Design of A Square-Waveguide Polarizer with A Thick Septum

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Abstract

This paper presents a design of a square-waveguide polarizer with a thick septum. The classic S-band design by Chen and Tsandoulas has a septum of thickness 1.27mm (0.011λ₀ at 2.6GHz), which is too thin to be scaled to higher frequencies. A square-waveguide polarizer with a thick septum is designed using a commercial electromagnetic simulation tool. The septum thickness is increased up to 15.0mm and the performance of the improved polarizer is analyzed. The improved polarizer shows reflection coefficient of less than -20dB, port-to-port isolation of greater than 20dB, and axial ratio of less than 1dB at 2.4-3.0GHz.

Key words: Waveguide component, Septum polarizer, Square waveguide

I. Introduction

A polarizer is a component for converting linearly polarized wave to circularly polarized one. The high-performance polarizers is usually implemented using a polarization-sensitive structure in a circular or square waveguide. The polarization sensitive structures such as metal post [1], dielectric slab [2], septum [3], corrugation [4], multiple grooves [5], and a single groove [6].

The septum polarizer is widely used since it simultaneously provides separation between input RHCP and LHCP ports. The classic design of Chen and Tsandoulas [3] has been used as a standard design for a circular [7] or square waveguide polarizer. In their design, the septum thickness is about 2% of the waveguide wall width, which is too thin for reliable fabrication at higher frequencies. For example, if we want a polarizer for 10GHz, the septum thickness will be 0.33mm, which is difficult to fabricate. One may use a finline structure to overcome the metal thickness problem, but this requires a new design effort. In this paper, we improved the Chen and Tsandoulas polarizer by greatly increasing the septum thickness. Microwave Studio™ by CST, a widely used electromagnetic simulation tool, is used in the design.

II. Design of the Polarizer

Fig. 1 shows the structure of a square-waveguide septum polarizer. It has two rectangular waveguide inputs (Port 1, Port 2) and one square wave (Port 3 mode 1, Port 3 mode 2). When one of the input port is excited with a horizontally polarized wave, the output port will have vertical and horizontal polarization components in phase quadrature producing a circularly polarized wave.

Fig. 2 shows the operating principle of the septum polarizer in the receiving mode. Assuming a left-hand circularly-polarized (LHCP) wave incident on the square waveguide aperture with the x-directed electric field Eₓ of unit magnitude and zero-degree phase, and the y-directed
electric field $E_x$ of unit magnitude and -90 degree phase.

$\begin{array}{cccccc}
\text{0} & \text{0} & \text{0} & \text{0} & \text{0} & \text{0} \\
\text{0} & \text{0} & \text{0} & \text{0} & \text{0} & \text{0} \\
\text{0} & \text{0} & \text{0} & \text{0} & \text{0} & \text{0} \\
\text{0} & \text{0} & \text{0} & \text{0} & \text{0} & \text{0} \\
\text{-90} & \text{-90} & \text{-90} & \text{-90} & \text{-90} & \text{-90} \\
\end{array}$

Fig. 2. Operating principles of the septum polarizer

The $x$- and $y$-polarized electric field travels in the negative $x$ direction and is split in equal magnitude into two input rectangular waveguide ports. The phase delay of the $x$-polarized field will be greater than that of the $y$-polarized field by 90 degrees. Thus the incident LHCP wave is transferred to Port 2 only and there will be no power in Port 1. For the right-hand circularly polarized (RHCP) operation, the direction of the $x$-polarized electric field is reversed and the same rule is applied. The result is that the RHCP wave is transmitted to Port 1 with no power in Port 2.

Fig. 3 shows the dimensional parameters of the square waveguide septum polarizer. First the classic design of the septum polarizer by Chen and Tsandoulos has been analyzed. The phase difference of $x$- and $y$-polarized is about 80 degrees instead of required 90 degrees. The lengths of the second and third section, $(L_5, L_3)$ are increased by the same ratio to obtain the required phase difference of 90 degrees.

