LEAKY-WAVE ANTENNAS WITH LOW SIDELOBES BASED ON STUB-LOADED RIDGE-RECTANGULAR WAVEGUIDES

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

1. Introduction

Leaky-wave antennas based on an open-waveguide structure can become a candidate of millimeter-wave antennas. Since such a structure is already open, leakage is produced by introducing not a physical cut, but asymmetry of the structure. As a result, it supports a leaky mode (instead of a bound mode) and therefore radiates all along its length, possess flexibility in beamwidth and scans the angle of maximum radiation by changing the frequency. One of these open-waveguide structures for antenna purposes is the stub-loaded ridge rectangular waveguide[1][2], which consists of a ridge rectangular waveguide with an asymmetrically located stub guide. This guide radiates in a single polarization (with negligible cross polarization at all scan angles) and its width can be reduced to less than a half wavelength by the ridging effect, so that for use of a scanning array antenna, extra main beam due to a grating lobe can be avoided. Furthermore, since this guide has many structural parameters, it can be expected to develop an antenna with high performance, for example, with low sidelobes. The design of such an antenna has been tried by using the equivalent circuits[1], but it can not use practically because the guide includes many conductor edges at which the fields diverge, and then the equivalent circuits do not give the accurate design data. Therefore we have first developed the accurate analytical method incorporating the singular field behavior into the aperture-field expressions[2]. This method is possible to design a leaky wave antenna with high performance. So in this paper, we have proposed a design procedure of a leaky wave antenna with low sidelobes and developed the antenna with the Taylor distribution of –30dB sidelobes based on the stub-loaded ridge rectangular waveguide. The validity of the designed antenna has been verified numerically and experimentally.

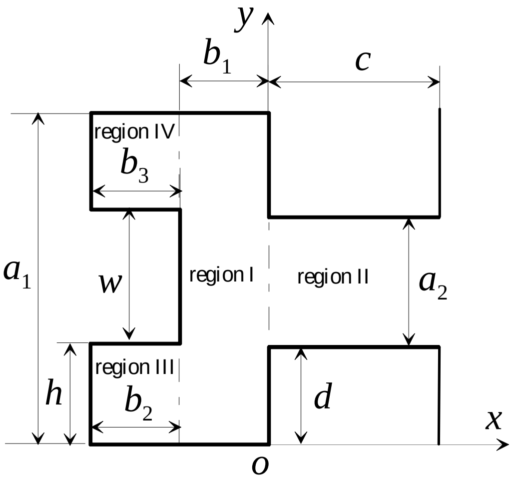
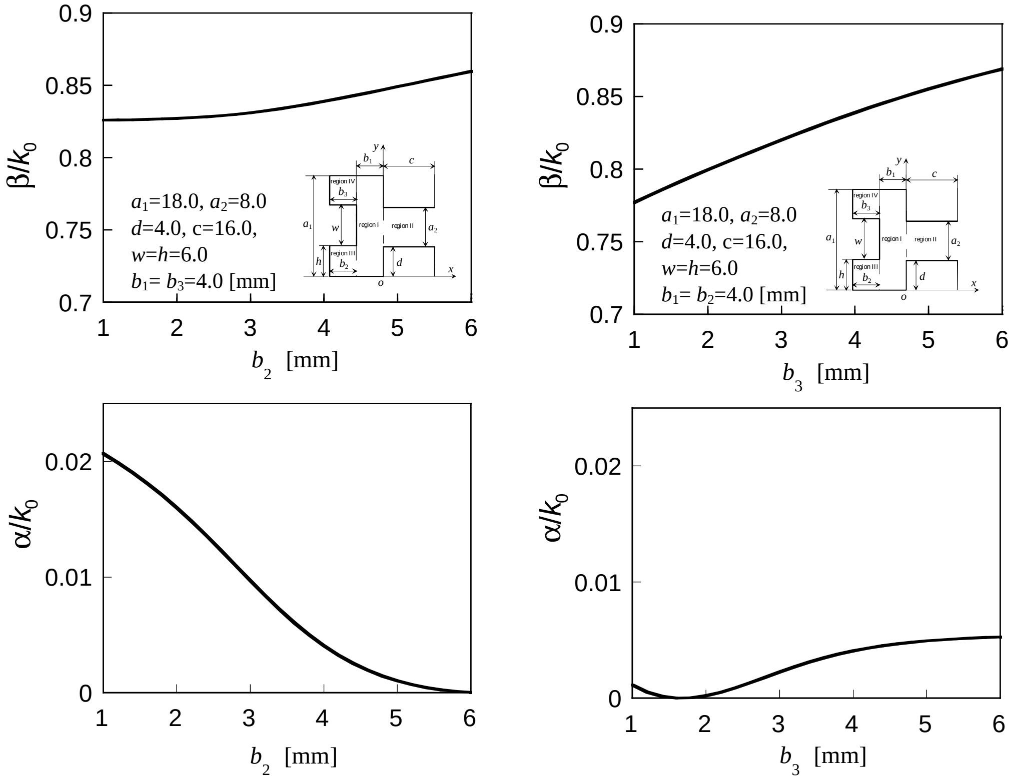


