Characteristic Planes of Microstrip and Unilateral Finline Tee-junctions

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Abstract— A unique set of reference planes which enters into the description of a three port E or H-plane tee-junction are its characteristics planes. These planes correspond to the positions of a short circuit at one typical port that will decouple a second port from one input port. The purpose of this paper is to establish these planes in the cases of microstrip and unilateral finline circuits. This is done in each case for a number of different geometries. The spacing between the first two characteristic planes across the junction is 360 deg. In the case of the H-plane tee junction, it is 180 deg in the case of the E-plane geometry.

1. INTRODUCTION

The parameters of E and H-plane tee-junctions are usually characterized at either the intersection between the symmetry planes of the main and side waveguides or at the physical opening of the junction. One other possibility is to adopt the characteristics planes for this purpose. Such planes provide a universal set of terminals in this class of network in both, microstrip line and waveguide. The concept of characteristics planes was first introduced in [1]. It has recently been applied in the descriptions of E and H-plane waveguide tee-junctions in WR-75 [2]. There is one such plane in the description of a wye-junction with three fold symmetry and there are two such planes in the definition of a right angled tee-junction. The purpose of this paper is to characterize microstrip in the H-plane and finline tee-junctions in the E-plane using this notation. This is done for both, parametric values of impedance levels and relative dielectric constants of the substrates. The scattering matrices of the circuits are separately calculated. This is done at an arbitrary frequency interval between 3 and 6 GHz. These sort of junctions enter in the construction of filters circuits and also in the design of rat races and other microwave circuits. The two geometries under consideration are illustrated in Figures 1 and 2. The geometry in Figure 1 is an example of an H-plane arrangement, that in Figure 2 is one of an E-plane structure. The eigenvalue problem of the H-plane circuit has been touched in [3]. Some typical works on tee-junctions are described in [4–15].

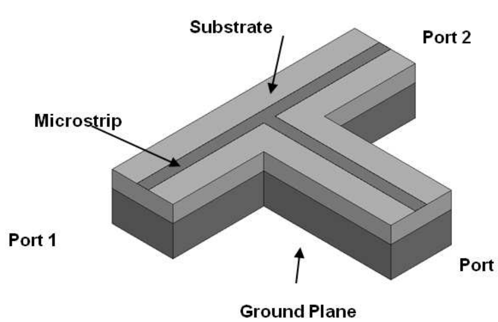


Figure 1: Schematic diagram of microstrip tee-junction.

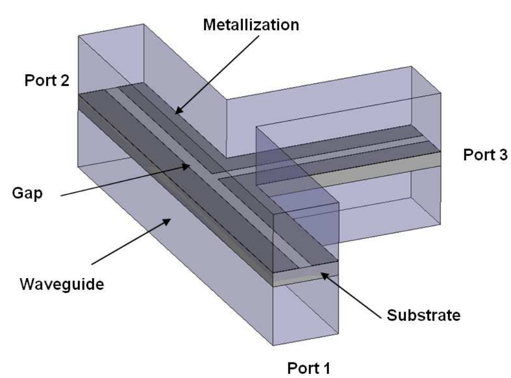


Figure 2: Schematic diagram of finline tee-junction.

2. CHARACTERISTIC PLANES OF H-PLANE TEE JUNCTION

A common 3-port microstrip junction is an H-plane right angled tee geometry. Its scattering matrix is

$$\overline{S} = \begin{bmatrix} \alpha & \delta & \gamma \\ \delta & \alpha & \gamma \\ \gamma & \gamma & \beta \end{bmatrix} \tag{1}$$

The network under consideration is reciprocal so that the matrix is symmetric about the main diagonal. A question arising with the description of this type of junction is the locations of its reference planes. One unique possibility is to adopt characteristic planes for this purpose. These planes have the positions of a short circuit at one typical port that will decouple a second port from an input one. There are two such planes in the description of the tee junction.

$$\alpha - \delta = -1 \tag{2a}$$

$$\beta - \frac{\gamma^2}{\delta} = -1 \tag{2b}$$

The first equation defines the characteristic planes in ports 1 and 2 of the junction; the second fixes that in port 3. Figures 3 and 4 illustrate typical in microstrip junction, the locations of the characteristic planes and the experimental arrangement.

