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Simulation of Wave Propagation in Waveguide Tee Junctions

Amit Arora

***Abstract:** In order to understand the behaviour of any microwave component, knowledge of electromagnetic (EM) field distribution inside the component is necessary. In this paper simulation of wave propagation in waveguide tees at X- band is presented in dominant mode. Pattern of electric field from front view, side view, and front and top view of magnetic field for dominant mode in rectangular waveguide is presented. Configuration of electric, magnetic field and power distribution at different time instants in microwave tees is explained. Power distribution and isolation property in E-H plane tee are also described.*

***Keywords:** E-plane tee, H-plane tee, Magic tee, Waveguide.*

I. INTRODUCTION

To understand the distribution and variation of fields in the rectangular waveguide and microwave tees simulation of component is proposed. CST (computer simulation technology) is fast and memory efficient numerical technique based on finite integration method [1]. CST produce results in 2D vector/scalar and 3D vector/scalar pictorial form. 2D plots depict fields at the port whereas 3D plots also having cutting plane option, i.e. can view the field variation inside the component at different time/phase instants. Scalar plots show only intensity, whereas vector plot presents intensity as well as direction and phase. Simulated results give the information regarding intensity and phase of individual field in the waveguide at different time instants or phases. Power distribution in all arms can also be understood by simulated results. After every half-wavelength distribution of fields repeats with 180^0 phase change.

II. THEORY

In the waveguide system tee junctions are used to combine the power coming from two lines and split the power into two separate lines with proper phase consideration by joining a similar cross-section waveguide in shunt or series connection [2]. Shunt and series connection is named as H-plane and E-plane three port tee respectively, whereas a combination of both connections is termed as E-H plane (magic or hybrid) tee which has four ports.

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***** Correspondence Author
Amit Arora*, Department of Electronics and Communication Engineering, CVR College of Engineering, Hyderabad, India.

In H-plane tee when input signal is fed from collinear arms port 1 and port 2, the output at H-arm is additive, whereas when wave signal is fed in H-arm signal divides (magnetic field loops are divided into collinear arms similar as the current is distributed in two parallel branches) equally and the phase at both collinear ports is same. In E-plane tee, when input signal is fed from collinear arms port 1 and port 2, the output at E-arm is subtractive [3], [4]. On the other hand, when wave signal is fed in E-arm, it divides equally and the phase difference between the output signals at both collinear ports is 180^0 [5], [6]. A combination of E-plane and H-plane tees makes an E-H plane or hybrid or magic tee. In magic tee if same signal is fed at both collinear arms output at H-arm is additive, whereas output at E-arm is subtractive of input signals. In the same tee if the signal is fed at H-arm signal is divided equally and in-phase in collinear arms and E-arm is isolated, whereas if the signal is fed at E-arm, signal is divided equally and out-of-phase in collinear arms and H-arm is isolated [7].

In this paper variation of electric and magnetic fields in the rectangular waveguide in dominant TE_{10} mode at 9.5 GHz is presented. A magnetic field distribution at different time instants in H-plane tee is described. Electric and magnetic field distribution in the E-plane tee at different time instants is shown and also illustrates the isolation property of the E-H plane tee.

III. SIMULATION AND RESULTS

The waveguide is transmission line/guiding structure in the microwave and millimeter frequency range. A hollow rectangular waveguide (width > height) is chosen for study.

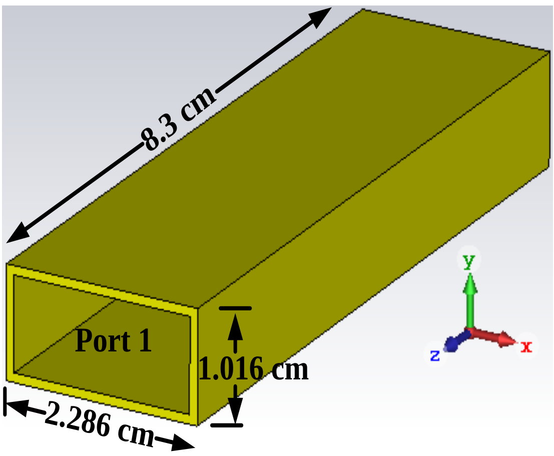
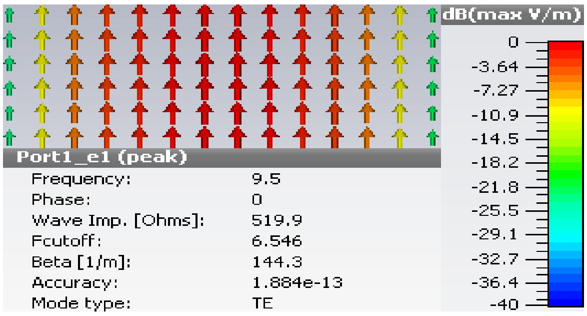


Fig. 1. 3D geometry of hollow rectangular waveguide.