Fig. 1. Cross-section view of a stub-loaded ridge rectangular waveguide. The stub guide is located asymmetrically to produce a vertically electric field component that propagates as a TEM wave at an angle in the stub guide and radiates power from the open end.

2. Analytical method and design procedure

A stub-loaded ridge-rectangular waveguide is shown in Fig. 1. The modified mode-matching method developed by us[3] takes the singular aperture functions into account, and is used to calculate the phase and the leakage constants. This approach divides the guide cross section into four regions, I, II, III, and IV, as shown in Fig. 1, and then the electric and magnetic field components in each region are matched through the singular aperture functions on the *xz* planes of the conductors[2].

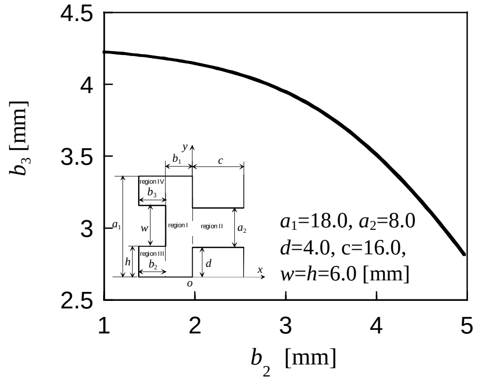
To design a leaky-wave antenna with low sidelobes, we first have to find out a group of



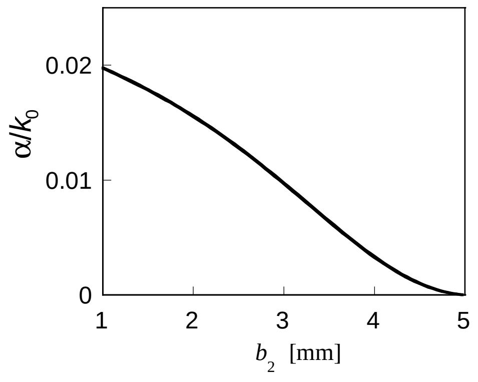
(a) Dependence of b_2 (b) Dependence of b_3

Fig. 2. Dependence of the structural parameters on the phase and the leakage constants at 12 GHz.

the guide structures that keep the phase constant a fixed value, while change the leakage constant widely. So we have investigated the dependence of various structural parameters on the phase and the leakage constants. As a result, we have found that the parameters that greatly affect these constants without changing the structure of the open end are the lengths b_2 and b_3. Figure 2(a) and (b) shows an example of the dependence of b_2 and b_3 on the phase and the leakage constants, respectively, where the other guide dimensions are shown in the inset. To compare with the experimental results later, the guide is designed in the X band. In our procedure, the design frequency is set at the higher end of the frequency band[4] (in the present case, 12 GHz). We can see from these results that the dependence of the length b_2 is weak on the phase constant β/k_0, and is strong on the leakage constant α/k_0, while that of b_3 is opposite. Therefore the change in the phase constant depending on b_2 can be compensated by changing b_3 a little bit. Figure 3(a) shows the relation between b_2 and b_3 to maintain the phase constant to a fixed value β/k_0= 0.83 and Fig. 3(b) shows the leakage constant α/k_0 as a function of b_2 in this case. This means that the leakage constant can be intentionally varied along the antenna axis without changing the phase constant, if we use a



(a) Relation between b_2 and b_3



(b) Relation between b_2 and α/k_0

Fig. 3. Condition to maintain the phase constant to a fixed value.

pair of b_2 and b_3 shown in Fig. 3(a). Then the leaky-wave antenna can be easily designed by determining this pair to match the leakage constant to the longitudinal distribution that realizes low sidelobes as described in the following section.

