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Comparative Studies on Wave Guide Open Slot Radiator, H-Plane T-Junction Radiator

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Abstract

In defence radar applications, slotted waveguides have excellent, predictable and replicable antenna parameters, when their mechanical manufacturing tolerances defined accurately and controlled. Open slot radiators in the narrow wall of rectangular waveguides are popularly used in several radar applications. Slots used are either longitudinal or inclined depending on the desired polarizations. The longitudinal slots are used for the generation of vertical polarized fields and vertical slots are used for horizontally polarized fields. Sometimes both polarizations are required in succession in defence radar applications. However when longitudinal inclined slots are coupled to a T-arm forming H-plane T-junction, they produce only vertically polarized fields. In this case it is possible to have more parameters for the design of the arrays. At the same time above two types of radiators exhibit different characteristics. In the view of this fact, intensive investigations are made, to bring out and consolidate their comparative characteristics. The admittance parameters, coupling and VSWR are numerically computed using the concept of TE, TM, hybrid and self-reaction concepts.

Keywords: H-Plane T-Junction, Hybrid and Self-Reaction, Longitudinal or Inclined Slot, Open Slot Radiators, Rectangular Waveguides, VSWR

1. Introduction

The microwave passive components are essential devices for most of the communication and radar applications. Slot radiator has been used extensively in antenna arrays and is very popular because of its compactness and space saving considerations. Depending on polarization requirements of the application, the slot antennas are located either in the narrow wall or in the broad wall of standard rectangular waveguides. It has been possible to provide good control of the excitation of the slot over a large dynamic range by the variation of inclination and offset of the slot from central line of waveguide[1-7].

It is well know that longitudinal slots radiate transversely polarized fields with respect to the waveguide axis. For longitudinal or dual polarization, the slots are located transverse to the waveguide axis. Transverse resonant slots in the broad wall are excited strongly so that they can be used in large arrays. The narrow wall inclined slots cutting the narrow wall will not be able to create resonance as narrow wall cannot accommodate resonant length at small inclinations. It is for this purpose such slots are extended into broad wall and these slots are often called as edge slots[8-10].

Slot antenna is radiating element formed by a slot in a metallic surface. An opening cut in conducting sheet or in one of the walls of the waveguide acts as the antenna. It is excited suitably by either by a coaxial cable or through the waveguide. In order to increase the gain and directivity, array of slots is used. One of the most widely used waveguide slots for antenna arrays is the inclined slot cut

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in the narrow wall of a rectangular waveguide. This slot, commonly called an edge slot, possesses the advantages of relative ease of construction, high-power handling, and broader frequency bandwidth over the broad wall slots. In addition, since the slot is machined in the narrow rather than the broad wall, neighboring slots in a planar array can be more closely spaced in the H-plane to avoid multiple beams while scanning. H-plane Tee junction does not exhibit phase reversal.

TEE-junctions in rectangular waveguides play a very important role in the design of microwave circuits, such as multiplexers, power dividers, directional couplers, filters, and phase shifters, electromagnetic radiators and polarization converters in modern communication systems[11-13]. H-plane Tee junction is used as array element. In conventional open ended slot arrays, there exists mutual coupling between the slots causing distortion in radiation patterns. Slot coupled H-plane Tee junctions are more suitable for array applications as it is possible to suppress cross polarized components there by reducing mutual coupling between slots.

Slots and slot coupled waveguide radiators find wide applications in communication and radars. Open slots can be used in either linear or planar arrays. When the slots are cut in the narrow wall of rectangular waveguide, they should be either longitudinal or inclined to use them as radiators. It is well known that the vertical slots in the narrow wall do not radiate. For horizontal polarization, the slots in the narrow wall which are even marginally inclined produce cross-polarized components. In such cases, slot coupled waveguide junctions are popular for polarization purity. E-plane and H-plane junctions can be used in linear arrays and are not suitable for two-dimensional arrays due to structural misalignment.

Shunt Tee is a three port device. When the power is fed to the coupled arm, it gets divided equally in two parts of the main guide[14]. Shunt Tees are common for power division applications, whereas in the present work these are used as radiators with vertical polarization. For this purpose, the power is fed at the input port of main guide with the corresponding output port terminated. The power is radiated through the port of coupled arm.