Figure 1 illustrates the 3D model of copper (annealed) rectangular waveguide with the inner dimensions 2.286 cm x 1.016 cm x 8.3 cm with normal background material and set background E_t = 0 in all directions. The electrical conductivity (σ) of copper (annealed) is 5.8 x 10^7 S/m, resistivity (ρ) 8930 kg/m^3, heat capacity 0.39 kJ/K/kg and thermal conductivity 401 W/K/m.



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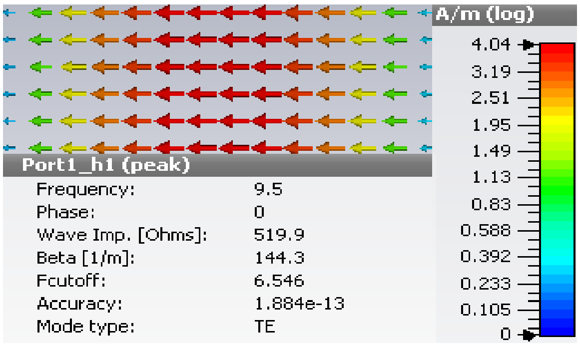

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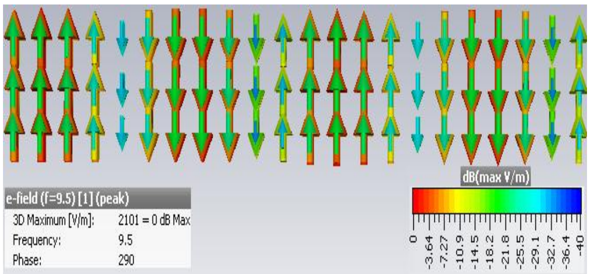

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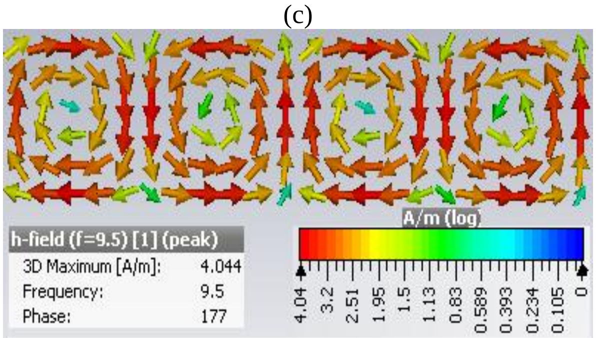


(d)

Fig. 2. 2D field pattern for TE_{10} mode with smart color scale.

2D vector plots (a) Electric field, (b) Magnetic field at front port, (c) Side view of electric field, and (d) Top view of magnetic field.

Figure 2 (a) shows the 2D vector plot of electric field distribution at front port. It clearly indicates the field is perpendicular to the bottom and top wall of rectangular guide and intensity is maximum at the center and gradually decreases towards the side walls. Figure 2 (b) displays the 2D vector plot of magnetic field distribution at front port. It depicts the field is parallel to the top and bottom walls and intensity is maximum at the center and gradually decreases to the narrow walls of rectangular waveguide. Figure 2 (c) displays the side view of electric field pattern, it represents along the length and intensity of the field is changing sinusoidally whereas figure 2 (d) displays the top view of magnetic field loops.

(a) H-plane tee or shunt tee: In H-plane tee, a section of similar (cross sectional dimensions of collinear and H arm are same) waveguide is joined through a slot (equal to the width of main waveguide) in the narrow wall of the main waveguide in the middle of its length. The axis of the side arm is parallel to the orientation of the H field in the main waveguide, hence termed as H-plane tee [7].

