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Analysis of a Matched Folded E-plane Tee

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Abstract

A method of moment based analysis of a folded E-plane tee with a shorting post has been presented using Multi Cavity Modeling Technique (MCMT). The folded E-plane tee is unlikely to the family of tees. The output ports are in the same planes which is an advantage for phased array applications. The input arm is shifted from the center to facilitate easy fabrication. Finally attempt has been made to improve the frequency response characteristic of the above mentioned waveguide circuit by inserting a shorting post. The proposed circuit has good agreement with the measured, MCMT and CST microwave studio simulated data.

Keywords: Shifted E-Plane Tee, multi cavity modeling technique, moment method analysis, global basis functions, shorting Post.

INTRODUCTION

Waveguide Tee-junction problem is as old as the iris and filters. Kaur describes how there is an emergency to utilize the electromagnetic spectrum with cognitive network [1]. The utilization of frequency is a big challenge and all time it is a big challenge for the researcher to design efficient component also. Further, design of such component is not easy for fabrication. So various numerical techniques are discussed by different authors for validation of results and made easy to design any component as per requirement. Variation Method, Boundary Element Method, Finite Element method, Full Wave Mode Matching Technique, Moment method, Resonator method, Overlapping T-block Method and Multiple Cavity Modeling Technique (MCMT) were used to analyze these structures [2-9]. Sharp [10] proposed an exact method for calculation of the electrical performance of the rectangular waveguide tee junction. Das et.al were analyzed an E-Plane folded Tee-junction, using MCMT. To analyze this structure they have used the piecewise triangular basis function [11]. Further, the analyzed structure is not matched to the junction and could not be used as a symmetric power divider. The author discussed a folded H-plane Tee using MCMT [15]. The author has also discussed the problem using a capacitive window [16].

In this paper effort has been made, for equal power division on inclusion of a shorting post to the structure. Using a shorting post the complexity has been increased for computation purposes. The main arm is folded and the E-plane arm is shifted from the center to facilitate easy fabrication. This structure is easy to cascade for 2^n output ports. The structure has been analyzed using MCMT. Further it has been analyzed using global basis function. The technique involves in replacing all the apertures and discontinuities of the waveguide structures, with equivalent magnetic current densities so that the given structure can be analyzed using only Magnetic Field Integral Equation (MFIE).Since only the magnetic currents present in the apertures are considered the methodology involves only solving simple magnetic integral equation rather than the complex integral equation involving both the electric and magnetic current densities. The methodology to analyze the structure has been described in [11-17].

FORMULATION OF THEORY

Fig. 1 shows a basic folded E-plane tee with shorting post, its cavity modeling and details of region is shown in Fig. 2, which shows that the structure has 3 waveguide regions and 4 cavity regions. The interfacing apertures between different regions are replaced by equivalent magnetic current densities. The electric field at the aperture is assumed to be

$$\vec{E} = \hat{u}_x \sum_{p=1}^{M} E_{px} e_{px} + \hat{u}_y \sum_{p=1}^{M} E_{py} e_{py} \quad (1)$$

Where the basis function e_p (p=1, 2, 3…M) are defined by

$$e_p^{i,y} = \begin{cases} \sin\left\{\frac{p\pi}{2L}(x - x_w + L)\right\} & \text{for } \begin{array}{l} x_w\text{-L} \le x \le x_w + L \\ y_w\text{-W} \le y \le y_w + W \end{array} \\ 0 & \text{elsewhere} \end{cases} \quad (2a)$$

$$e_p^{i,x} = \begin{cases} \sin\left\{\frac{p\pi}{2W}(y - y_w + W)\right\} & \text{for } \begin{array}{l} x_w\text{-L} \le x \le x_w + L \\ y_w\text{-W} \le y \le y_w + W \end{array} \\ 0 & \text{elsewhere} \end{cases} \quad (2b)$$

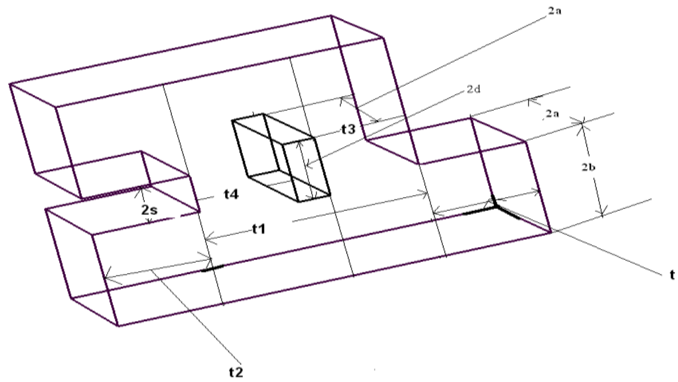

Figure 1: Three dimensional view of a folded E-plane tee with shorting post.