The Tee arm is coupled to the main guide usually by a longitudinal slot. However, the coupling can be made by inclined slot[15] in the narrow wall of main guide. This structure is also useful to produce vertically polarized waves. This new coupling system provides additional design parameter for the array designer. Longitudinal slot coupled Shunt Tees are analyzed by few researchers[16], but inclined slot coupled wave guide Shunt Tees are not reported in open literature. Shunt Tee is used as array element. Slot coupled Shunt Tees are more suitable for arrays applications as it is possible to suppress cross polarized components there by reducing mutual coupling between slots[17-18].

There are two modes to interpret the mechanism of inclined slots each radiating linear polarization. It is well known that a vertical slot in narrow wall of rectangular waveguide does not radiate. The electric field in such a slot is horizontally directed. But in applications where vertically polarized fields are required from inclined slots, it is possible to obtain them by coupling the slot into shunt Tee arm forming a Shunt Tee. Although the analysis is highly involved, it has been possible to obtain admittance data as a function of slot parameters and frequency.

In the present paper, the admittance characteristics of inclined slot in the narrow wall of Shunt Tee are determined from self reaction and discontinuity in modal current.

The analysis consists of two parts:

- First part consists of evaluation of self reaction for the feed guide. This in turn consists of evaluation of self reaction of horizontal and vertical components of the magnetic current.
- The second part consists of evaluation of self reaction for the Tee arm.

Open inclined slots are used to produce horizontally polarized fields. Vertical slot in the narrow wall of a waveguide does not radiate and electric field is horizontal. As it does not contribute for radiation, the slot is made inclined marginally from broadside. Due to inclination, it produces cross-polarized field components. Due to marginal inclination of the slot, horizontal components dominate vertical components in amplitude. On the other hand, longitudinal slot produce vertically polarized fields. Sometimes both polarizations are required in succession in defence radar applications. For this purpose, an H-plane Tee junction with inclined slot is best suited. In view of the above facts, comparison is made between open slot and storage slot.

2. Admittance Characteristics of Inclined Slot in the Narrow Wall of a Rectangular Waveguide

An inclined slot in the narrow wall of the rectangular waveguide is shown in Figure 1. The normalized admittance loading on the feed waveguide is expressed in terms of self reaction <a,a> of the equivalent magnetic current in the slot and discontinuity in modal current.

Inclined Slot in the narrow wall of a rectangular waveguide is used to produce horizontally polarized fields. But due to inclination, there exists cross polarized components. On the other hand, longitudinal slot produces vertically polarized fields. In order to produce radiation with polarization purity, the inclined is coupled to a Tee arm in such a way; H-plane Tee junction is created. In the present, both types are investigated and the characteristics are compared with one another.

By the concept of self-reaction[19] and discontinuity in modal current[20] the admittance characteristics of such a longitudinal slot are obtained in the present work. The self-reaction is evaluated from the magnetic field and magnetic current. The magnetic field is determined from the appropriate vector electric potential. This is found from the solution of the Helmholtz equation[21-24].

As the slot of present interest has a length of about half the wavelength, the electric field in the slot is assumed to be sinusoidal. The field is x-directed. The equivalent magnetic current is given by

$$\mathbf{M}=\mathbf{E}_s\,(\xi,\eta,0)\times\mathbf{U}_y \qquad (1)$$

Here, $\mathbf{E}_s$ is the electric field in the slot and is assumed to be sinusoidal and $\mathbf{U}_y$ is the unit vector.

The expression of $\mathbf{E}_s$ is,

$$\mathbf{E}_s=\mathbf{U}_\xi\ \mathrm{E}_m\,\mathrm{Sin}\,[\mathrm{k}(\mathrm{L}-|\eta|)]\quad |\eta|\le L\,,\ |\xi|\le W \qquad (2)$$

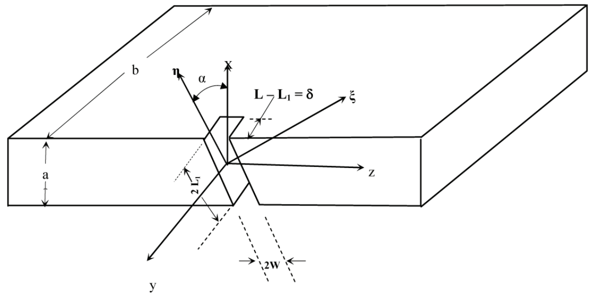

Figure 1. Inclined slot in the narrow wall of a rectangular.