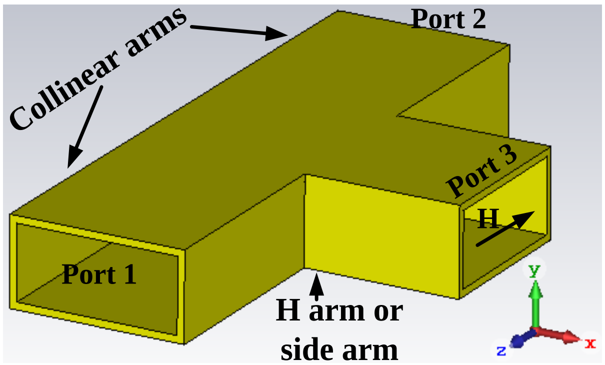
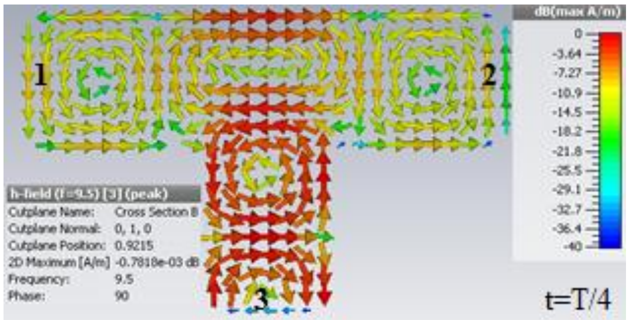


Fig. 3. 3D model of H-plane tee or Shunt tee.

Figure 3 depicts the geometry of H-plane tee used for simulation. Port 1 and 2 are at collinear arms, whereas port 3 is at H-arm is having 2.3 cm length. Width, height and length of main waveguide (in cm) are 2.286, 1.016 and 8.3 respectively.



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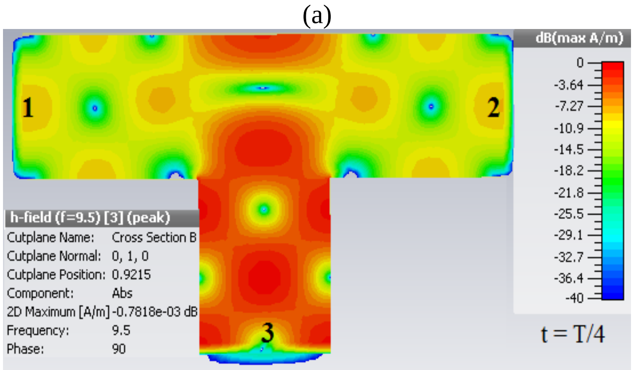

(b)

Fig. 4. 3D magnetic field plots (a) Vector, and (b) Scalar.

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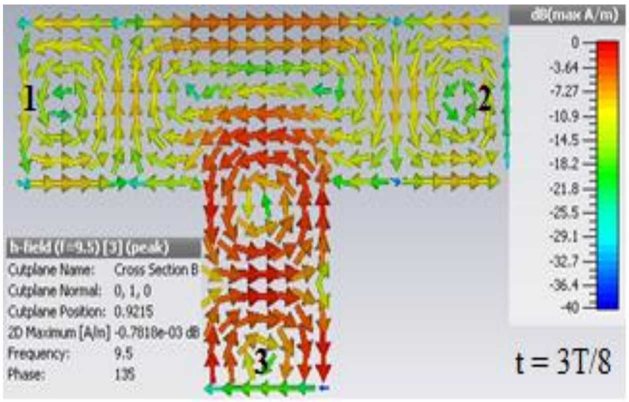
Figure 4 (a) shows 3D vector cross sectional view and figure 4 (b) illustrates 3D scalar plot of magnetic field at t = T/4 when input at port 3. It clearly indicates that the intensity of magnetic field is high in the H-arm and at center of collinear arm is minimum.



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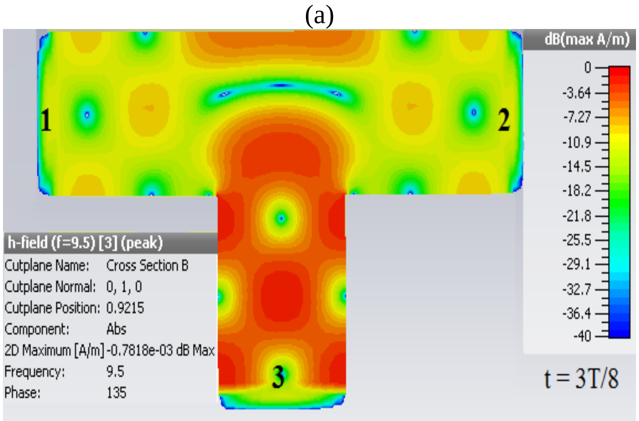


(b)

Fig. 5. 3D plots of magnetic field at t = 3T/8 when input fed at port 3 (a) Vector, and (b) Scalar.

