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A Three-Way Power Divider for Partially Parallel Feed in an Alternating Phase-Fed Single-Layer Slotted Waveguide Array

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1. Introduction

Demands for high-gain and high-efficiency antennas are increasing for millimeter frequency waveband applications. Mass productivity as well as antenna efficiency is an important feature for commercial applications. A single-layer slotted waveguide array [1] is an attractive candidate for high-efficiency planar antennas because of its negligible transmission loss. A co-phase fed waveguide array, using π-junctions to divide a power in phase to the radiating waveguides has been developed [2]. Perfect electrical contact between the slot plate and the grooved base plate is required in order to realize the theoretically predicted efficiency. To achieve higher mass productivity, an alternating phase-fed waveguide array which consists of a series of T-junctions in the feed waveguide as is shown in Fig. 1 is also developed [3]. Close electrical contact between the waveguides and the slot plate is not needed because the total current between them is zero.

In these arrays, the longer becomes the series-feed circuit, the narrower becomes the bandwidth due to the long line effect. In this paper, a parallel feed structure installed to the feed circuit of an alternating phase-fed array in the part as shown in Fig. 2, is proposed. By decreasing the number of radiating waveguides arranged serially, the long line effect is reduced and the bandwidth becomes wider. A similar structure for the co-phase array was developed previously [4]. The key component in this proposed structure is an H-plane three-way power divider with a desired power dividing ratio and reflection suppression simultaneously. The authors have conducted the moment-method analysis to realize this circuit.

2. Structure and Design

The structure of the three-way power divider is shown in Fig. 3 (a). It consists of two waveguides which are coupled to each other through a window, and another waveguide oriented at the front side of a coupling window perpendicularly. In this paper, the three-way power divider is designed to excite 2n+1 radiating waveguides with uniform amplitude in a half of the array antenna, where n is an integer. 1/(2n+1) of an input power from Port 1 is divided into Port 2 and the rest is divided equally into Ports 3 and 4. To accomplish the alternating-phase feed between adjacent radiating waveguides, the phase difference between S_{21} and S_{31} should satisfy the condition expressed as $\arg(S_{21}) - \arg(S_{31}) = \arg(S)$, where $\arg(S)$ is the phase of transmission from Port 3 or Port 4 to the radiating waveguide of the T-junction neighboring to this power divider. The reflection to Port 1 should also be suppressed. There are two coupling windows in this power divider. Window II should be controlled by w_2 to get a desired power division ratio 1/(2n+1). Window I should have a proper width w_1 to achieve equal power to Ports 3 and 4 so that it has a resonance itself and its magnetic current has only a dominant sinusoidal distribution. The widths of the input and main waveguides are a_1 and a_2, respectively. The width of the output waveguide is l. The distance from the center of Window I to a shorted plate is s. An inductive wall located at $x = p$, and $z = q$ is utilized to suppress the reflection to Port 1 together with the short position s. Let a dominant (TE_{10}) mode of unit amplitude be incident from Port 1. The structure as well as the field are two-dimensional and have no variation along the y-direction.

Fig. 3 (b) shows the analysis model of this three-way power divider. By applying the field equivalence theorem, both the internal and the external apertures of the two coupling windows are covered with perfect electric conductors together with unknown magnetic currents $\mathbf{M}_1, \mathbf{M}_2$ for Window I and $\mathbf{M}_3, \mathbf{M}_4$ for Window II. The inductive wall is replaced by several unknown line

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currents $\mathbf{J}_i(i=1\sim N)$ with only the y-component on its surface [5][6], where N denotes the number of the line currents on the surface of the inductive wall. Then the analysis model is divided into five canonical regions so that the dyadic Green's function for each region can be analytically derived. Integral equations for $\mathbf{M}_k(k=1\sim 4)$ and $\mathbf{J}_i(i=1\sim N)$ are derived from the continuity conditions of the tangential components of the magnetic fields on the windows as well as the condition for cancellation of tangential electric field on the wall surface. A set of linear equations are derived by applying Galerkin's method of moments [2][7][8]. Once the magnetic and electric currents are obtained, the scattering characteristics can be calculated in a straight forward manner.

