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Abstract

A groove polarizer in a circular waveguide has the advantage of structural simplicity and moderately wide bandwidth, which is particularly useful at high millimeter-wave frequencies where manufacturing tolerances are critical. This paper presents design, fabrication and measurements of a W-band groove polarizer in a 2.2mm diameter circular waveguide. First, a design procedure of the polarizer is presented for optimum performance. Next, a W-band groove polarizer is designed for low axial ratio and good impedance matching. The designed polarizer has been fabricated using a numerically controlled machining center. Test of the fabricated polarizer has shown fair agreements between the design and the measurement.

Keywords
groove polarizer, millimeter-wave, W-band groove, waveguide component, impedance matching

I. Introduction

A microwave polarizer is a device that converts a linearly polarized wave into a circularly polarized one, and vice versa. Microwave polarizers can be classified into two types: one which converts the polarization of a plane wave-like radiated field, and the other that converts the polarization of a wave inside a circular or square waveguide. The waveguide polarizer is employed typically in the transmitter and receiver...

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chains of satellite communication systems for polarization diversity[1]. Widely-used waveguide polarizer structures include a single groove [2] or multiple grooves [3], ridges [4][5], a septum [6], a dielectric slab [7] and corrugations[8].

The groove polarizer is formed typically in a circular waveguide by introducing a quarter-wave groove on the waveguide inner wall [2]. Due to its structural simplicity and good performance, it is particularly useful at the W-band, where manufacturing tolerances often result in inferior device performance. Since proposed in 2002 [2], the groove polarizer has been investigated mostly by Yoneda and co-workers [2][3].

At the W-band, where the wavelength is in the order of 3mm, fabrication tolerances are very critical so that a technique for accurately implementing the W-band groove polarizer needs to be investigated. In this paper, a simple method of implementing a groove polarizer is presented, where the block containing the groove is machined separately and connected to a circular waveguide at both ends. The design, fabrication and measurements of the proposed groove polarizer structure are described in the following.

II. Polarizer Design

Fig. 1 shows the structure and design parameters of the groove polarizer. In Fig. 2 we have shown directions of the electric field vectors at the input port and at the output port, which are set up for the analysis of the groove polarizer. The incident electric field E1I can be decomposed into one component whose direction is normal to the groove aperture (denoted as v mode) and the other component whose direction is parallel to the groove aperture (denoted as h mode) as shown in Eq. (1).

\[ \mathbf{E}_{1I} = \frac{1}{\sqrt{2}} (\mathbf{E}_{2h} + \mathbf{E}_{2v}) \]

The electric field lines of the v and h modes are shown in Fig. 3. The two modes undergo different phase shifts at the junction between the circular waveguide and the groove edge and during the propagation along the groove length since the groove's effects on the v and h modes are different[9]. When the amplitudes of the two modes are approximately equal and their phase differ by 90 degrees, a circularly polarized wave emanates from the waveguide, which is described by Eq. (2) below,

\[ \phi_v - \beta_v L - (\phi_h - \beta_h L) = \frac{\pi}{2} \]
where $\phi$ is the phase shift at the junction between the waveguide and the groove, and $\beta_h$, $\beta_v$ are the propagation constant of the h or v mode. From Eq. (2), we obtain a formula for the groove length $L$.

$$L = \frac{1}{\Delta \beta / \beta_0} \frac{\lambda_0}{4} (1 + \frac{\Delta \phi}{\pi/2}) = \frac{1}{\Delta \beta / \beta_0} \frac{\lambda}{4} m$$ (3)

where $\Delta \beta = \beta_v - \beta_h$ and $\Delta \phi = \phi_v - \phi_h$ and $\beta_0$ and $\lambda_0$ are the phase constant and the wavelength in vacuum, and $m$ is equal to $1 + \frac{\Delta \phi}{\pi/2}$.

The circular waveguide diameter $D$ is chosen such that the cutoff frequency of the dominant TE$_{11}$ mode is 0.8 to 0.85 times the operating frequency. The groove width $W$ is chosen to be 0.2-0.5 times the waveguide diameter. From parametric analyses, the optimum groove depth is close to the groove width so that the groove depth is set to be same as the groove width. With other parameters fixed, the groove length $L$ is varied until there is a 90-degree phase difference in the transmitted v and h modes. A parametric analysis on the groove width $W$ shows that the reflection coefficient is small when $W$ ranges from 0.33D to 0.38D.