Figure 5 (a) illustrates 3D vector magnetic field cross sectional view and figure 5 (b) demonstrates 3D scalar plot of magnetic field at t = 3T/8 when input at port 3. It clearly indicates that distribution of magnetic field is symmetric in the collinear arm and the distribution center is the midpoint of main waveguide.

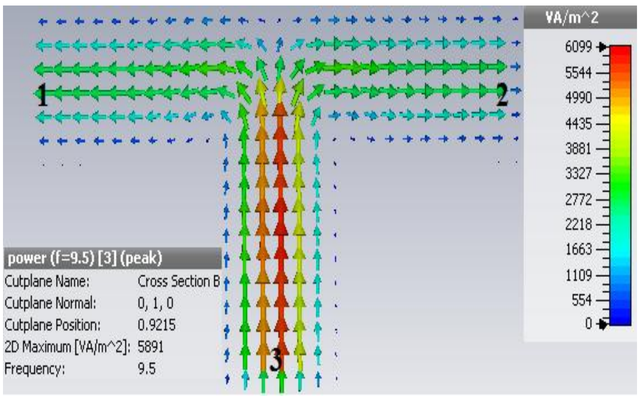


Fig. 6. 3D vector plot of power distribution in collinear arm.

Figure 6 displays the equal power distribution at the junction of H-plane tee when the input is fed at H-arm. It is used as a 3-dB power splitter.

(b) E-plane tee or Series tee: In E-plane tee, a section of similar (cross sectional dimensions of collinear and E arm are same) waveguide is joined through a slot (equal to the height of main waveguide) in the broader wall of the main waveguide in the middle of its length. Axis of the side arm is parallel to the orientation of E field in the main waveguide, hence the name E-plane tee [7].

b)

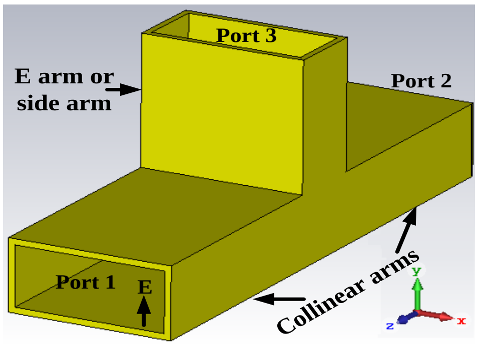
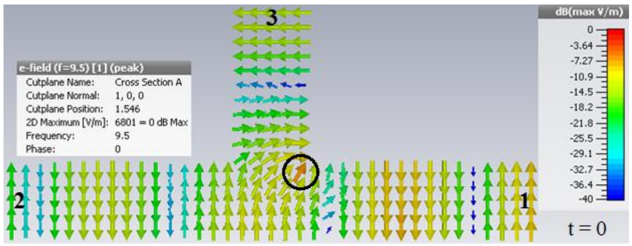


Fig. 7. 3D geometry of E-plane tee or series tee.

Figure 7 depicts the geometry used for simulation in CST for E-plane tee. Port 1 and 2 are at collinear arms, whereas port 3 is at E-arm is having 2.3 cm length. Width, height and length of main waveguide (in cm) are 2.286, 1.016 and 8.3 respectively.



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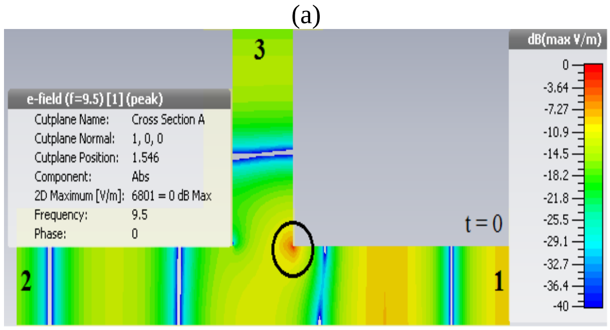
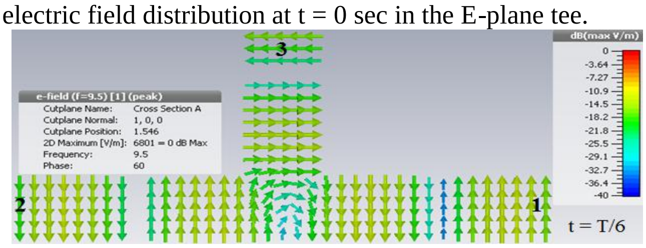


(b)

Fig. 8. 3D E-field plots (a) Vector, and (b) Scalar at t = 0 sec when input at port 1.