Here, a and b are narrow and broad dimensions of the waveguide, E_m is maximum electric field, $\mathbf{U}_\xi$ is unit vector along ξ axis, $k = \frac{2\pi}{\lambda}$, 2L is the length of the slot and 2W is the width of the slot.

As the electric field is x-directed, the magnetic current is z-directed.

Apply the concept of self-reaction to the slot.

$$\langle \mathrm{a,a}\rangle = -\int\int \mathbf{H_t}(\xi,\eta,0).\ \mathbf{M}\ \mathrm{ds} \qquad (3)$$

Here, $\mathbf{H_t}$ $(\xi,\eta,0)$ is tangential component of the magnetic field due to magnetic current.

$$\mathrm{H_t}(\xi,\eta,0)=\frac{1}{2\pi}\frac{1}{k120\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{\bar{\mathcal{K}}(k_\xi,k_\eta)}{k_y}.e^{j(k_\xi\xi+k_\eta\eta)}dk_\xi dk_\eta \qquad (4)$$

$$\bar{\mathcal{K}}(k_\xi,k_\eta)=\bar{k}\times\bar{k}\times\frac{1}{2\pi}\iint_{slot}\bar{E}_s(\xi',\eta',0)e^{-j(k_\xi\xi'+k_\eta\eta')}d\xi' d\eta'\times\bar{U}_y$$

Where, Substitute Equation (1) in (3).

Self-reaction is simplified to the following form

$$\begin{aligned}\langle \mathrm{a,a}\rangle = {} & \frac{W^2E_m^2}{30\pi^2}\left\{Cin(x)+[Cin(x)-\frac{1}{2}Cin(2x)].\cos(x)-[Si(x)-\frac{1}{2}Si(2x)]\sin(x)\right\}\\ & +j\frac{W^2E_m^2}{30\pi^2}\left\{\{Si(x)+[Si(x)-\frac{1}{2}Si(2x)]\cos(x)+\left[Cin(x)-\frac{1}{2}Cin(2x)-\ln\left(\frac{e^{3/2}L}{2W}\right)\right]\sin(x)\right\}\end{aligned} \qquad (5)$$

Where $x = 2kL$

The slot under the present consideration is replaced by an equivalent shunt admittance parameter and it is given by

$$Z = \frac{\langle \mathrm{a,a}\rangle / II}{Z_{01}} = \frac{-\langle \mathrm{a_r + ja_j}\rangle / II}{Z_{01}} = \frac{1}{g_n + jb_n} \qquad (6)$$

Here, I is the discontinuity in modal current.

The discontinuity in modal current is obtained using the concept reported by Marcuvitz and Swinger[20] as

$$\begin{aligned}\mathrm{I} \;=\; & \mathrm{j}\frac{5.08\times10^7\beta_{01}}{f}WE_{\mathrm{m}}\sqrt{\left(\frac{2}{\mathrm{ab}}\right)}\frac{\pi\mathrm{Sin}\alpha}{\beta_{o1}\mathrm{b}}\frac{1}{\mathrm{k}^2-\left(\beta_{01}\mathrm{Sin}\ \alpha\right)^2}\frac{\sin\beta_{01}\mathrm{W}\cos\alpha}{\beta_{01}\mathrm{W}\cos\alpha}\\ & .\left[\mathrm{k}\left\{\cos\mathrm{k}\delta\cos\left(\beta_{01}\mathrm{L_1}\sin\alpha\right)-\mathrm{CoskL}\right\}-\beta_{01}\sin\alpha\sin\mathrm{k}\delta\sin\left(\beta_{01}\mathrm{L_1}\sin\alpha\right)\right]\end{aligned} \qquad (7)$$

Where V_m=2W.E_m, $\beta_{01} = \sqrt{k^2 - \left(\frac{\eth}{b}\right)^2}$, δ is the depth of cut in the broad wall= L-L_1, $Y_{01} = \frac{\beta_{01}}{\omega\mu_o}$, α is the slot inclination with respect to vertical, 2L_1 is the length of the portion of the slot present in the narrow wall, and Y_{01} is the wave admittance of the dominant mode.

