Design Equations for the H-plane Power Divider with a Circular Post in a Rectangular Waveguide

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Abstract

Universal design equations are presented for the H-plane T-junction power divider with a circular conducting post in a rectangular waveguide. For a given operating frequency and power split ratio, the post offset from the T-junction center line, the distance between the post and the waveguide wall, and the post diameter can be adjusted to obtain a minimum reflection at the input waveguide. Optimum values of the post offset are given in terms of the normalized frequency and the power split ratio. Corresponding values of the post diameter and the distance of the post from the waveguide wall are given in terms of the normalized frequency and the post offset.

Key words : Waveguide Power Divider, H-plane T-junction, Design Equations, Antenna Feed Network.

Ⅰ. Introduction

The H-plane T-junction power divider is widely used in multiplexers and diplexers[1]~[3] and in the feed network of slotted waveguide antenna arrays[4]~[7]. The H-plane power divider with a septum and impedance-matching iris has been studied by several authors[5]~[8]. Recently Bang and co-workers have presented universal design formulas for the H-plane T-junction septum power divider[8].

The H-plane T-junction with an impedance matching post has been studied by several authors[3],[4],[9]. Wu and Wang have studied the H-plane T-junction with a partial-height circular post[3]. They varied the diameter and height of the post for wideband operation. Hirokawa and co-workers analyzed the T-junction power divider with a circular conducting post for use in the slotted waveguide array[9]. They found optimum values of the post diameter and the post location for 1:1 power ratio at a specific frequency in a particular waveguide.

The H-plane power divider with a circular conducting post in the rectangular waveguide, shown in Fig. 1, consists of a T-junction and a power-dividing post. The offset of the circular post from the junction center introduces an unequal power split between two output ports. For each offset, the post diameter and the distance of the post from the waveguide wall can be adjusted for minimum reflection at the input waveguide.

In this paper, we present universal design equations for the H-plane T-junction power divider with a circular post in a form useful in the design of feed network for waveguide antennas.

Ⅱ. Derivation of Design Equations

Fig. 2 shows the cross section of an H-plane T-junction power divider with a circular post. The power divider is excited at the port 1 with a dominant TE_{10}-mode incident wave. The optimum power divider, impedance-matched over the widest possible frequency range, is designed in the following way. First, we note that the power split ratio is mostly controlled by the post offset Δ. For each value of Δ, the post diameter d and the distance h of the post from the waveguide wall are adjusted until the reflection at the input port

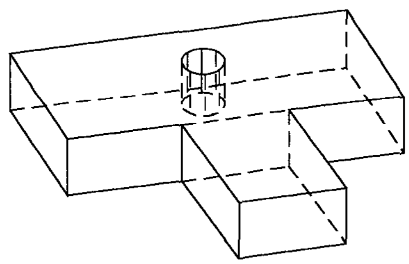

Fig. 1. H-plane power divider with a circular conducting post in a rectangular waveguide.

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is minimized over the widest possible frequency range. The cutoff frequency of the TE_{10} mode is given by $f_c = c/2a$, where c is the speed of light and a is the dimension of the waveguide broad wall. It is assumed that the operating frequency of the power divider ranges from 1.2 f_c to 1.8 f_c. In this work we analyzed the power divider using a commercial electromagnetic software HFSS™ of the Ansoft Corporation.

Fig. 3 shows the input reflection coefficient ($|S_{11}|$) of the power divider optimally designed at a specific frequency for various values of the post offset. It can be seen that a low-reflection T-junction power divider with a circular post can be designed at a single frequency.

Fig. 4 shows the power split ratio r versus the frequency for various values of the post offset, which is defined by

$$r \equiv |S_{31}|^2 / |S_{21}|^2 \tag{1}$$

A wider range of power split ratios can be realized at lower frequencies, although the power split ratio is more frequency-sensitive.