Figure 8(a) shows the 3D vector plot of electric field distribution in the E-plane tee. At t = 0 sec intensity of electric at the one corner of the E-arm is maximum as highlighted in the figure with a circle and phase at both collinear ports is same. Figure 8(b) shows the corresponding 3D scalar plot of electric field distribution at t = 0 sec in the E-plane tee.



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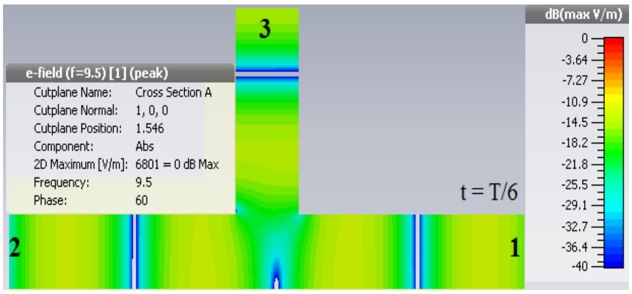
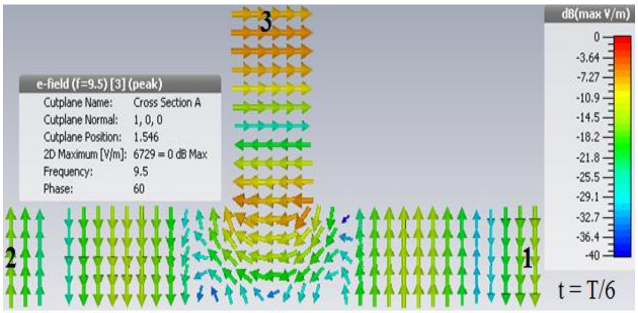


(b)

Fig. 9. 3D E-field plots (a) Vector, and (b) Scalar at t = T/6 when input at port 1.

Figure 9 (a) shows the 3D vector plot of electric field in E-plane tee when input is fed from port 1. It clearly indicates at t = T/6 electric field is symmetric at the junction and collinear arms. Figure 9 (b) depicts a corresponding 3D scalar plot.



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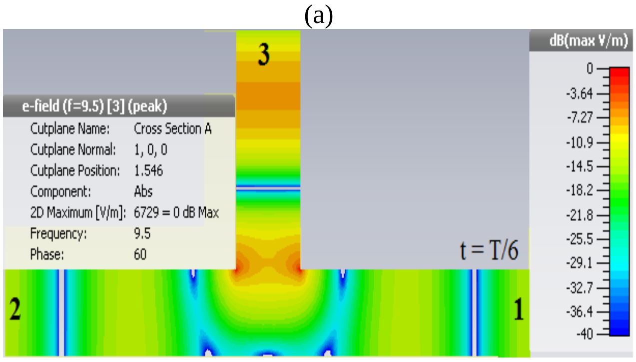
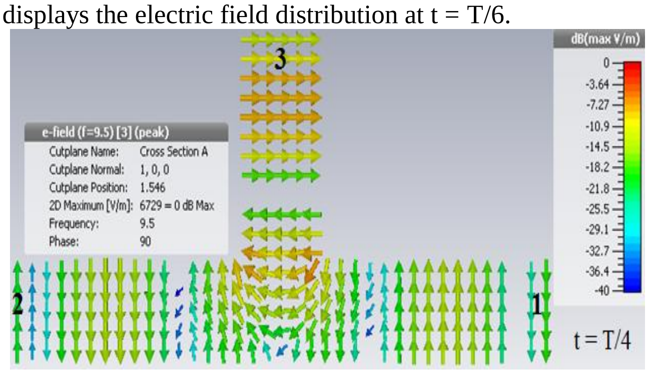


(b)

Fig. 10. 3D E-field plots (a) Vector, and (b) Scalar at t = T/6 when input at port 3.