The expression for the normalized Conductance is obtained using the expression [12]:

$$g_n = \frac{Z_{o1}|II|}{a_r} \tag{8}$$

The expression of the conductance is obtained as:

$$g_n = \frac{\left[\cos k\delta \cos\left(\beta_{01} L_1 \sin\alpha\right) - \cos\left(\frac{x}{2}\right) - \frac{\lambda}{\lambda_g} \sin\alpha \sin k\delta \sin\left(\beta_{01} L_1 \sin\alpha\right)\right]^2}{cin(x) + \left[cin(x) - \frac{cin(2x)}{2}\right]\cos x - \left[\sin x - \frac{\sin(2x)}{2}\right]\sin x} \tag{9}$$

3. Admittance Characteristics of Inclined Slot Coupled H-Plane Tee Junction

The H-plane Tee junction with inclined slot is shown in Figure 2. In the present work port 1 is the feed port, port 3 is the radiating port with port 2 matched terminated. In general applications of H-plane Tee junction, the input is given at port 3 and the arms containing port 1 and 2 are in shunt. The circulating magnetic field traveling down in arm 3 meets the junction between arm 1 and 2 and splits the power between the two arms if they are of same length. The resulting H-field has the same phase and magnitude in each arm. An H-plane Tee junction can be used as a radiator, when the Tee arm is coupled to the primary guide through a slot. The radiating field from the Tee arm is always vertically polarized irrespective of the slot geometry and orientation. It couples the power from the feed guide/primary guide to the Tee arm. The major advantage is that an additional slot parameter is available for the design. In order to design such an array for producing very low side lobe patterns, an analysis of the junction is made to obtain the admittance characteristics[25-29].

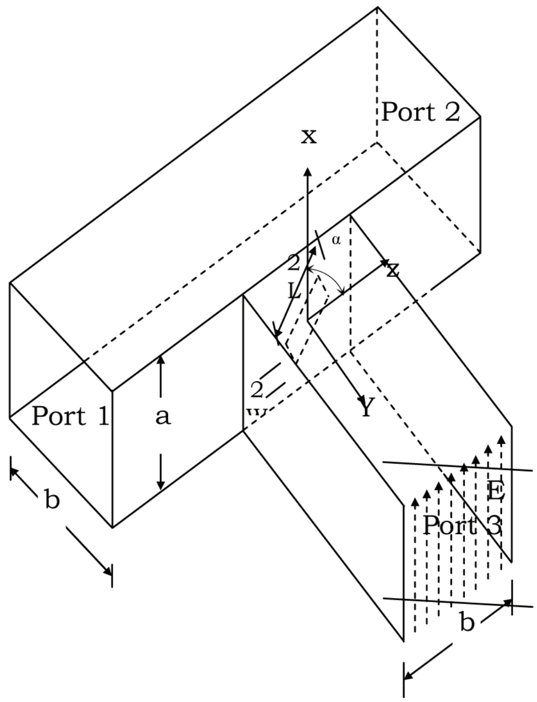

Figure 2. H-plane Tee junction using inclined slot.

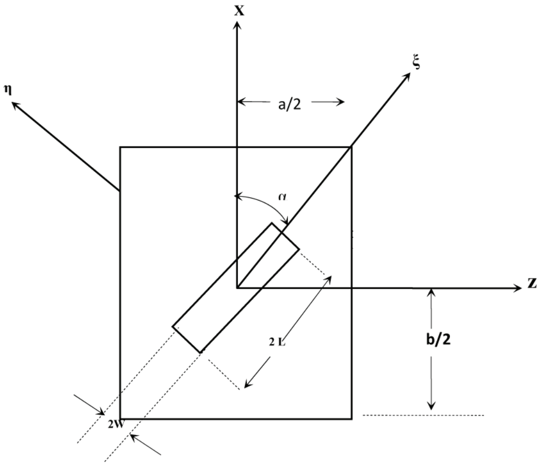

Figure 3. Geometry of inclined slot.