Table 1 shows the performance of a groove polarizer with $W = 0.35D$ and $D = 2.2$mm. The length of the groove is approximately one wavelength in vacuum. The reflection coefficients are less than -30dB in each mode.

### Table 1. Performance of a groove polarizer with $W = 0.35D$

<table>
<thead>
<tr>
<th>$\beta_v / \beta_0$</th>
<th>0.7807</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_h / \beta_0$</td>
<td>0.5312</td>
</tr>
<tr>
<td>$m$</td>
<td>1.0673</td>
</tr>
<tr>
<td>$\Gamma_{1R}$</td>
<td>-37.5dB</td>
</tr>
<tr>
<td>$\Gamma_{2v}$</td>
<td>-31.3dB</td>
</tr>
<tr>
<td>$\Gamma_{2h}$</td>
<td>-47.3dB</td>
</tr>
<tr>
<td>$L / \lambda_0$</td>
<td>1.069</td>
</tr>
</tbody>
</table>

Based on the parametric study, a polarizer is designed which has the following dimensions: $D = 2.2$mm, $W = 0.80$mm, $L = 3.43$mm with performance shown in Fig. 4 to Fig. 6. The designed polarizer has reflection coefficient of less than -20dB, axial ratio of less than 1dB at approximately 10% bandwidth.
The designed polarizer has been fabricated by micro-wire electrical discharge machining. Fig. 8 shows both end faces of the fabricated polarizer. A circular waveguide with a groove at 45 degrees from the vertical direction can be seen. Guide pins (a total of 8) and mating screw holes (a total of 5) are placed around the circular waveguide.

The fabricated polarizer has been measured with the Agilent 8510C vector network analyzer with a W-band extension unit. Fig. 9 shows a setup of the fabricated polarizer for measurement. A transition between the circular waveguide and the WR-10 rectangular waveguide is connected the polarizer at both ends. The polarizer is precisely connected to the transition using two guide pins and bolts and screws. Only slight misalignment is sufficient to produce significant errors in the reflection coefficient measurement so that a precise connection is very important [10].
The input transition is connected to the polarizer for the excitation of the slant polarization while the output transition launches the vertical or horizontal polarization to the output plane. The transmission from the slant polarization \( E_{1h} = E_v \) and the vertical polarization \( E_{2h} = E_v \) have been measured and denoted as \( T_x \) and \( T_y \). The axial ratio is then calculated from Eqs. (4a) and (4b) given below.

\[
AR = \sqrt{\frac{|T_x|^2 + |T_y|^2 + \Delta}{|T_x|^2 + |T_y|^2 - \Delta}} \quad (4a)
\]

\[
\Delta^2 = |T_x|^4 + |T_y|^4 + 2|T_x|^2|T_y|^2\cos(2\angle T_x - T_y) \quad (4b)
\]

Fig. 10 shows the measured reflection coefficient of the slant polarization of the fabricated polarizer. The reflection coefficient is less than -22 dB over 10% percent frequency centered at \( f_0 \). The measured reflection coefficient is higher that the simulated one (-32 dB at \( f_0 \)) given in Fig. 4. The difference is believed to be due to errors in fabrication and mating alignment.

The transmission coefficients have been measured for the horizontal and vertical polarizations. The difference in the magnitude of the transmission coefficient is less than 0.2 dB while the difference in the phase is less than 5°. Fig. 11 shows the axial ratio calculated from measured transmission coefficients. The axial ratio is less than 0.7 dB over 10% bandwidth. The measured axial ratio is higher than the simulated one (0.1 dB at \( f_0 \)) shown in Fig. 6, which is again believed to be due to finite precision in machining and waveguide flange mating.

**IV. Conclusions**

We have presented a groove polarizer structure which is suitable for precision fabrication at the W-band. The grooved portion has been separately fabricated and connected to a circular waveguide at both ends. A design theory and a parametric analysis of the groove polarizer have been presented. An optimum design of the groove polarizer operating at W-band was given. The designed polarizer has been fabricated and tested. Measurements have shown that the proposed polarizer has reflection coefficient of less than -22 dB and axial ratio of less than 0.7 dB over 10% bandwidth at W-band. The polarizer presented in this paper may find wide applications in the millimeter-wave radars and communication systems.

**References**

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