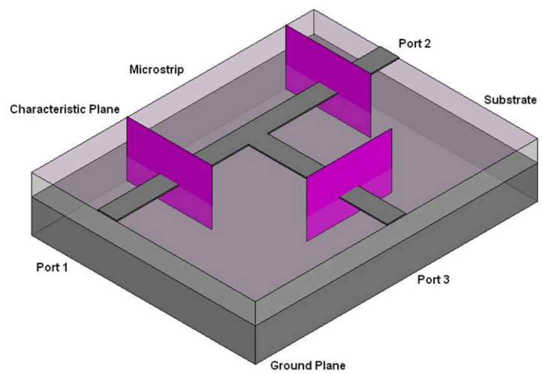


Figure 3: Characteristics planes of microstrip tee junction.

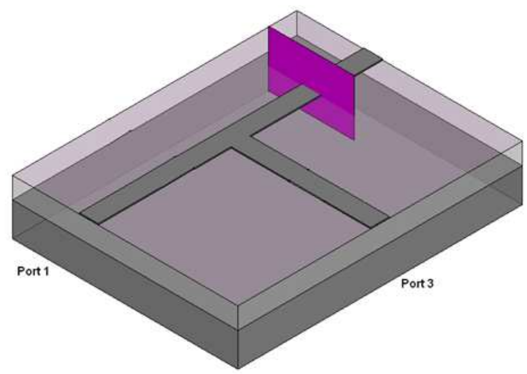


Figure 4: Experimental arrangement for measurement of a typical characteristic plane.

The two characteristic planes are equi-distance from the opening of the junction prowled

$$\alpha - \delta = \beta - \frac{\gamma^2}{\delta} \tag{3}$$

This condition is satisfied provided

$$\frac{\gamma}{\delta} = \sqrt{2} \tag{4}$$

The nature of the scattering matrix of the E-plane tee junction is different and is dealt with separately.

3. CHARACTERIZATION OF H-PLANE MICROSTRIP TEE-CIRCUITS

It is necessary in order to tabulate universal data in an unambiguous way in the descriptions of right angled tee-junctions to express the results at its characteristics planes. This may be done by defining electrical angles.

$$\theta_i = \frac{2\pi d_i}{\lambda_g} \quad i = 1, 2, 3, \ldots \tag{5}$$

The coordinate system adopted by J. T. Allanson et al. is that at the intersection between the symmetry planes of the main waveguide and the side waveguide. Other authors, such as Mansour have chosen the reference planes to coincide with the opening of the waveguides of the junction. The convention adopted here is to place the reference terminals at the characteristics planes of the junction. It is indicated in Figure 6 in the case of microstrip.

In order to carry out the fast efficient eigenmodes dispersion analysis for multilayer and multiconductor planar tlines, the hybrid fields are expressed by superposing TE-to and TM-to- with Hertzian scalar potentials. The solution to the boundary value problem describing electromagnetic wave propagation in the z direction in the structure under investigation can be found using SVD method [18].

The guide wavelength in the transmission line may be accurately deduced by recognizing that the characteristic planes repeat every half wavelength at a single frequency. It provides therefore

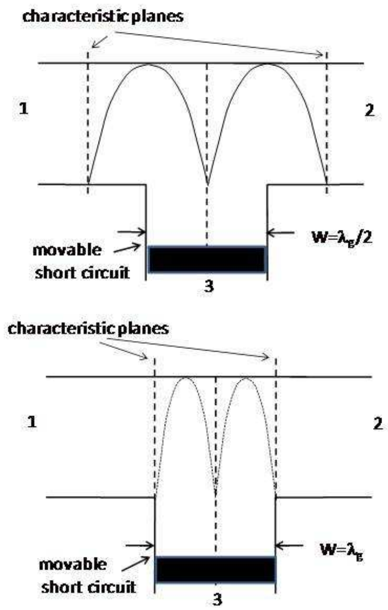


Figure 5: Characteristics planes at two different frequencies.