3.1 Analysis of Inclined Slot Coupled H-Plane Tee Junction

The analysis of an inclined slot coupled H-Plane Tee junction consists of two parts. First part consists of the evaluation of the self reaction in the feed guide. This in turn consists of the evaluation of the self reaction of the horizontal and vertical components of the magnetic current. The second part consists of the evaluation of self-reaction in the Tee arm.

The total self reaction is given by

$$\langle \mathrm{a,a} \rangle_{\mathrm{t}} = \langle \mathrm{a,a} \rangle_{l} + \langle \mathrm{a,a} \rangle_{\mathrm{v}} + \langle \mathrm{a,a} \rangle_{t} \qquad (10)$$

Here, $\langle a,a \rangle_{l}$ *and* $\langle a,a \rangle_{\mathrm{v}}$ correspond to self reaction of the magnetic field in feed guide and $\langle \mathrm{a,a} \rangle_{\mathrm{t}}$ correspond to the coupled guide.

3.2 Self-Reaction due to Horizontal Component of Magnetic Current in the Feed Guide

The expression for the self-reaction due to the longitudinal component of the slot along z is given by

The self reaction $\langle \mathrm{a,a} \rangle_{l}$ is defined as

$$\langle \mathrm{a,a} \rangle_{l} = -\int_{v} \mathrm{H.M\ dv} \qquad (11)$$

Here, **H** is the magnetic field and **M** is the magnetic current.

Here, **M** is given by

$$\mathbf{M} = \mathbf{E}_{S} \times \mathbf{a}_{y} \qquad (12)$$

Here, $\mathbf{E}_{\mathrm{S}}$ is the electric field in the slot and is assumed to be sinusoidal and $\mathbf{a}_{\mathrm{y}}$ is the unit vector normal to the aperture plane. $\mathbf{E}_{\mathrm{S}}$ is given by

$$\mathbf{E}_{\mathrm{s}} = \mathbf{a}_{\mathrm{x}}\, \mathrm{E}_{\mathrm{m}} \sin \mathrm{k}\left(L - \left| \mathrm{z} \right|\right)$$

$$\text{for} \qquad \frac{\mathrm{a}}{2} - \mathrm{W} \text{�} \mathrm{x} \text{�} \frac{\mathrm{a}}{2} + \mathrm{W} \qquad (13)$$

$$\text{and} \qquad -\mathrm{L} \text{�} \mathrm{z} \text{�} \mathrm{L}$$

Here, a and b are narrow wall and broad wall dimensions of the waveguide, E_{m} is maximum electric field, $k = \frac{2\pi}{\lambda}$, 2L is the length and 2W is the width of the slot for the analysis of self reaction due to longitudinal component of the slot.

As the magnetic current is distributed over the surface, the volume integral is reduced to surface integral. It is essential to take the effect of image in the wall into account for the evaluation of self reaction. Therefore, the above expression becomes

$$\langle \mathrm{a,a} \rangle_{l} = -\int_{s} \mathrm{H.2M\ ds} \qquad (14)$$

The vector electric potential **F** of the Z-directed magnetic current has only Z component given by

$$\mathbf{F} = \mathrm{a}_{\mathrm{z}} \mathrm{F}_{\mathrm{z}}$$

The Components of electric field are obtained from the relation

$$\mathbf{E}_{s} = -\nabla \times \mathbf{F}$$

Applying orthogonality condition of the Eigen functions of the discrete continuous spectrum and after simplification, the above expression becomes [22].

$$F_{z}(x,y,z) = \sum_{m}^{\infty}\sum_{n}^{\infty} -\frac{\varepsilon_{m}\varepsilon_{n}}{\gamma_{mn}ab} E_{m} \sin^{2} \alpha\ 2W \sin\alpha \cdot \cos\frac{m\pi y}{b} \cos\frac{n\pi x}{a}$$
$$\cos m\pi \cos\frac{n\pi}{2} \frac{\sin\left(n\pi W \sin\alpha/a\right)}{\left(n\pi W \sin\alpha/a\right)} \cdot \frac{k}{k^{2}+\gamma_{mn}^{2}} \Big[\cos kL \sin\alpha e^{-\gamma_{mn}|z|} -$$
$$e^{-\gamma_{mn} L \sin\alpha} \cosh\gamma_{mn} z - \frac{\gamma_{mn}}{K} \sin k\left(L\sin\alpha - |z|\right)\Big] \qquad (15)$$

