An E-Plane Folded Magic Tee for X Band Applications

Jyotisankar Kalia
Department of Electronics and Communication Engineering
National Institute of Technology Rourkela
kaliaalokamie@gmail.com

***Abstract* — Magic tee or hybrid tee is a 4-port microwave passive device and is commonly used for duplexing, mixing and impedance measurement in radar. The four arms of a conventional magic tee direct four different directions, mutually perpendicular to each other. This creates inconvenience when the device is used. To avoid this, an E-Plane folded magic tee has been proposed and simulated using CST Microwave Studio for X-Band radar applications. In the proposed design the collinear arms of the tee have been folded back parallel to the E-arm. So for the proposed design, the collinear arms direct same direction and thus easy to combine or divide power. The proposed design plays an important role in downsizing the microwave radar system and reducing the system weight without hampering its basic properties.**

Index Terms — Crossed Polarized, E-Plane, H-Plane, Scattering Matrix, X-Band

I. Introduction

An Ideal magic tee or hybrid tee is a 4-port microwave passive reciprocal device and is a combination of E and H plane tees [1]-[2]-[3]. Out of four arms the two side arms are called as collinear arms and remaining two are H and E arms, which are crossed polarized or electromagnetically decoupled from each other. If power is fed in H arm, it will be equally divided in phase to two side arms and if power is fed in E arm it will be equally divided out of phase. Similarly if the collinear arms will be fed equal powers, these will be added at port 4 and subtracted at port 1. The magic tee is commonly used for duplexing, mixing and impedance measurement in radar. The scattering matrix of an ideal magic tee is given below.

$$S = {}^{1}\!/_{\sqrt{2}} \begin{vmatrix} 0 & 1 & -1 & 0 \\ 1 & 0 & 0 & 1 \\ -1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{vmatrix} \qquad (1)$$

The matrix tells that all the four ports are perfectly matched as $S_{11}=S_{22}=S_{33}=S_{44}=0$. Again as there is no power flow between pots 1 and 4 and also between 2 and 3, $S_{14}=S_{41}=0$ and $S_{23}=S_{32}=0$. The input port divides power equally to the collinear arms. So $S_{24}=S_{34}$, because of H arm and $S_{31}=(-S_{31})$, because of E arm. As the device is reciprocal $S_{12}=S_{21}$, $S_{13}=S_{31}$, $S_{24}=S_{42}$ and $S_{34}=S_{43}$. The matrix is satisfying unity property [1]-[2]-[3] which says that, "the sum of the products of each term of any raw or column of the matrix 'S' multiplied by its complex conjugate is unity. i.e.

$$\sum_i^n S_{ij} \,.\, S_{ij}^* = 1 = \left|S_{ij}\right|^2 \qquad (2)$$

$$where, i = 1, 2, 3, 4 \; and \; j = 1, 2, 3, 4$$

As the Unity property is satisfied, the device or network is lossless as ideal. The structure of a conventional magic tee is shown below.

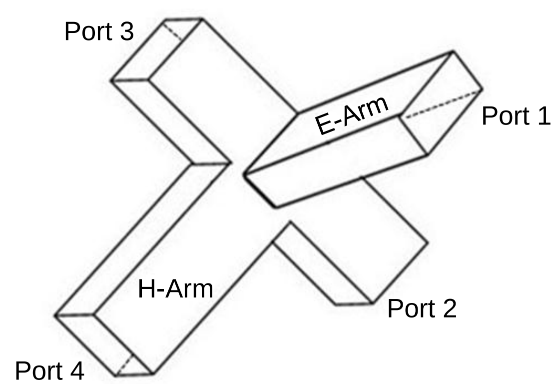

Fig. 1. Structure of the Conventional Magic Tee

II. Problem Formulation and Solution

The conventional magic tee occupies much space, as the collinear arms point to opposite directions. Also more no of bends and twists are needed when it is used with radars and the system becomes clumsy. To avoid this clumsiness a folded back magic tee[4]-[5] has been proposed, where the collinear arms containing port 2 and 3 are folded back and made parallel to the E-Plane arm [4]-[6]. So it can be called as E-

Plane folded magic tee and could be used for system downsizing in radars along with seamless flex waveguides [7]. The structure of the proposed magic tee with dimensions is shown in the fig. 2, where arm dimensions are shown in mm by dotted lines and the thickness of the walls is taken negligible.