$\begin{array}{cccccc}
L_0 & L_1 & L_2 & L_3 & L_4 & L_5 \\
68.6 & 36.9 & 33.9 & 34.4 & 11.0 & 68.3 \\
H_0 & H_1 & H_2 & H_3 & H_4 & H_5 \\
0 & 8.7 & 19.4 & 32.8 & 56.6 & 68.3 \\
\end{array}$

Table 1 shows dimensions of the polarizer. The design frequency is 2.75GHz. The square waveguide wall dimension is 68.29x68.29mm where cutoff frequencies of $TE_{01}$ and $TE_{02}$ modes are 2.20GHz and 3.11GHz. The operating frequency range is limited by these two frequencies since the $TE_{01}$ mode is inevitable excited in the square waveguide septum polarizer. Thus the maximum possible bandwidth of a square waveguide septum polarizer is given by

$$BW(\%) = \frac{\sqrt{2} - 1}{(\sqrt{2} + 1)/2} \times 100 = 34$$

Therefore, the bandwidth will be maximum when the design frequency is chosen by

$$f = \frac{\sqrt{2} + 1}{2} f_c = 1.207 f_c$$

In our design it will be 2.66GHz. The reflection coefficient at each port and port-to-port isolation will be deteriorated as the frequency approaches the cutoff frequency. Thus the optimum frequency

$$f_{opt} = \frac{0.97 \sqrt{2} + 1.1}{2} f_c = 1.236 f_c$$

which will be 2.72GHz in our design.

The wavelength of the $TE_{01}$ mode in our design is given by

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - (f/f_c)^2}} = 181.82 \text{ mm} \ @ \ 2.75 \text{ GHz}$$

The total length of the polarizer is given by

$$L_1 + L_3 + L_4 + L_5 = 104.84 \text{ mm}$$

which is 57.7 percent of the $TE_{01}$ mode wavelength.

The operating frequency range of the polarizer is from 2.6GHz to 3.2GHz. The septum thickness is 1.27mm which is about 2% of the waveguide wall dimension. When the dimensions are reduced by a factor of 5 for operation at 15GHz, the septum thickness will be 0.254mm, which is too small for reliable fabrication.

The septum thickness is increased to 5, 10, and 15mm and the performance of the polarizer is analyzed. Fig. 4 shows the reflection coefficient of the polarizer versus the septum thickness. Port 2 will have the same reflection coefficient as Port 1 due to structural symmetry. In all cases, the input reflection coefficient is less than -18dB at 2.5-2.9GHz if the septum thickness is less than 5mm.

When the septum thickness is increased to 10mm and 15mm, the maximum value of the reflection coefficient rises to -17dB and -14dB, respectively.

Fig. 5 shows the axial ratio versus the septum
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thickness. The axial ratio is calculated using

\[
AR = \sqrt{\frac{E_x^2 + E_y^2 + \sqrt{E_x^4 + E_y^4 + 2E_x^2E_y^2\cos(2\delta)}}{E_x^2 + E_y^2 - \sqrt{E_x^4 + E_y^4 + 2E_x^2E_y^2\cos(2\delta)}}}
\]

(6)

Fig. 5 Axial ratio versus the septum thickness

![Graph showing axial ratio vs. septum thickness](image)

Fig. 6 Isolation between two input ports versus the septum thickness

\[
\text{AR (dB)} = 10\log_{10}AR
\]

(7)

where \(E_x, E_y\) are the magnitude of the \(x\) and \(y\) component of Port 3 mode 1 and Port 3 mode 2 respectively, and \(\delta\) is the phase difference between two modes. The axial ratio is less than 0.2dB in all cases at 2.5-2.9GHz. The axial ratio increases as the frequency decreases.

Fig. 6 shows the isolation between two input ports versus the septum thickness. The isolation is less than -24dB, -22dB, -19dB, -17.5dB when the septum thickness is 1.527mm, 5mm, 10mm, and 15mm respectively. From the foregoing analysis, one can conclude that the septum thickness can be increased to 3mm (7% of the waveguide wall width) without appreciable degradation in the polarizer performance (2.5dB and 0.1dB increase in the reflection coefficient and the axial ratio, respectively).

III. Conclusion

A square waveguide polarizer with a thick septum has been designed based on the classic design by Chen and Tsanoudas. It has been shown that the septum thickness can be increased to 7% of the waveguide wall width from the original 2% without much degradation in the polarizer performance. The septum thickness may be increased to 14% percent of the waveguide wall width with slight degradation in the performance.
References