The expression for the magnetic field which is z directed is derived from the Maxwell's Equation and is given by

$$H_{z} = \frac{1}{\mathrm{j}\omega\mu_{\mathrm{o}}}\left(\mathrm{k}^{2} F_{z} + \frac{\partial^{2}}{\partial z^{2}} F_{z}\right) \qquad (16)$$

From the above Equations the self reaction is simplified to the following form

$$\langle \mathrm{a,a} \rangle_{l} = \frac{2.54\ \mathrm{V}^{2}{}_{\mathrm{m}}\ \pi^{2} \mathrm{Sin}^{4} \alpha}{\mathrm{j} f \mu_{\mathrm{o}} \lambda^{2} \mathrm{ab} \gamma_{\mathrm{mn}} \left(\mathrm{k}^{2} + \gamma_{\mathrm{mn}}^{2}\right)} \sum_{\mathrm{m}}^{\infty}\sum_{\mathrm{n}}^{\infty} \in_{\mathrm{m}} \in_{\mathrm{n}} \cos^{2} \mathrm{m}\pi . \cos^{2} \frac{\mathrm{n}\pi}{2} \left[\frac{\sin\left(\mathrm{n}\pi \mathrm{W} \sin\alpha/\mathrm{a}\right)}{\left(\mathrm{n}\pi \mathrm{W}\sin\alpha/\mathrm{a}\right)}\right]^{2} \times$$
$$\left[\begin{array}{l} \cos\left(\mathrm{kLSin}\ \alpha\right)\left\{2\,\mathrm{e}^{-\ddagger_{\mathrm{mn}}\mathrm{LSin}-} - \cos\left(\mathrm{kLSin}-\right) + \left(\frac{\gamma_{\mathrm{mn}}}{\mathrm{LSin}\alpha} \sin(\mathrm{kLSin}\alpha)\right)\right\} \\ -0.5\left(1 + \mathrm{e}^{-2\ddagger_{\mathrm{mn}}\mathrm{LSin}-}\right) \end{array}\right] \qquad (17)$$

3.3 Self Reaction of the Vertical Component of the Magnetic Current

The field distribution in the slot having the length 2L and width 2W is assumed in the form of

$$\mathbf{E}_{\mathrm{s}} = \mathbf{a}_{\mathrm{z}}\, \mathrm{E}_{\mathrm{m}} \sin \mathrm{k}\left(\mathrm{L} - |\mathrm{x}|\right) \qquad (18)$$

$$\text{for} \quad \frac{a}{2} - L \le x \le \frac{a}{2} + L \quad \text{and} \quad -\mathrm{w} \le z \le \mathrm{w}$$

Here b and a are broad and narrow dimensions of the feed guide.

As the magnetic current M is

$$\mathbf{M} = \mathbf{E}_{\mathrm{s}} \times \mathbf{a}_{\mathbf{x}} \qquad (19)$$

Here, $\mathbf{E}_S$ is the electric field in the slot and is assumed to be sinusoidal and $\mathbf{a}_x$ is the unit vector normal to the aperture plane.

The magnetic field is along the x-direction in the slot configuration of the present interest.

$$\mathrm{H} = H_x \mathrm{a}_x$$

$$\mathrm{H} = -\frac{\mathrm{j}}{\omega\mu_o}\left(\frac{\partial^2 F_x}{\partial y^2} + \frac{\partial^2 F_x}{\partial z^2}\right)\mathrm{a}_x \qquad (20)$$

It is obtained from the concept of vector electric potential **F**. As the magnetic current is x-direction, **F** is also x-directed.

$$\mathbf{F} = \mathbf{a}_x \; \mathrm{F}_x \qquad (21)$$

Here, F_x is x directed electric vector potential of the magnetic current.