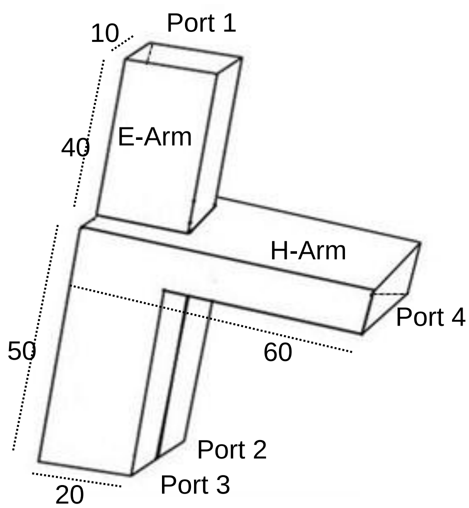

Fig. 2. Structure of the Proposed Magic Tee

III. Design of the E-plane Magic Tee

The E-Plane magic tee is designed in CST Microwave Studio software. The device material is chosen as a perfect electric conductor and is considered as filled with air dielectric [8]. The waveguide cross-section ‘a×b’ of the device is taken ‘20mm×10mm’ i.e. a=2b and the wall thickness is considered negligible. Now the cutoff frequency for the TE_{10} dominant mode [1]-[2]-[3] can be calculated using the following equation.

$$f_c = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} = \frac{c}{2a} = \frac{3\times 10^{10}}{4} = 7.5\ Ghz \quad (3)$$

So the signal to be propagated with this system must have frequency higher than 7.5 GHz and thus wavelength lower than 4cm. The device is designed to work in the dominant mode as this mode has less distortion. As the mode of propagation is TE there will be only magnetic field in the propagation direction.

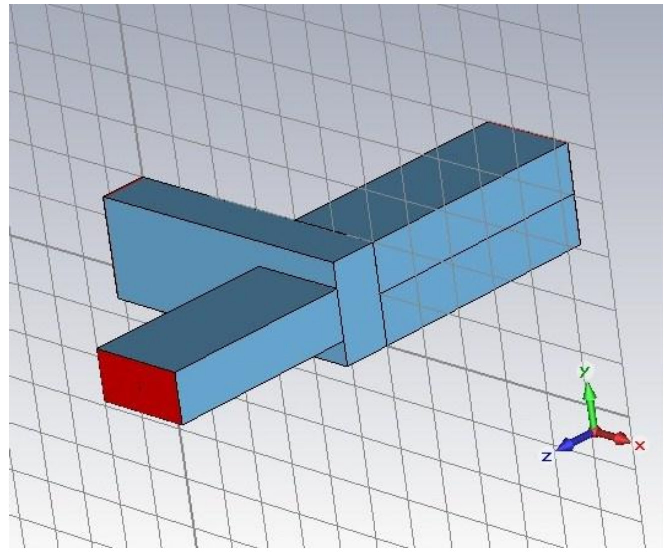

Fig. 3. CST Generated E-Plane Folded Magic Tee

IV. Simulation and Discussion

The proposed magic tee is designed for the X-Band applications. The X-band ranges from 8.5-12.5GHz which is more than the calculated cutoff frequency. The designed device is simulated at 11.5 GHz frequency with TE_{10} mode.