By curve-fitting numerical results, we obtain the following formula for the optimum value of the normalized post offset($\delta \equiv \Delta/a$) in terms of the power split ratio($r=P_3/P_2$) and the normalized frequency($F \equiv f/f_c$).

$$\delta = (-4.4883 - 32.5500\ln F + 55.7553\ln^2 F + 76.3662\ln r - 1.5759\ln^2 r + 0.8040\ln^3 r)/(1 - 1.5118\ln F + 0.0503\ln r + 0.0118\ln^2 r) \times 10^{-3}, \quad 1.2 \le F \le 1.5 \tag{2}$$

$$\delta = (-0.9832 + 1.3916\ln F + 36.5806\ln r + 19.6417\ln^2 r - 2.3242\ln^3 r)/(1 - 2.8369\ln F + 1.9574\ln^2 F + 0.1442\ln r) \times 10^{-3}, \quad 1.5 \le F \le 1.8 \tag{3}$$

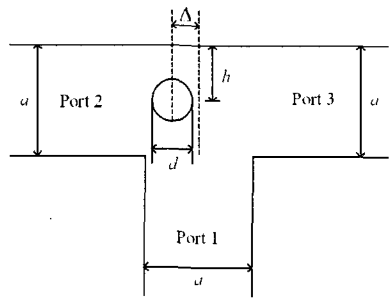

Fig. 2. Cross section of the H-plane power divider with a circular post.

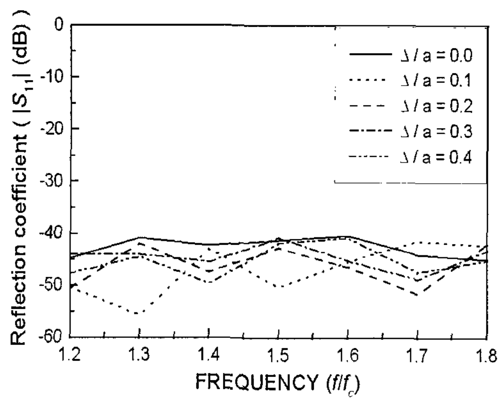

Fig. 3. Input reflection of the optimized power divider.

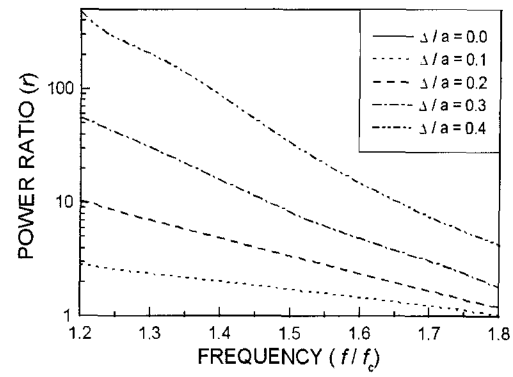

Fig. 4. Power split ratio versus frequency for various post offsets.

Since the formula is expressed in terms of normalized quantities, it can be used for the design of power divider in an arbitrary rectangular waveguide, i.e. in waveguides such as WR-90, WR-75, WR-28 etc.

We note in Fig. 4 that with the maximum post offset limited to $0.4a$ and at a specific frequency there is an upper limit in the power split ratio. The maximum realizable power spilt ratio is smaller at higher frequencies. Design equations (2) and (3) are valid only within this limit. The following formula for the maximum power split ratio is obtained by fitting the curve for $\Delta = 0.4a$ in Fig. 4.

$$r_{max} = \frac{1}{-2.6214 + 6.2333F - 4.9534F^2 + 1.3173F^3} \tag{4}$$

Eqs. (2) and (3) are plotted in Fig. 5 for various values of the power split ratio. The post offset is a smooth function of the frequency.

Corresponding to the normalized post offset, there are optimum values of the post diameter d and the distance h of the post from the waveguide wall yielding a low reflection at the input port over a broad fre-

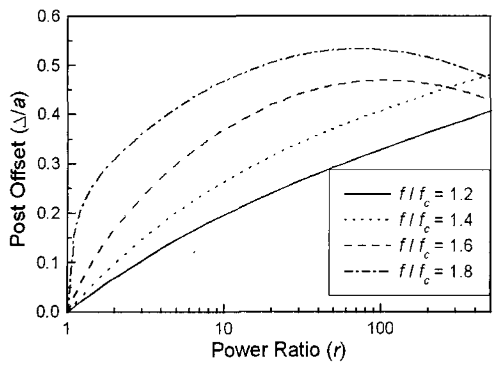

Fig. 5. Post offset versus frequency for various power split ratios.