$$F_x(x,y,z) = \sum_m^\infty \sum_n^\infty \frac{\varepsilon_m E_m \cos\alpha}{\gamma_{mn}\, ab} \cdot \cos\frac{m\pi y}{b} \sin\frac{n\pi x}{a} \cos m\pi \sin\frac{n\pi}{2}.$$
$$\frac{2k}{\left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{n\pi}{a}\right)^2}\left(\cos\left(n\pi L\cos\alpha/a\right) - \cos kL\cos\alpha\right)^2 \cdot$$
$$\left[\frac{2 - e^{-\gamma_{mn}\left|z+W\cos\alpha\right|} - e^{\gamma_{mn}\left|z-W\cos\alpha\right|}}{\gamma_{mn}}\right] \qquad (22)$$

Here, F_x is related to $\mathbf{E}_s$ by,

$$\mathbf{E}_s = -\nabla \times \mathbf{F} \qquad (23)$$

By definition, the self reaction is given by

$$\langle a,a\rangle_v = -\text{�}_s \; \mathbf{H.M}\; ds \qquad (24)$$

The self- reaction $\langle a,a\rangle_v$ due to the vertical component of the magnetic current in the primary guide is obtained as

$$\langle a,a\rangle_v = \frac{j1.27 V_m{}^2 \pi^2 \mathrm{Cos}^2 \alpha}{\mathrm{f}\mu \mathrm{w}\lambda^2\; ab} \sum_{\mathrm{m}}^\infty \sum_{\mathrm{n}}^\infty \frac{\in_{\mathrm{m}}}{\ddagger_{\mathrm{mn}}{}^2}\left[\frac{1}{\left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{n\pi}{a}\right)^2}\right] \cos^2 \mathrm{m}\pi \mathrm{Sin}^2 \frac{\mathrm{n}\pi}{2}.$$
$$\left[\cos\left(\frac{n\pi L\,\mathrm{Cos}\,\alpha}{a}\right) - \cos\left(kL\cos\alpha\right)\right]^2 \left[2\cos - + \frac{e^{-2\ddagger_{mn} W\,\mathrm{Cos}\,\alpha}}{\ddagger_{mn} W} - \frac{1}{\ddagger_{mn} W}\right] \qquad (25)$$

3.4 Self-Reaction in the TEE Arm

The expression for self-reactance in Tee arm is evaluated for the sake of completeness, it is presented here.

$$\langle \mathrm{a,a}\rangle_t = 2\sum_{\mathrm{m}}^\infty \sum_{\mathrm{n}}^\infty (\mathrm{Y}_0)^e{}_{mn}\left(V^e{}_{mn}\right)^2 + 2\sum_{\mathrm{m}}^\infty \sum_{\mathrm{n}}^\infty (\mathrm{Y}_0)^m{}_{mn}\left(V^m{}_{mn}\right)^2 \qquad (26)$$

Here,

$$V^e_{mn} = \frac{V_m}{\pi}\left[\frac{ab\,\varepsilon_m\;\varepsilon_n}{(ma)^2 + (nb)^2}\right]^{1/2} \frac{1}{2}\left[\left(\frac{m\pi}{b}\cos\alpha + \frac{n\pi}{a}\sin\alpha\right).(\cos kL - \cos AL)\right.$$
$$\left.\frac{2k}{k^2 - A^2}\frac{\sin BW}{BW}.\sin\overline{m+n}\frac{\pi}{2}\right] + \frac{1}{2}\left[\left(\frac{m\pi}{b}\cos\alpha - \frac{n\pi}{a}\sin\alpha\right).(\cos kL - \cos CL)\right.$$
$$\left.\frac{2k}{k^2 - C^2}\frac{\sin DW}{DW}.\sin\overline{m-n}\frac{\pi}{2}\right] \qquad (27)$$

$$V^m_{mn} = -\frac{V_m}{\pi}\left[\frac{ab}{(ma)^2 + (nb)^2}\right]^{1/2}\left[\left(\frac{n\pi}{a}\cos\alpha - \frac{m\pi}{b}\sin\alpha\right).(\cos kL - \cos AL)\right.$$
$$\left.\frac{2k}{k^2 - A^2}\frac{\sin BW}{BW}.\sin\overline{m+n}\frac{\pi}{2}\right] + \left[\left(\frac{n\pi}{a}\cos\alpha + \frac{m\pi}{b}\sin\alpha\right).(\cos kL - \cos CL)\right.$$
$$\left.\frac{2k}{k^2 - C^2}\frac{\sin DW}{DW}.\sin\overline{m-n}\frac{\pi}{2}\right] \qquad (28)$$