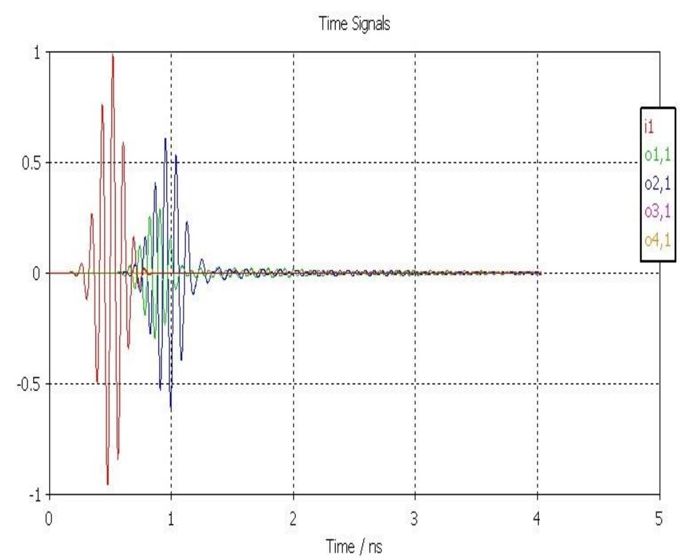

Fig. 4. Time Signals

Fig. 4. shows the time signals i.e. the incident and reflected or transmitted wave amplitudes at the ports versus time. The incident wave amplitude is called i1 and the reflected or transmitted wave amplitudes of the 4 ports are o1,1, o2,1, o3,1 and o4,1. We can see that the o2,1 and o3,1 are identical so

only o2,1 is visible and is nearly half in amplitude of i1. o4,1 is nearly zero as the incident power is equally divided between port 2 and 3 and negligible power transmitted to port 4. We can also see that the proposed tee is able to complete the power division process with in four nano seconds only.

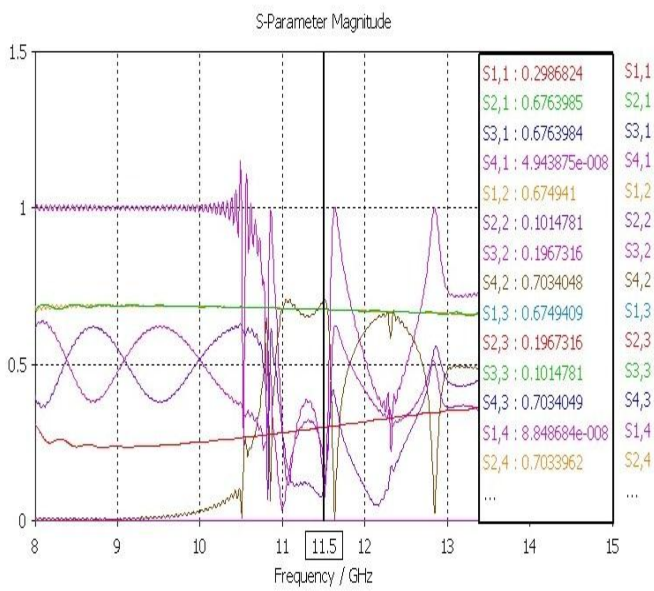

Fig. 5. S-Parameters in Magnitudes

$$S = \begin{vmatrix} 0.3 & 0.68 & 0.68 & 8.85 \times e^{-5} \\ 0.68 & 0.1 & 0.2 & 0.7 \\ 0.68 & 0.2 & 0.1 & 0.7 \\ 4.94 \times e^{-8} & 0.7 & 0.7 & 0.1 \end{vmatrix} \quad (4)$$

Equation (4) shows the Scattering matrix (Magnitudes Only) [9] of fig. 5. It says that the input applied at port1 is equally divided to ports 2 and 3 as S_{21}=S_{31}=0.68 and as it is a reciprocal or symmetric device S_{12}=S_{13}=0.68. If power will be fed at port 4, then also it will be equally divided into port 2 and 3 so S_{24}=S_{34}=0.7 and because of the symmetry property S_{42}=S_{43}=0.7. All the four are nicely matched as the reflection coefficient for port 2, 3 and 4 is 0.1 and for port 1 is 0.3. We know VSWR= (1+|Γ|) / (1-|Γ|), where 'Γ' is the reflection coefficient. So the VSWR is 1.86 for port 1 and 1.22 for the remaining. The designed magic tee does not satisfy unity property as it is not an ideal one.

As port 1 and 4 are crossed polarized, the transmission coefficients S_{14} and S_{41} have very small values. Also the collinear ports transfer a very small power to each other, so S_{23}=S_{32}=0.2.

