b=0 are indicated by the dashed lines. We can find that the dispersion characteristics for t/b=0.5 shift towards the low frequency by the effect of the ridge. As a result, even the waveguide with the width a less than a half wavelength, that is, a/λ_0<0.5, works well as a leaky-wave antenna as expected. The effect of the various parameters of the guide on both the dispersion and the radiation behaviors will be presented at the talk.

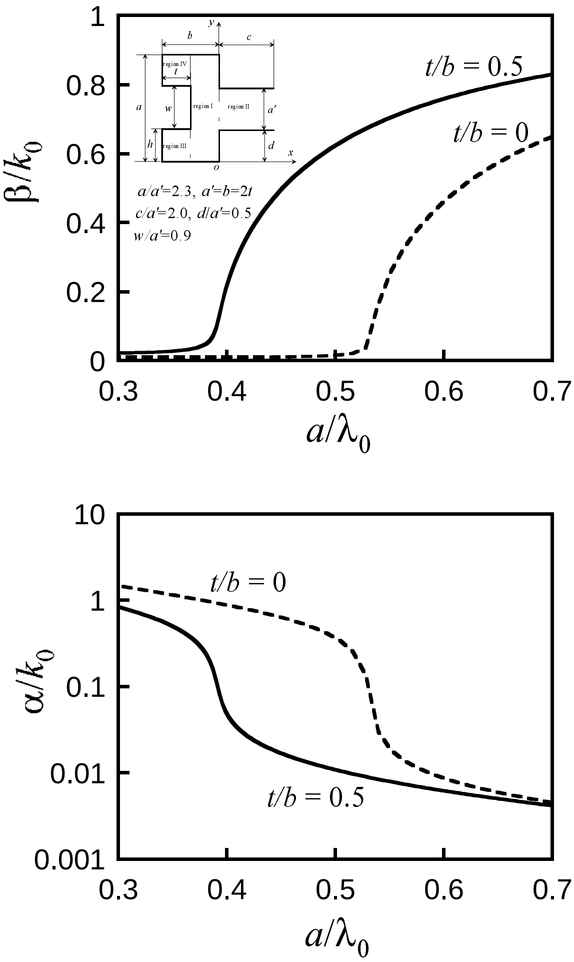

Fig. 3. Behavior of the normalized phase and attenuation constants as a function of the normalized frequency a/λ_0 for the stub-loaded ridge-rectangular waveguide (t/b =0.5). For comparison, the calculated results for the stub-loaded rectangular waveguide (t/b = 0) are also indicated by the dashed lines.

4. Experiment

To verify the results obtained above, we took a measurement of the phase and attenuation constants. The structure that was measured is the same as that for the calculation (a=17.6mm). Both values of the phase and attenuation constants were obtained by measuring S_{21} between the launching and receiving ends of the line, for various values of line length. Figure 4 shows the measured results, indicated by the black dots. The solid curve in this figure is the theoretical result for the present method. Although there is a little difference between the theoretical and measured results in the attenuation measurement, the behavioral features of the stub-loaded ridge waveguide presented here are very similar each other. We also took a measurement of the radiation characteristics and these results will be presented at the talk.

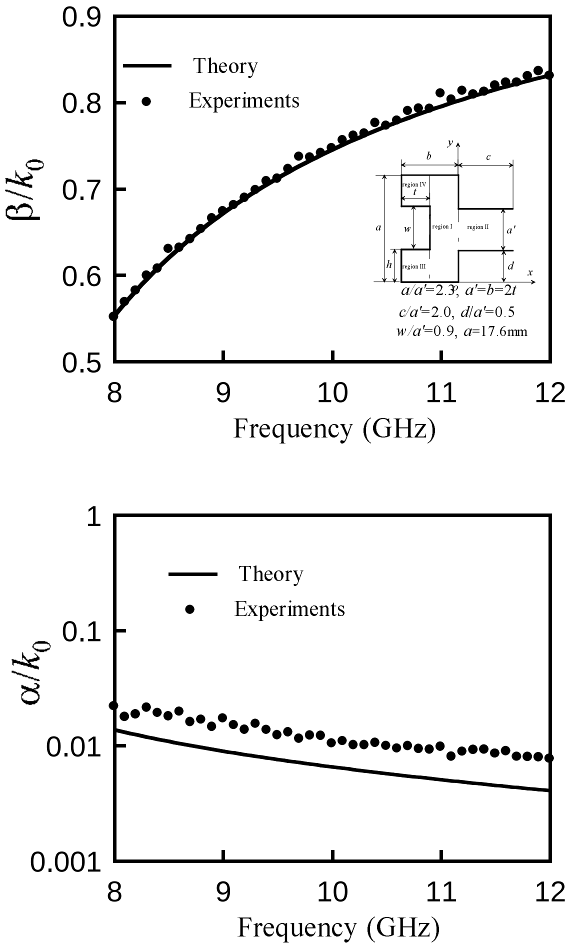

Fig. 4. Comparison of theoretical and measured values for the normalized phase and attenuation constants as a function of the frequency.

5. Conclusions

We have proposed the stub-loaded ridge waveguide that works as a leaky-wave antenna. This structure is very complicated, so we have presented a new analytical method that is very useful for this guide and have shown the phase and attenuation constants. Finally, we have verified their behavioral feature experimentally. To reduce and otherwise control the sidelobes of the radiation patterns, the desired aperture amplitude distributions of the leaky-wave antenna must be realized by varying the leakage constant along the aperture length, while maintaining the phase constant. The structure of such an antenna will be presented in near future. This work was supported in part by a Grant-in-Aid for Scientific Research (09650432) from Japan Society for the Promotion of Science and by the Aid of Doshisha University's Research Promotion Fund.

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