Figure 10(a) clearly indicates that at t = T/6 intensity of electric field at the junction of E arm and main waveguide is high and also illustrate the distribution of electric field is bending at the center of main waveguide. Figure 10(b) displays the electric field distribution at t = T/6.



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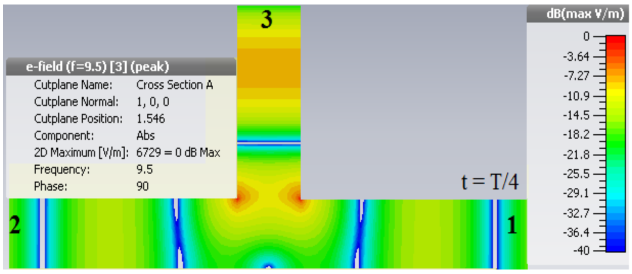
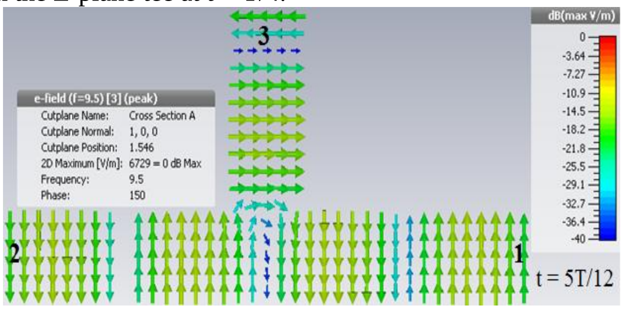


(b)

Fig. 11. 3D E-field plots (a) Vector, and (b) Scalar at t = T/4 when input at port 3.

Figure 11(a) shows the variations of electric field, it is maximum at both corners of side arm and orientation of electric field varies when it enters in main waveguide. Figure 11(b) displays the corresponding 3D electric field distribution in the E-plane tee at t = T/4.



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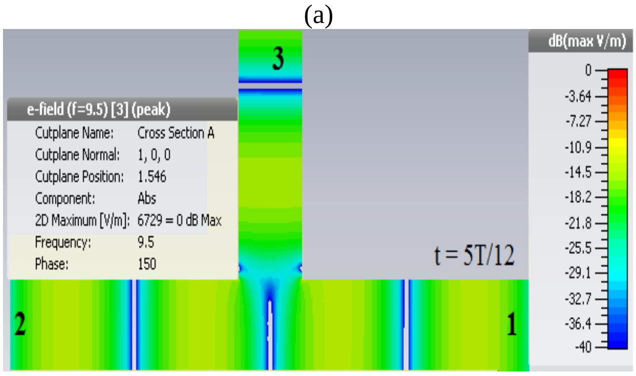
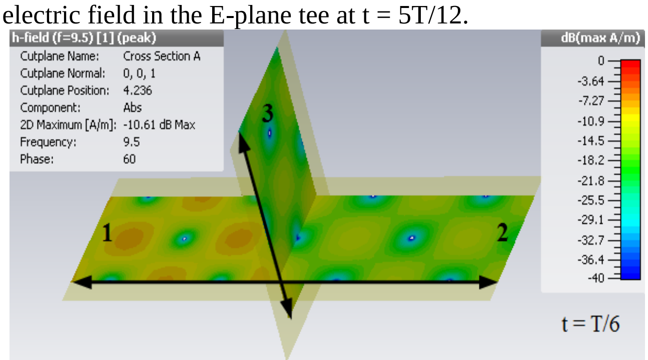


(b)

Fig. 12. 3D E-field plots (a) Vector plot, and (b) Scalar.

Figure 12(a) shows at the center of main waveguide electric field intensity is minimum and equal and opposite polarity electric field emerges at both collinear arms at t = 5T/12. Figure 12(b) displays the corresponding 3D scalar plot of the electric field in the E-plane tee at t = 5T/12.