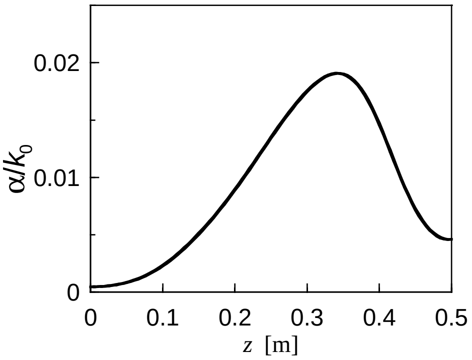


Fig. 4. Longitudinal distribution of the leakage constant α(*z*) realizing the Taylor distribution of –30dB sidelobes.

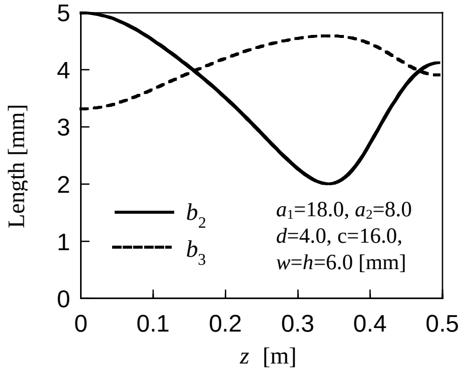


Fig. 5. Longitudinal distribution of the lengths b_2 and b_3 realizing the leakage constant α(*z*) of Fig. 4.

3. Design example

As a design example, we consider the antenna in the X band mentioned above, of which 3dB beamwidth is 5 degrees and angle of the maximum radiation is 55 degrees at the frequency 12GHz. Then the antenna length L becomes 50cm. The Taylor distribution with –30dB sidelobes is used as the aperture field distribution $A(z)$. Then $A(z)$ is given by the following equation[5].

$$A(z) = 1 - 0.581\cos(\frac{2\pi z}{L}) - 0.03\cos(\frac{4\pi z}{L}) + 0.003\cos(\frac{6\pi z}{L}) \qquad (1)$$

The longitudinal distribution of the leakage constant α(*z*) can be derived from

$$\alpha(z) = \frac{1}{2}\frac{\left|A(z)\right|^2}{\frac{P(0)}{P(0)-P(L)}\int_0^L \left|A(z')\right|^2 dz' - \int_0^z \left|A(z')\right|^2 dz'} \qquad (2)$$

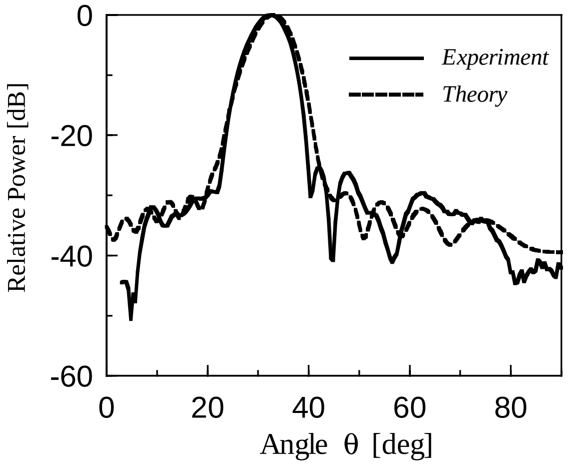
where $P(0)$ is the input power at z=0 and $P(z)$ is the remaining power at z=L. $P(L)$ is assumed here to be 10%[6]. Figure 4 shows the distribution of the leakage constant along the antenna axis calculated by substituting Eq. (1) into Eq. (2). Figure 5 shows the lengths b_2 and b_3 obtained from the design chart of Fig. 3, in order to realize the desired distribution of the leakage constant in Fig. 4. Therefore the leaky-wave antenna with low sidelobes can be realized by varying b_2 and b_3 along the antenna axis as shown in Fig .5, while keeping the other structural parameters constant.