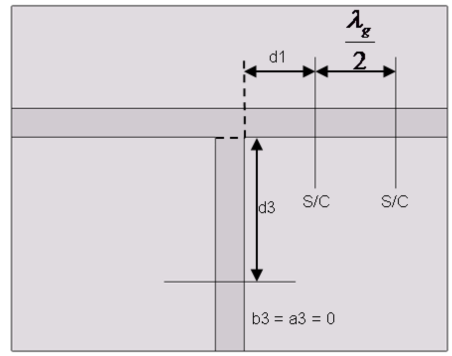


Figure 6: Definition of characteristic planes in right angled microstrip tee-junction.

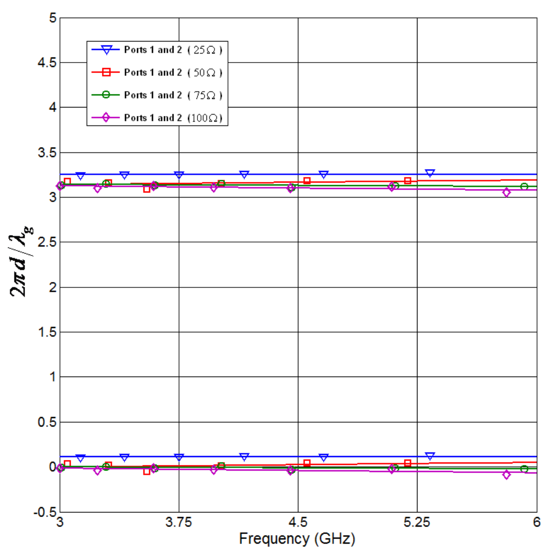


Figure 7: Calculated characteristic planes at port 1 or 2 of the microstrip tee-junction over the frequency range of 3 to 6 GHz.

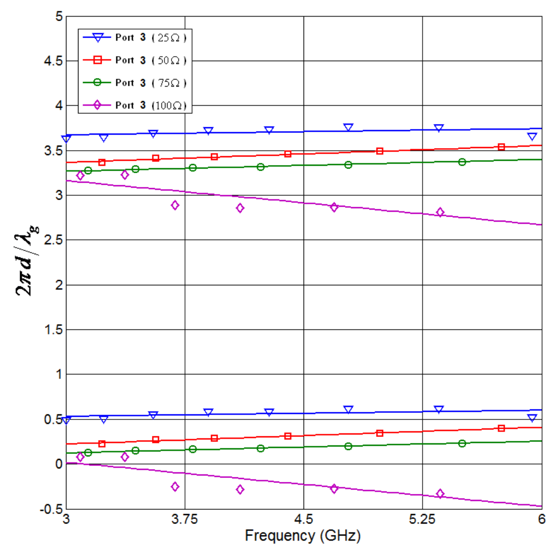


Figure 8: Calculated characteristic planes at port 3 of the microstrip tee-junction over the frequency range of 3 to 6 GHz.

one means of measuring or calculating the wavelength of the transmission line, including fringing effects. This allows the experimental reference plane to be chosen at will and translate it to that of the junction.

The characteristics planes of the structure in Figure 1 are summarized in Figures 7 and 8.