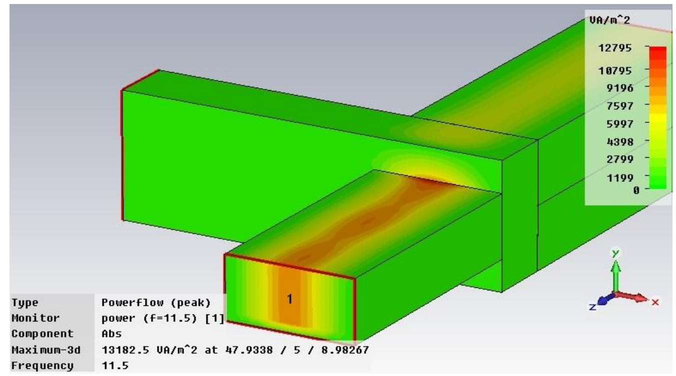

Fig. 6. Power Flow from the Input Port

The power flow shows that the maximum power of the input port is 13182.5 VA/m^2, equally divided in to the collinear arms only and a negligible power flows to port 4.

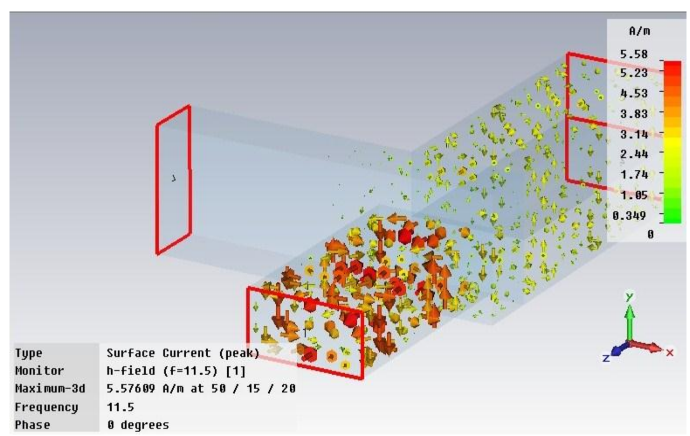

Fig. 7. Surface Current Flow from the Input Port

The surface current also tells that the input current of 5.57609 A/m is almost equally divided into port 2 and 3 and negligible current passes to port 4.

V. Conclusion

An E-Plane folded magic tee is proposed to downsizing the radar system. The simulation results tell that all the four ports of the designed magic tee are well matched. It divides power equally to the collinear ports and the E-Plane and H-Plane ports are crossed polarized or electromagnetically decoupled from each other. Also because of its physical structure this magic tee is convenient for use as power divider in radar system without hampering the properties of a conventional magic tee.

ACKNOWLEDGEMENT

The author expresses his gratitude to the department of Electronics and Communication Engineering, National Institute of Technology Rourkela for providing computing facility towards this work. The author also wish to thank the department of Electronics and Telecommunication Engineering, Ghanashyam Hemalata Institute of Technology and Management Puri, where he practically observed the problem with the conventional magic tee, when working with microwave test bench and passive devices.

REFERENCES

[1] S Y Liao, Microwave Devices and Circuits, Pearson Education Inc. Third Edition 2011.

[2] D M Pozar, Microwave Engineering, Wiley India Pvt. Ltd. Third Edition 2007.

[3] M Mitra, Microwave Engineering, Dhanpat Rai and Co. First Edition 2003.

[4] Zhong-Bo Zhu, Shi-Wei Dong, Ying Wang and Ya-Zhou Dong, "Design of K Band E-plane Folded Magic Tee Matched in Two ways for Spatial Power Combining," *IEEE International Conference on Electronics, Communication and control (ICECC)*, pp.4078-4081, September 2011.

[5] ZX Wang, W B Dou and G H Li, "A Design of H-Plane Magic Tee at W Band," *IEEE International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, Vol-1, pp. 280-283, April 2008.

[6] Karl R. Vaden, "Computer Aided Design of Ka-Band Waveguide Power Combining Architectures for Interplanetary Spacecraft," Technical Report, NASA, February 2006.

[7] CMT Waveguide Component Specification and Design Handbook, Seventh Edition

[8] CST Microwave Studio Tutorials, Version 4, 2002.

[9] P Debnath and S Roy, "An Analysis of Wave Guide E-Plane Tee as 3dB splitter at X Band Using HFSS Software," *International Journal of Soft Computing and Engineering (IJSCE)*, Vol-2, January 2013.