4. Experiment

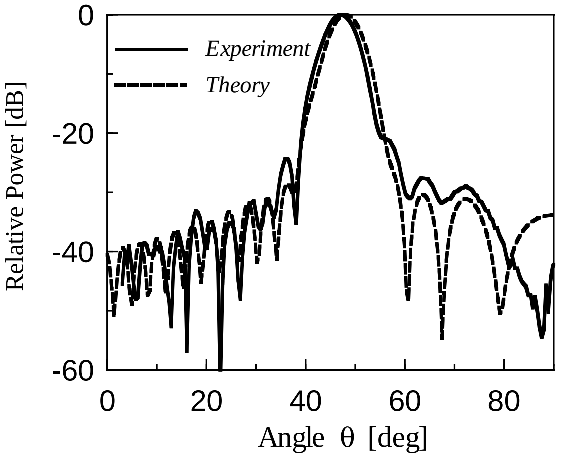
To verify the validity of the designed antenna, we took a measurement of the radiated near-field patterns. The structure under the test is the same as that for the calculation. Figure 6(a)-(c) shows the experimental results measured at 8, 10 and 12 GHz, respectively, which are indicated by the solid lines. The dashed lines in these figures are the theoretical results that are calculated from the field on the antenna aperture based on the phase and the leakage constants. The measured results agrees very well with the theoretical ones. Figure 7 shows the angle of the maximum radiation as a function of the frequency. The dots indicate the measured results, while the solid line is the theoretical ones. Both results agree well each other, so we can confirm that the designed antenna works well as a frequency scanning antenna experimentally.

5. Conclusions

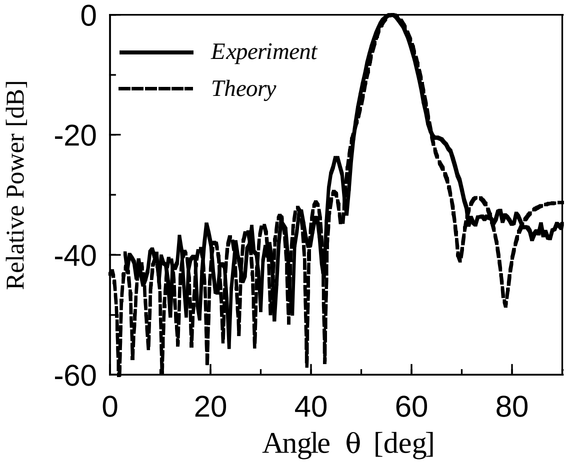
We have developed a leaky-wave antenna with low sidelobes based on the stub-loaded ridge waveguide. This structure includes many conductor edges, so we have proposed the design procedure using the accurate analytical method in which the edge



(a) 8 GHZ



(b) 10 GHZ



(c) 12 GHZ

Fig. 6. Comparison between the measured and the calculated radiation patterns.

conditions are incorporated into the field expressions. As an example, we have designed the leaky-wave antenna with the Taylor distribution of –30dB sidelobes and have verified its validity numerically and experimentally. This work was supported in part by a Grant-in-Aid for Scientific Research (C) (13650439) from Japan Society for the Promotion of Science and by Grants from the Research Center for Advanced Science and Technology, Doshisha University.

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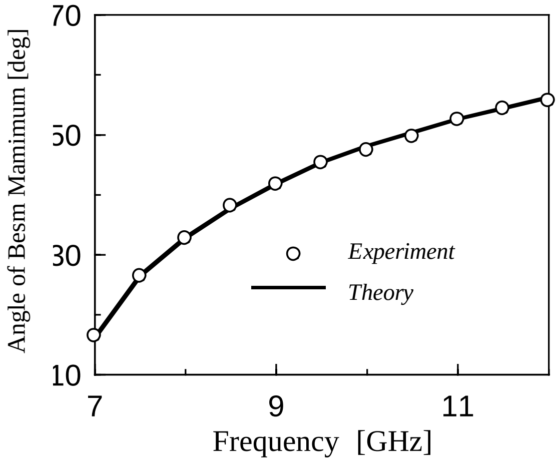

Fig. 7. Measured angle of the maximum radiation as a function of the frequency.ns.