quency range. The following are curve-fitted equations for the optimum values of d and h.

$$d/a = 1.0596F^3 + (1.8917\delta - 4.7003)F^2 - (4.5784\delta^2 + 5.3575\delta - 6.8437)F + 3.4516\delta^3 + 7.6412\delta^2 + 3.6702\delta - 3.1975 \quad (5)$$

$$h/a = -0.3800F^3 - (0.4567\delta - 1.5856)F^2 + (2.4552\delta^2 + 1.4641\delta - 2.3738)F - 2.0377\delta^3 - 3.5976\delta^2 - 1.1293\delta + 1.7170 \quad (6)$$

Figs. 6 and 7 show optimum values of d and h versus the normalized frequency for various post offsets. The optimum post diameter decreases monotonically with the increasing frequency. Larger diameter posts are required for large offsets. The distance of the post from the waveguide wall is smaller for larger offset values.

When the power is not equally divided, there is a phase difference between signals at two output ports. The phase information is necessary, for example, in the design of the power divider for the antenna feed network. Fig. 8 shows the phase difference($\Delta\phi \equiv \angle S_{31} - \angle S_{21}$) versus the normalized frequency for various post offsets.

The magnitude of the phase difference increases with the frequency. We obtain Eq. (7) for the phase difference by curve-fitting numerical results as a function of the normalized frequency and the post offset.

$$\Delta\phi(\text{deg.}) = (0.1350 - 139.2931\delta + 53.2915\delta^2 + 79.0774\delta^3 + 1.8929\ln F - 4.9618\ln^2 F)/(1 - 0.4993\delta - 3.0601\ln F + 6.3778\ln^2 F - 4.7486\ln^3 F) \quad (7)$$

Now we summarize procedures for designing the power divider using formulas (2) to (7). In the first

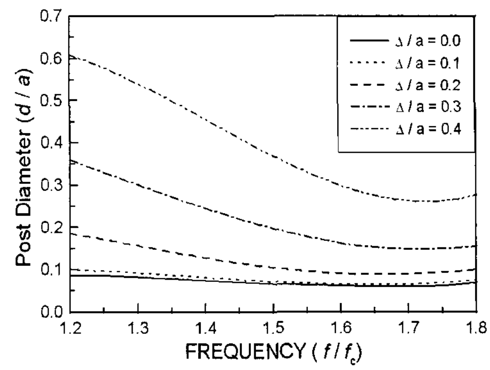

Fig. 6. Optimum post diameter versus frequency.

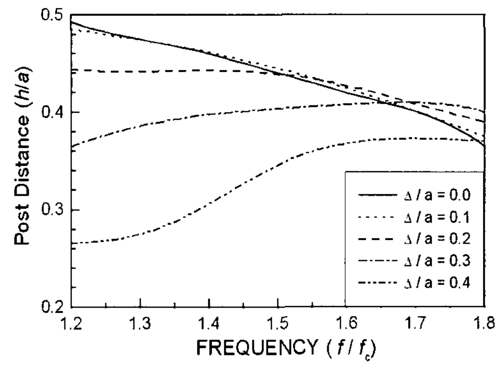

Fig. 7. Optimum post distance from the waveguide wall versus frequency.

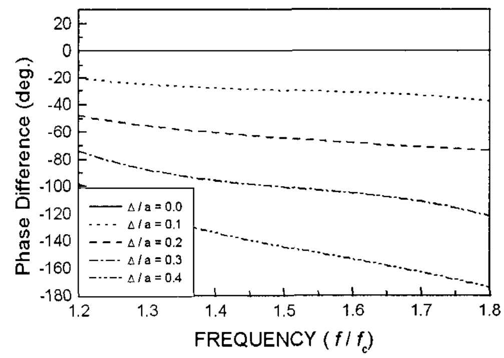

Fig. 8. Phase difference between two output ports versus frequency for various post offsets.

step, referring to Fig. 2 and considering requirements on the maximum power ratio and the frequency bandwidth, we determine the proper value of the waveguide broad wall dimension a. Referring to Fig. 2, we find that for a wideband operation the waveguide dimension should be chosen so that the center frequency is around $1.7f_c$. For large power split ratios, we let the center frequency be around $1.3f_c$.