3. Results

The authors design a three-way power divider at 25.3GHz. As an example of the design, n is chosen to be 4. Therefore, the power ratio dividing into Port 2 should be $1/9$ ($\cong -9.542\mathrm{dB}$). Fig. 4 shows the power ratio between Ports 3 and 4 denoted as $(|S_{31}|/|S_{41}|)^2$ versa the width of Window I. While other parameters are remained unchanging, except that the location of the inductive wall is determined for any fixed w_1 to suppress the reflection to Port 1. w_1 is determined as $w_1 = 6.50$mm, where $(|S_{31}|/|S_{41}|)^2$ is -0.037dB ($\cong 0.996$). w_2 is determined to be 5.01mm where $|S_{21}|$ is $-9.51\mathrm{dB}$. For this case, the inductive wall is located at $p = 3.77mm, q = -1.25mm$ and the frequency characteristic of the reflection to Port 1 is shown in Fig. 5. At the design frequency, the reflection is suppressed less than -40dB. It is suppressed below -10dB over a 500MHz bandwidth. The frequency characteristic of the power ratio dividing to Port 2 is also shown in Fig. 5. The increasing of reflection $|S_{11}|$ away from the design frequency mainly attributes to decreasing of $|S_{21}|$, while the maximum of $|S_{21}|$ is obtained at the design frequency.

Fig. 6 shows the frequency characteristic of the power ratio dividing to Port 3. For all the frequency, very similar characteristic can also be available for Port 4, because there are little difference in amplitude and phase of division between Port3 and Port 4. The frequency characteristic of the ratio of divided power $(|S_{31}|/|S_{41}|)^2$ and the phase difference between Port 3 and Port 4 ($\arg(S_{31}) - \arg(S_{41})$) are shown in Fig. 7. Through the frequency band, the ratio of divided power is almost constant of -0.1dB, and the phase difference falls into a range of ± 1.5 degrees. At the design frequency, the phase difference between $\arg(S_{21}) - \arg(S_{31})$ (92.13 degrees) and $\arg(S)$ (117.50 degrees) is not zero, but it is 25.37 degrees. It remains as a problem until the above difference is cancelled out.

4. Conclusion

The authors have proposed a three-way power divider for widening the bandwidth of an alternating phase-fed single-layer slotted waveguide array. In this power divider, the authors can control the power dividing to the center output port by the width of Window I. Also, the condition of equal amplitude division to the right and left output ports can also be obtained by the width of Window II. However, the suppression of reflection to Port 1 away from the design frequency is not sufficient yet. Experimental verification is also left for further study.

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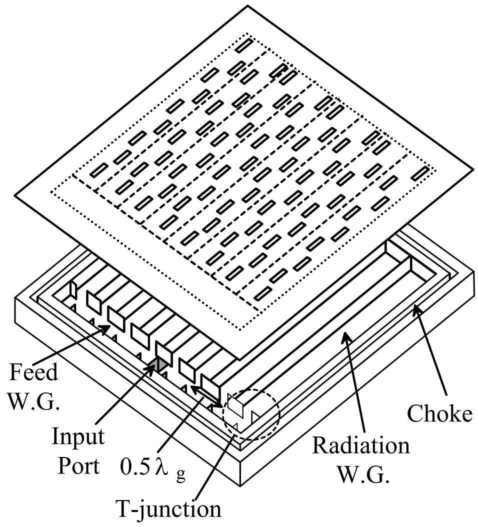

Fig. 1 Alternating phase-fed single-layer slotted waveguide array antenna

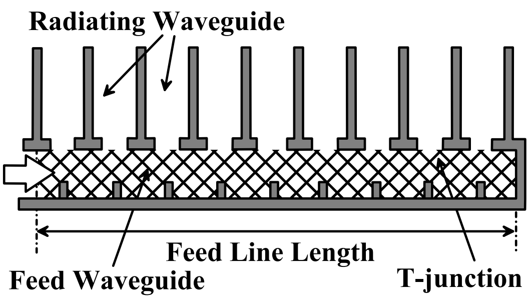

Fig. 2 (a) Conventional series feed circuit for an alternating phase-fed waveguide array

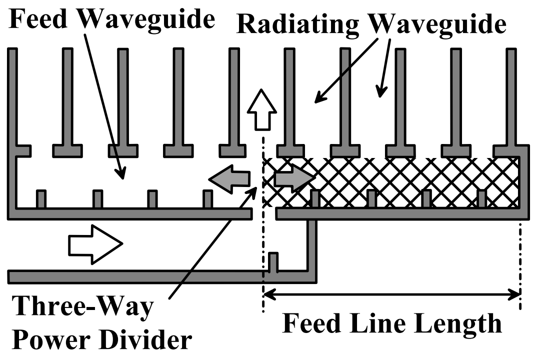

Fig. 2 (b) Partially parallel feed circuit for an alternating phase-fed waveguide array

Tab. 1 Design parameters of three-way power divider (unit: mm)

a_1	a_2	l	w_1	t_1
7.94	7.94	7.90	6.50	3.00
w_2	t_2	p	q	s
5.01	3.00	3.77	-1.25	4.40