This is done for parametric values of impedance between 25 and 100 Ω over a frequency band between 3 and 6 GHz. The dielectric constant of the substrate is 3.12. The corresponding standing wave patterns are illustrated in Figures 9(a) and (b). The midband scattering parameters at the midband and edge band frequencies at the first characteristic planes are

$$\left.\begin{aligned}\alpha &= 0.942\angle -176.13^\circ\\ \beta &= 0.920\angle -179.14^\circ\\ \gamma &= 0.286\angle 87.78^\circ\\ \delta &= 0.147\angle 67.14^\circ\end{aligned}\right\}\text{1st}$$

and for the other characteristic plane

$$\left.\begin{array}{r}\alpha = 0.302\angle -21.25^\circ\\ \beta = 0.390\angle 129.32^\circ\\ \gamma = 0.638\angle 53.01^\circ\\ \delta = 0.692\angle 157.72^\circ\end{array}\right\}\text{2nd}$$

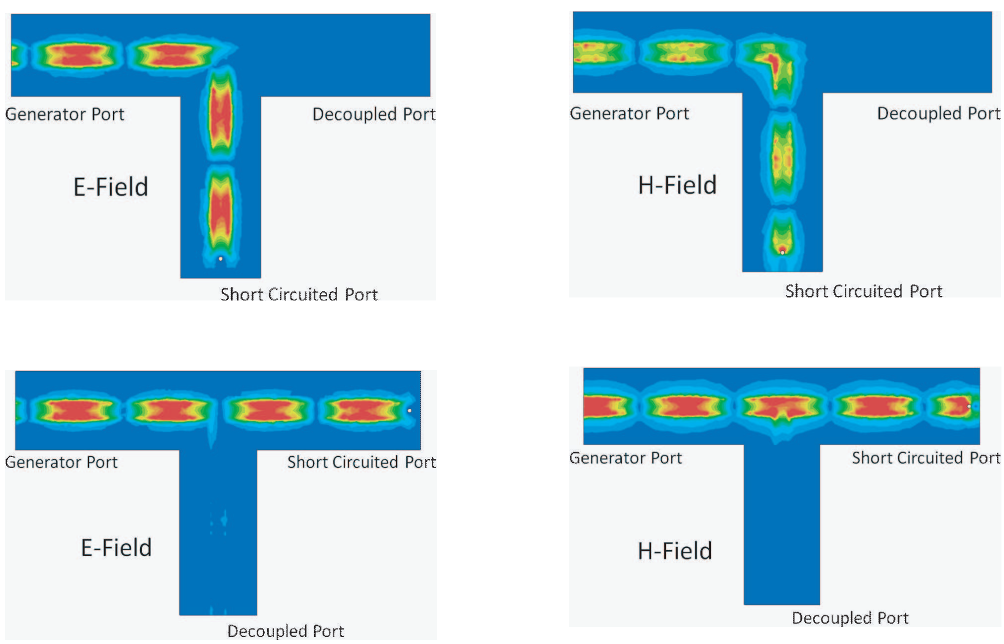
The scattering parameters obtained in this way satisfy the unitary condition.

$$\begin{aligned}|\beta|^2 + 2\,|\gamma|^2 &= 1.010 \quad \text{1st}\\ &= 0.966 \quad \text{2nd}\\ |\alpha|^2 + |\gamma|^2 + |\delta|^2 &= 0.991 \quad \text{1st}\\ &= 0.977 \quad \text{2nd}\end{aligned}$$

$|\gamma|$ these should be chosen to 1, 0.

The amplitudes of these quantities are of course independent of the choice of the reference planes adopted. Figure 9 illustrates the electromagnetic field patterns with short circuits pistons at the characteristic planes.

Exchanging the generator and short circuit conditions between ports 1 and 3 leaves in a reciprocal circuit the field patterns unchanged.



(a) (b)

Figure 9: (a) Standing wave solution of electric field in the H-plane microstrip. (b) Standing wave solution of magnetic field in the H-plane microstrip.