Next we determine the post offset Δ for the given power split ratio using Eqs. (2) and (3). Note that there is an upper limit r_{max} in the power split ratio as given by Eq. (4). After the post offset is found, corresponding optimum values of the post diameter d and the distance h of the post from the waveguide wall can be obtained using Eqs. (5) and (6). Finally, we calculate the phase difference using Eq. (7) and use this information in the correction of phase discrepancies between two outputs.

Ⅲ. Test of Design Equations

To test proposed equations, we design a sample 4:1 power divider operating at 28 GHz. We use the standard rectangular waveguide WR-28 (a=7.11 mm). Then the normalized frequency f/f_c is 1.33. From Eq. (2), the normalized post offset Δ/a is found to be 0.158 so that the post offset Δ is 1.12 mm. Similarly, according to Eqs. (5) and (6), the post diameter and the post distance from the waveguide wall are found to be 0.84 mm and 3.24 mm, respectively. Finally, we obtain a phase difference of $-43.8°$ using Eq. (7).

To verify the design, we analyze the designed power divider with Ansoft HFSS™. Figs. 9 and 10 show the input reflection, the power ratio and the phase difference. One can observe that the designed power divider shows a performance optimized at 28 GHz.

To compare our design formulas with results available in the literature, we design a 1:1 power divider presented in [9]. The waveguide broad wall dimension is 58.1 mm and the design frequency is 3.9 GHz. Our design formulas yield the post diameter, d= 3.93 mm, the distance of the post from the waveguide wall, h=25.52 mm. The post offset is zero for a 1:1 power divider. Design results presented in [9] are d=4 mm and h=25.5 mm, which agree well with our results.

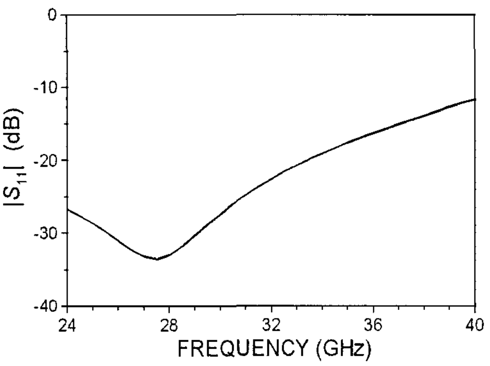

Fig. 9. Input reflection of a sample power divider versus frequency.

Fig. 11 shows the input reflection coefficient of the power divider. Measured values are from [9] while calculated values are obtained using HFSS™ with d=4 mm and h=25.5 mm. We note that there is a small difference between measurement and simulation in the frequency of lowest reflection. The calculated minimum value of reflection is about -50 dB while the measured value is -35 dB. We conjecture that the discrepancy is due to dimensional tolerances in the manufactured power divider and a finite accuracy inherent in the numerical field simulation.

As a final test of our formulas, we design a sample power divider with a=19.05 mm(WR-75), f=11.0 GHz and r=4.9=6.9 dB. Our formulas give d=2.50 mm, h =8.41 mm, Δ=3.80 mm, $\Delta\phi$ = $-60.2°$. We fabricated the body of the power divider in two pieces - the top wall and the rest of the divider. The circular post with diameter of 2.50 mm and height of 9.53 mm is carefully positioned inside the waveguide at the location dictated by the design formula.

Fig. 12 shows the input reflection coefficient of the sample power divider. We notice a slight shift between

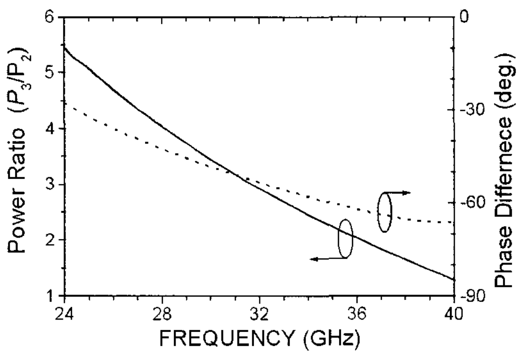

Fig. 10. Power split ratio and the phase difference of a sample power divider versus frequency.