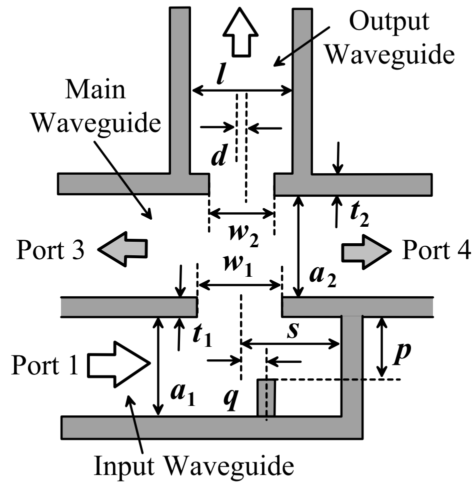

Fig. 3 (a) Configuration and parameters of a three-way power divider

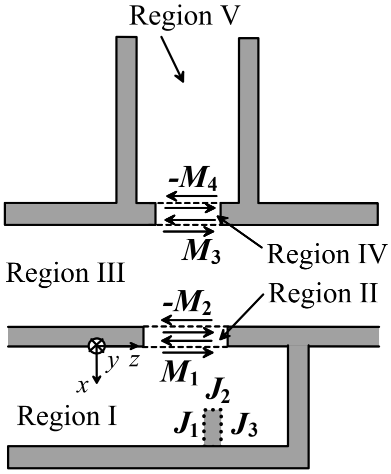

Fig. 3 (b) Unknown electric and magnetic currents in the analysis model

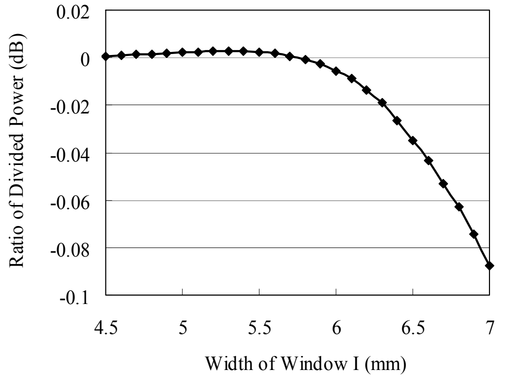

Fig. 4 Ratio of divided power $(|S_{31}|/|S_{41}|)^2$ as a function of window width w_1

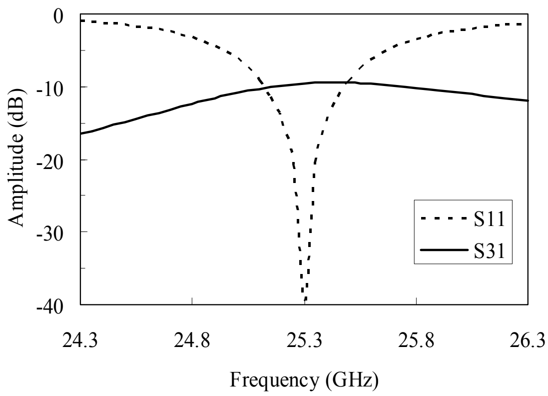

Fig. 5 Frequency characteristics of reflection (S_{11}) and transmission to Port 2 (S_{21})

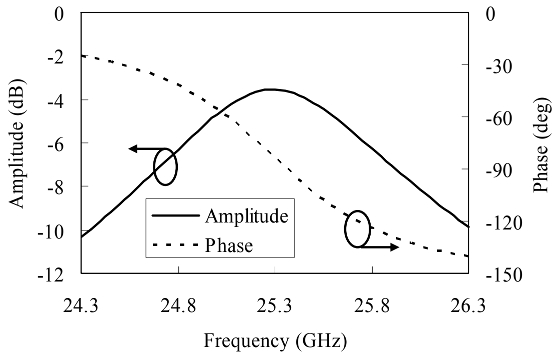

Fig. 6 Frequency characteristics of transmission to Port 3 (S_{31})

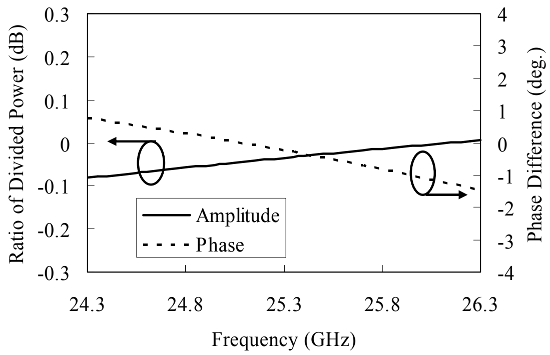

Fig. 7 Frequency characteristics of ratio of divided power $(|S_{31}|/|S_{41}|)^2$ and phase difference of divided power between Port 3 and Port4 $[\arg(S_{31})-\arg(S_{41})]$