4. *E*-PLANE UNILATERAL FINLINE TEE-JUNCTION

The unilateral finline waveguide is an example of an E-plane geometry it is described by the a and b dimensions of the rectangular waveguide, by the gap (W) and by the thickness (H) and by the dielectric constant of the substrate (ε_r). The relative dielectric constant employed in this work is 2.2 and the waveguide is WR-75. The schematic diagram under consideration is indicated in Figure 10. The definitions of the reference planes are here arbitrarily taken at the openings of the waveguide of the rectangular waveguides of the junction rather than at those of the finline circuit. This is shown in Figure 11. The analysis of the unilateral finline can be solved using various numerical methods. The initial conditions of the structure are usually based on some existing approximate closed form expressions [16, 17] in conjunction with a spectral domain approach (SDA). It is here, however, fixed by having recourse to a full-wave simulator. This type of planar transmission line differs from the microstrip case in that it is a dispersive structure.

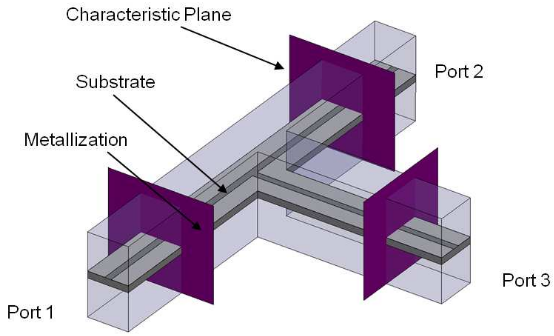


Figure 10: Characteristics planes of the E-plane finline tee-junction.

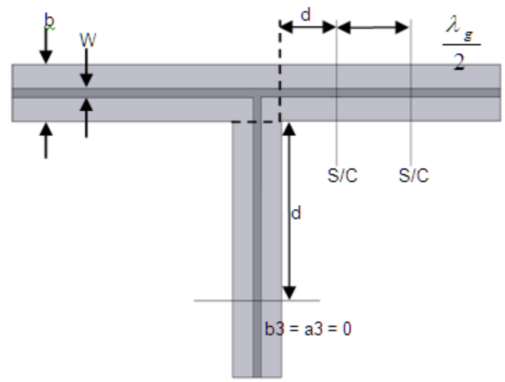


Figure 11: Definition of characteristic planes of right angled finline tee-Junction.

The scattering matrix of differs from that of the H-plane geometry in that the phases of S_{31} and S_{32} are 180 degrees out of phase with those S_{13} and S_{31} [2].

$$\overline{S} = \begin{bmatrix} \alpha & \delta & \gamma \\ \delta & \alpha & -\gamma \\ \gamma & -\gamma & \beta \end{bmatrix}$$

The reflection coefficients at the points of this main waveguide and at the side one is in this instance given by

$$\rho_{1,2} = \alpha + \delta = -1 \tag{6a}$$

$$\rho_3 = \beta + \frac{\gamma^2}{\delta} = -1 \tag{6b}$$

Figures 12 and 13 indicate the connection between the characteristics planes between 9 to 15 GHz of the unilateral finline circuit in Figure 2 at ports 1 or 2 and at port 3. In the construction of the frequency response of this type of circuits the guide wavelength adopted is, of course, that at the midband frequency.

The midband scattering parameters at the characteristics planes are

$$\begin{aligned} \alpha &= 0.339\angle 64.74^\circ \\ \beta &= 0.398\angle 113.76^\circ \\ \gamma &= 0.652\angle 114.89^\circ \\ \delta &= 0.676\angle -87.13^\circ \end{aligned}$$

This gives

$$|\beta|^2 + 2\,|\gamma|^2 = 1.008612$$

and

$$|\alpha|^2 + |\gamma|^2 + |\delta|^2 = 1.04$$

The standing wave patterns of the different possible experimental arrangements are shown in Figures 14(a) and (b).

The lack of negative signs in the description of the scattering matrix of the H-plane tee junction compared to that of the E-plane geometry produces on electric field in the inner box of the junction which is zero whereas it produces the dual condition in the latter arrangement.

One important consequence of this situation is that the spacing between the dominant characteristic planes is 360 deg. In the case of H-plane junction and 180 deg. in the other case.