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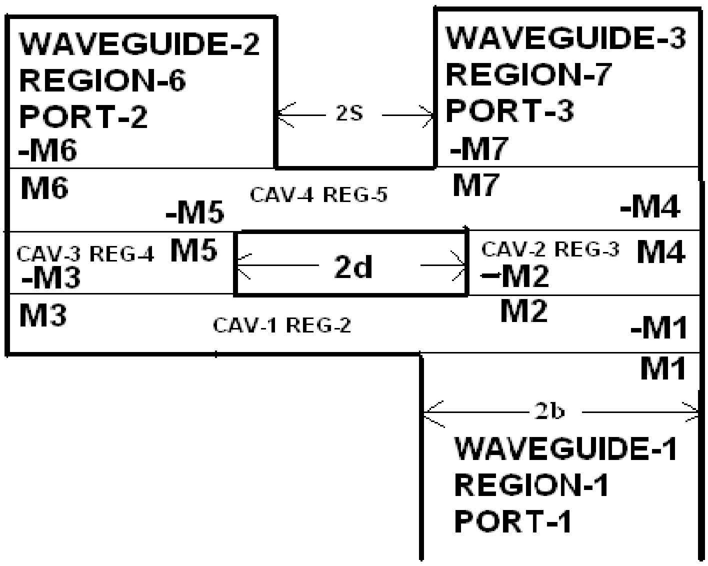

Figure 2: Cavity modeling and details of regions of folded E-plane tee with shorting post.

In the equation 2(a) & (b),

- $L = a, W = b$, $x_w = 0$ and $y_w = b + s$ for aperture 1 with respect to cavity-1 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = W + d$ for aperture 2 with respect to cavity-1 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = -W - d$ for aperture 3 with respect to cavity-1 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = 0$ for aperture 2 with respect to cavity-2 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = 0$ for aperture 3 with respect to cavity-3 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = 0$ for aperture 4with respect to cavity-2 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = 0$ for aperture 5 with respect to cavity-3 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = W + d$ for aperture 4 with respect to cavity-4 axis.
- $L = a, W = (2b + s - d)/2$, $x_w = 0$ and $y_w = -W - d$ for aperture 5 with respect to cavity-4 axis.
- $L = a, W = b$, $x_w = 0$ and $y_w = b + s$ for aperture 7 with respect to cavity-4 axis.
- $L = a, W = b$, $x_w = 0$ and $y_w = -b - s$ for aperture 6 with respect to cavity-4 axis.
- Where 2a=22.86 mm, 2b=10.16 mm, s=2 mm and d=3.2 mm.
- Where 2s is the distance between waveguide-2 and waveguide-3.
- t_1=20.2 mm is the length of cavity along Z-axis.

The X-component of incident magnetic field at the aperture for the transmitting mode is a dominant TE_{10} mode and is given by

$$H_x^{inc} = -Y_0 \cos\left(\frac{\pi x}{2a}\right) e^{-j\beta z}$$

EVALUATION OF THE CAVITY SCATTERED FIELD

The tangential components of the cavity scattered fields are derived in [16]. The final form of the tangential components of the cavity scattered field will be same as given in [17], where L_c is the length and W_c is the width of the cavity. L_i and W_i are the half length and half width of i^{th} aperture.

$$\begin{aligned} H_x^{cav^j}\left(M_i^x\right) = -\frac{j\omega\varepsilon}{k^2}\sum_{m=1}^{\infty}\sum_{n=0}^{\infty}\frac{\varepsilon_m\varepsilon_n L_i W_i}{2L_c W_c}\left\{k^2 - \left(\frac{m\pi}{2L_c}\right)^2\right\}\sin\left\{\frac{m\pi}{2L_c}(x + L_c)\right\} \\ \times\cos\left\{\frac{n\pi}{2W_c}(y + W_c)\right\}\cos\left\{\frac{n\pi}{2W_c}(y_w + W_c)\right\}\operatorname{sinc}\left\{\frac{n\pi}{2W_c}W_i\right\}F_x(p)\times \\ \frac{(-1)}{\Gamma_{mn}\sin\{2\Gamma_{mn}t_c\}}\begin{cases}\cos\{\Gamma_{mn}(z - t_c)\}\cos\{\Gamma_{mn}(z_0 + t_c)\} & z>z_0 \\ \cos\{\Gamma_{mn}(z_0 - t_c)\}\cos\{\Gamma_{mn}(z + t_c)\} & z<z_0\end{cases} \end{aligned} \quad (3)$$