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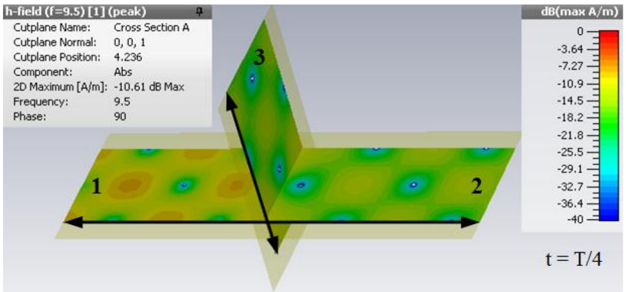
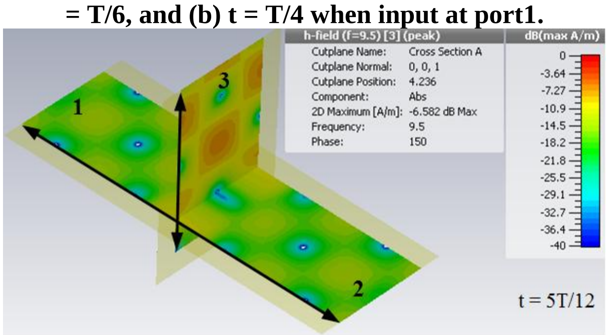


(b)

Fig. 13. 3D magnetic field scalar plot of E plane tee at (a) t = T/6, and (b) t = T/4 when input at port1.



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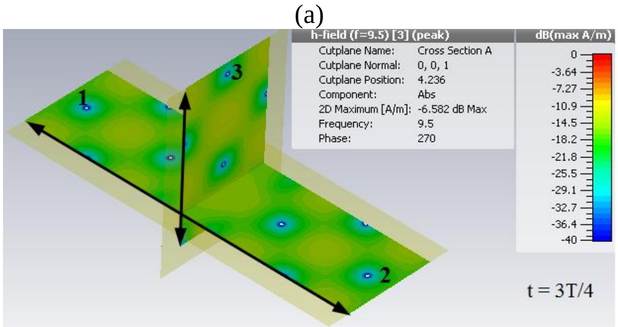
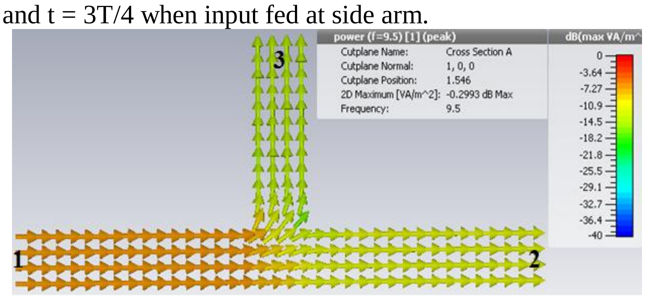


(b)

Fig. 14. 3D magnetic field scalar plots at (a) t = 5T/12, and (b) t = 3T/4 when input at 3.

Figure 13(a) and (b) depicts the symmetrical distributions of magnetic field at one collinear arm and side arm in the E-plane tee at t = T/6 and t = T/4 when input fed at other collinear arm. Figure 14(a) and (b) displays the symmetrical distributions of magnetic field at collinear arms at t = 5T/12 and t = 3T/4 when input fed at side arm.



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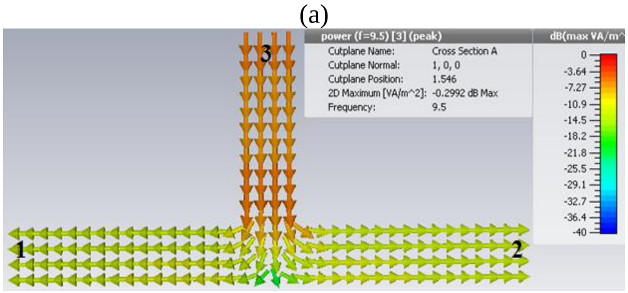

(b)

Fig. 15. Power distribution in E-plane tee when input fed at (a) Port 1, and (b) Port 3.

Figure 15 (a) shows the power distribution at the junction when input fed at port 1. Figure 15 (b) represent splitting of power equally when the input at port 3.

(c) E-H plane tee or Magic tee: In E-H plane tee, sections of similar waveguide are joined through a slot of narrow as well as a broader wall of the main waveguide in the middle of the length. The axis of the joined at narrow arm is parallel to the orientation of H field, whereas axis of the joined at broader arm is parallel to the orientation of E field in the main waveguide [7].