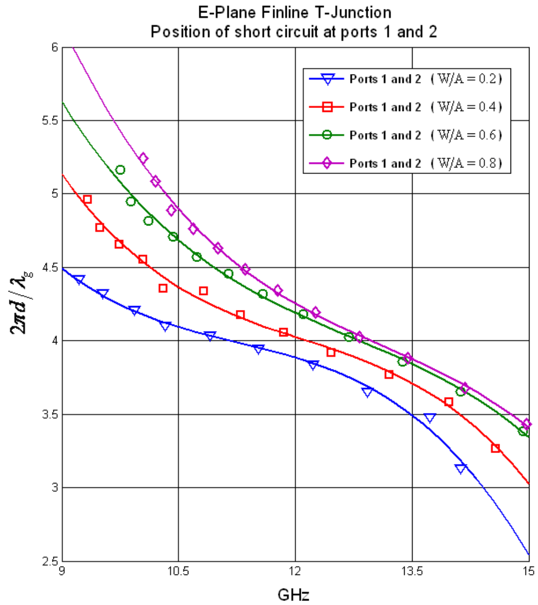


Figure 12: Calculated characteristic planes of the E-plane unilateral finline tee-junction at ports 1 or 2 between the frequency range of 9 to 15 GHz.

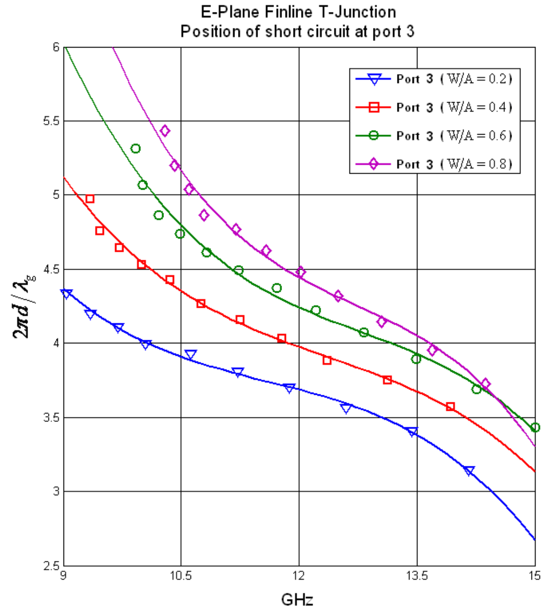


Figure 13: Calculated characteristic planes of the E-plane unilateral finline tee-junction at port 3 between the frequency range of 9 to 15 GHz.

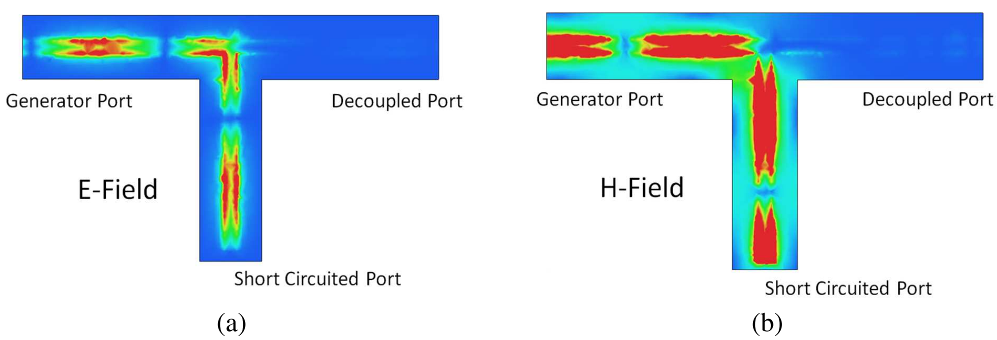


Figure 14: (a) Standing wave solution of electric field in E-plane unilateral finline. (b) Standing wave solution of magnetic field in E-plane unilateral finline.

5. CONCLUSIONS

The purpose of this paper is to establish the characteristic planes of microstrip and finline circuits. A knowledge of these planes allow unique representations of these type of circuits. The former is an example of an H-plane or shunt network and the latter is one of an E-plane or series tee-junction.

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