Where t_c is half length of the cavity in z-direction and Γ_{mn} is the propagation constant

$$\Gamma_{mn} = \sqrt{k^2 - \left(\frac{m\pi}{2L}\right)^2 - \left(\frac{n\pi}{2W}\right)^2}.$$

$$k = \omega\sqrt{\mu\varepsilon}$$

$$\varepsilon_i = \begin{cases} 1, & \text{i=0} \\ 2, & \text{i} \neq 0 \end{cases}$$

$$F_x(p) = \left[\cos\left\{\frac{\pi}{2}\left(-\frac{mx_w}{a_i} + p - m\right)\right\}\sin c\left\{\frac{\pi L}{2}\left(\frac{p}{L} - \frac{m}{a_i}\right)\right\}\right.$$

$$\left. + \cos\left\{\frac{\pi}{2}\left(\frac{mx_w}{a_i} + p + m\right)\right\}\sin c\left\{\frac{\pi L}{2}\left(\frac{p}{L} + \frac{m}{a_i}\right)\right\}\right]$$

Similarly other component of magnetic fields can be obtained. At the region of the window, the tangential component of the magnetic field in the aperture should be continuous and applying the proper boundary conditions at the aperture the electric fields can be evaluated [17]. The Galerkin's specialization of the method of moments is used to obtain 14M-different equations from the boundary condition to enable determination of $E_p^{i,x/y}$. From the moment matrices, S-parameters will be calculated.

NUMERICAL RESULTS AND DISCUSSION

Theoretical data for the magnitude of scattering parameters for folded E-plane tee at X-band has been compared with CST Microwave Studio simulated and measured data.

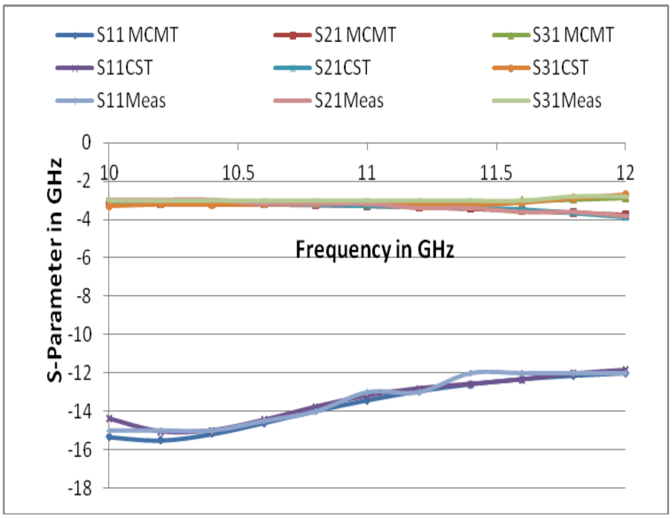

Figure 3: Comparison of MCMT and CST Microwave Studio simulated for S-Parameter of a folded E-plane tee without shorting post and t1=20.2mm when excited at port-1.

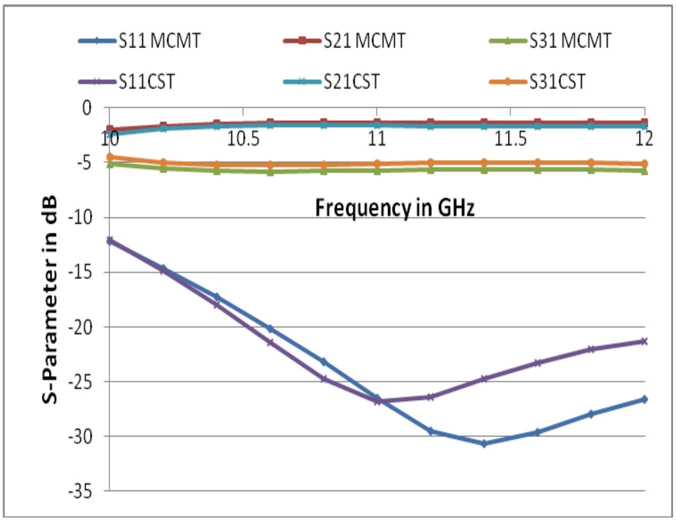

Figure 4: Comparison of measured, MCMT and CST Microwave Studio simulated for S-Parameter of a folded E-plane tee with shorting post and t_1=20.2mm when excited at port-1.