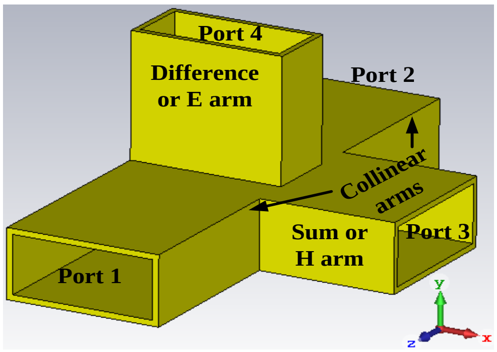

Fig. 16. Geometry of E-H plane tee or Magic Tee.

Figure 16 shows the 3D geometry used for the simulation of E-H plane tee, which has four ports. Port 1 and port 2 are at collinear arms, whereas port 3 is at H-arm and port 4 is at E-arm is having 2.3 cm length. Width, height and length of main waveguide (in cm) are 2.286, 1.016 and 8.3 respectively.

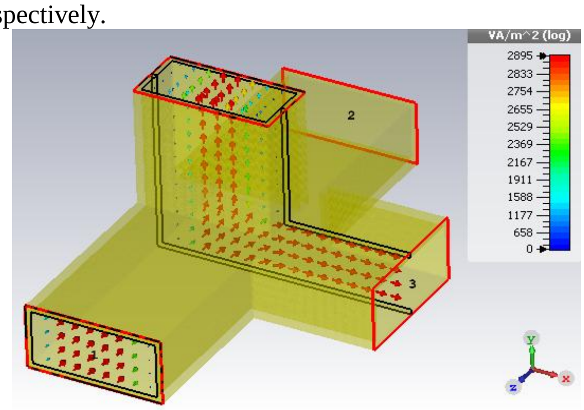

Fig. 17. Power distribution when input at port 1.

Figure 17 shows that when a signal is fed at port 1, it is divided equally between ports 3 and 4, whereas the other collinear arm is isolated. Similar results can be obtained when port 2 is excited.

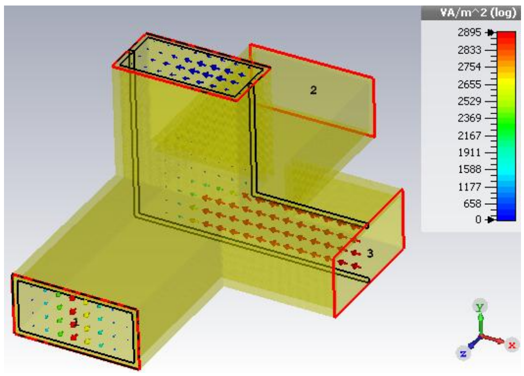

Figure 18. Power distribution when input at port 3.

Figure 18 shows that when the signal is fed at H-arm, power splits equally and in-phase in collinear arms whereas E-arm is isolated.

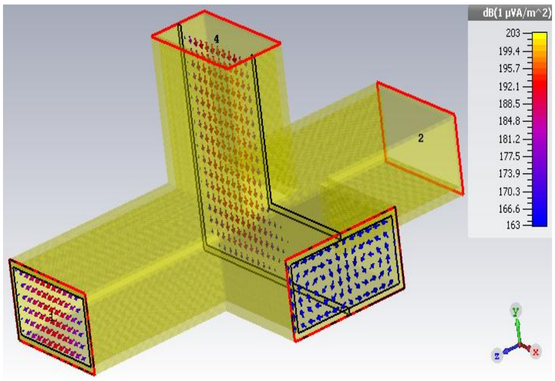

Fig. 19. Distribution of power when the input at port 3.

Figure 19 illustrates that when signal fed at E-arm, power splits equally and out-of-phase in collinear arms whereas H-arm is isolated.

IV. CONCLUSION

In this paper, visualization of electric and magnetic field in the rectangular waveguide is presented through CST simulation. Simulated results of magnetic field in the H-plane tee at different time instants and power distribution are explained. The symmetric magnetic distribution property of the H-plane tee is also presented. Variation of electric and magnetic fields in the E-plane tee at different time instants is also described through scalar and vector plots. The symmetric electric distribution property of E-plane is also explained. Isolation of ports and splitting of power are also illustrated in magic tee.

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AUTHOR PROFILE

Amit Arora received B. E. degree in electronics engineering from Jiwaji University, Gwalior, India, in 2000, M. Tech. degree in electronics and communication engineering from Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India, in 2008 and Ph.D. degree in microwave engineering from IIT (BHU), Varanasi, India in 2017. Presently working as Associate Professor (ECE) in CVR College of Engineering, Hyderabad, India.