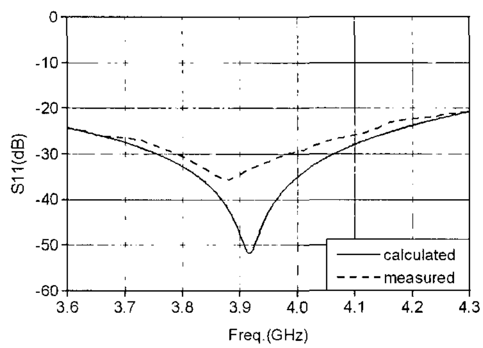

Fig. 11. Input reflection coefficient of a 1:1 power divider presented in [9].

measurement and simulation in the frequency of lowest reflection. Fig. 13 shows the power split ratio between two output ports. The calculated power split ratio at 11 GHz is 6.7 dB while the measured value is 7.0 dB. Fig. 13 shows the phase difference($\Delta\phi$) between two ports. The measured phase difference agrees well with the simulated value at the design frequency(11 GHz).

In Figs. 12 to 14 we observe small differences between measurement and simulation, which are again believed to be due to dimensional tolerances in the fabricated power divider and a finite accuracy inherent in the numerical field simulation.

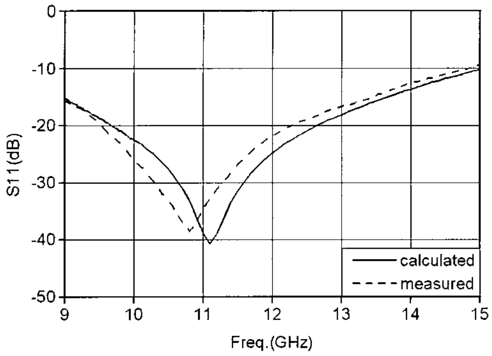

Fig. 12. Input reflection coefficient of a sample power divider in WR-75 waveguide.

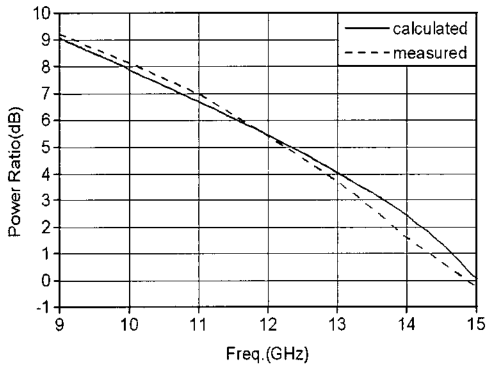

Fig. 13. Power split ratio of a sample power divider in WR-75 waveguide.

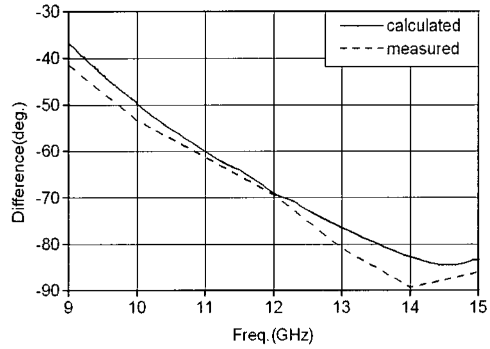

Fig. 14. Phase difference between two output ports of a sample power divider in WR-75 waveguide.

Ⅳ. Conclusions

In this paper, we present a set of universal design formulas for the H-plane power divider with a circular conducting post in a rectangular waveguide. Specifically we propose design equations for the optimum values of the post offset, the post diameter and the distance of the post from the waveguide wall. Additionally we present an equation for the phase difference between output ports of an optimized power divider. Proposed formulas are tested first by a sample design of a 4:1 power divider operating at 28 GHz, secondly by a 3.9 GHz 1:1 power divider presented in the literature, and lastly by an experimental 11 GHz power divider. From these tests, we confirm the validity of proposed design formulas.

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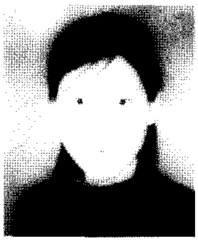

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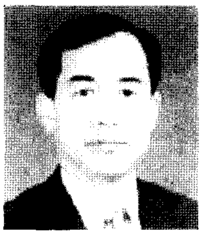

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