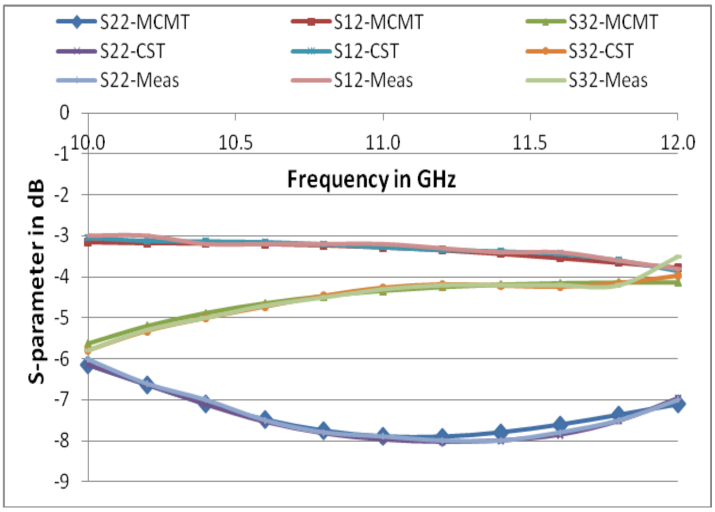

Figure 5: Comparison of measured, MCMT and CST Microwave Studio simulated for S-Parameter of a folded E-plane tee with shorting post and t1=20.2mm when excited at port-2.

MATLAB codes have been written for analyzing the structure and numerical data have been obtained after running the codes. The structure was also simulated using CST microwave studio. The theory has been validated by the excellent agreement between the CST Microwave Studio simulated and measured data.

The magnitude of S-parameters of a folded E-plane tee without shorting post with t_1=20.2mm when excited at port-1 is shown in Fig- 3, which shows that S_{21} and S_{31} are different. In Fig. 4-6 the magnitude of S-parameters for the proposed have shown, which show that the $S_{21,}$ $S_{12,}$ S_{13} and S_{31} have the equal magnitude, near about 3dB over the frequency range 10-12 GHz. In Fig- 7, the phase of the S_{21} and S_{31} have shown.

The difference in phase of S_{21} and S_{31} are near about 120^0 as computed by CST and MCMT at the junction.

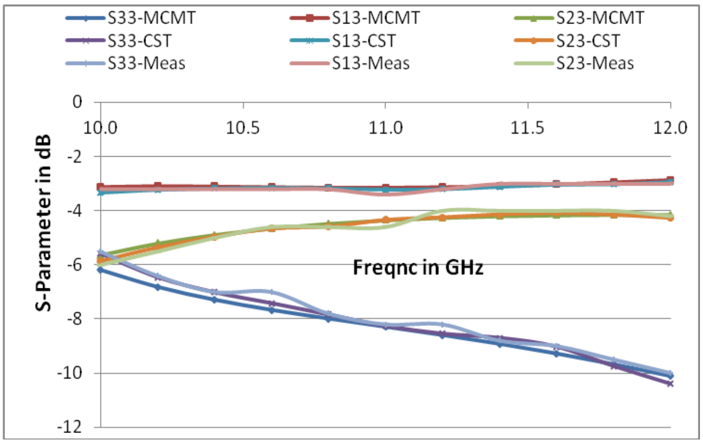

Figure 6: Comparison of measured, MCMT and CST Microwave Studio simulated for S-Parameter of a folded E-plane tee with t_1=20.2mm when excited at port-3.

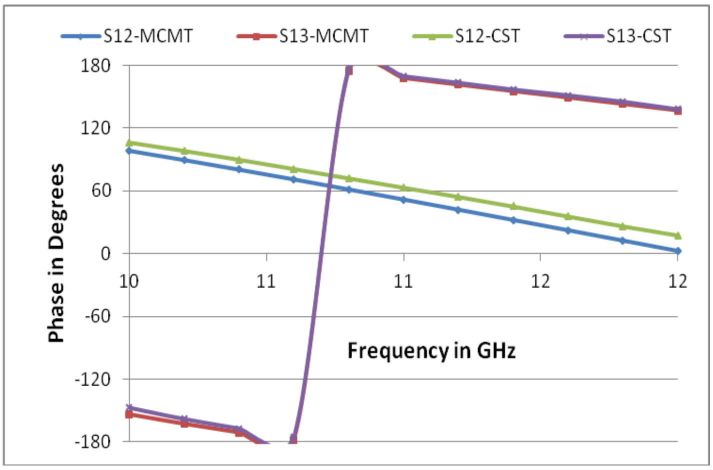

Figure-7: Comparison of MCMT and CST Microwave Studio simulated and for phase of S-Parameter S21, S12, S13, and S31 of folded E-plane tee with t1 =20.2mm.

CONCLUSION

The result shown in Fig-3 depicts that the folded E-plane tee without shorting post is not matched to the junctions for equal power division. The inclusion of shorting post makes the junction matched and equal power division can be achieved over the frequency range of 10-12 GHz. Furthermore it can be tuned to any band by changing the shorting post dimensions. The phase of S_{12} and S_{13} of the circuit are different so it cannot be used as an efficient power combiner unless a phase shifter is used.

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