Where,

$$\mathrm{A} = \frac{m\pi}{b}\cos\alpha + \frac{n\pi}{a}\sin\alpha\,, \qquad \mathrm{B} = \frac{m\pi}{b}\sin\alpha - \frac{n\pi}{a}\cos\alpha$$

$$\mathrm{C} = \frac{m\pi}{b}\cos\alpha - \frac{n\pi}{a}\sin\alpha\,, \qquad \mathrm{D} = \frac{m\pi}{b}\sin\alpha + \frac{n\pi}{a}\cos\alpha$$

$$(\mathrm{Y}_0)^e{}_{\mathrm{mn}} = \frac{\gamma_{\mathrm{mn}}}{\mathrm{j}\omega\mu_0} \qquad (29)$$

$$(\mathrm{Y}_0)^m{}_{\mathrm{mn}} = \frac{\mathrm{j}\omega\in}{\gamma_{\mathrm{mn}}} \qquad (30)$$

The impedance Z is given by

$$Z = -\frac{\langle \mathrm{a,a}\rangle}{II} \qquad (31)$$

Here, I = discontinuity in the modal currents.

The expression for discontinuity in modal current (I) is [23],

$$I = jY_{01}\iint_{slot} \mathbf{a}_y \times \mathbf{E}_S \cdot \mathbf{a}_z \left(\frac{2}{ab}\right)^{1/2} \frac{\pi}{b\beta_{01}} ds \qquad (32)$$

Where,

$$\mathbf{E}_S = \mathrm{a}_y \mathrm{E}_m \sin k\left(L - |\xi|\right)$$

Using the concept of discontinuity in the modal current reported by Marcuvitz and Schwinger[20] and simplified for the inclined slot. It appears in the form,

$$\mathrm{I} = -2\mathrm{j}\mathrm{Y}_{01}\mathrm{V}_{\mathrm{m}}\mathrm{Sin}\alpha \frac{\mathrm{Sin}\left(\mathrm{W}\beta_{01}\mathrm{Cos}-\right)}{\mathrm{W}\beta_{01}\mathrm{Cos}-}\sqrt{\left(\frac{2}{\mathrm{ab}}\right)}\frac{\pi}{b\dagger_{01}}\frac{k}{\left(\beta_{01}\mathrm{Sin}\alpha\right)^2-\left(\frac{4\pi^2}{\lambda^2}\right)}\left[\mathrm{Cos}\left(\beta_{01}\mathrm{LSin}\alpha\right)-\mathrm{CoskL}\right] \tag{33}$$

From the expressions of self reaction and discontinuity in modal current, the admittance parameters are numerically computed.

The normalized admittance is of the slots of the present is given by

$$y = \frac{Y}{Y_{01}} = g_n + jb_n \qquad \text{Here, Y=}\frac{1}{Z} \tag{34}$$

Here Y_{01} is the characteristic wave admittance for the dominant mode, g_n is the normalized conductance and b_n is the normalized susceptance.

4. Results

From the expressions by (7), (10), (17), (25), (26), (33) and (34) the variation of normalized admittance is computed as a function of frequency for standard X-band wave guide dimensions and different slot parameters. The data is obtained both for open slot radiator as well as H-plane Tee junction. Variation of coupling and VSWR is also evaluated as a function of frequency. The results are presented in Figures 4-9.The results are obtained at the

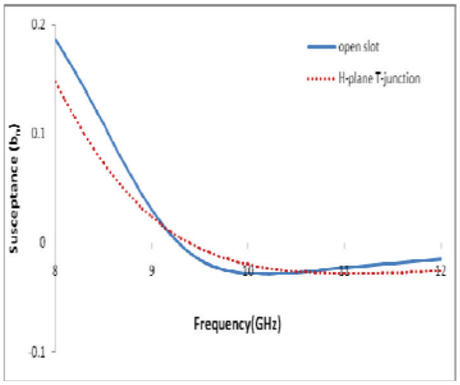

Figure 4. Variation of conductance, susceptance, with frequency for a=1.016 cm, b=2.286 cm, 2W=0.16 cm, α=30^0.

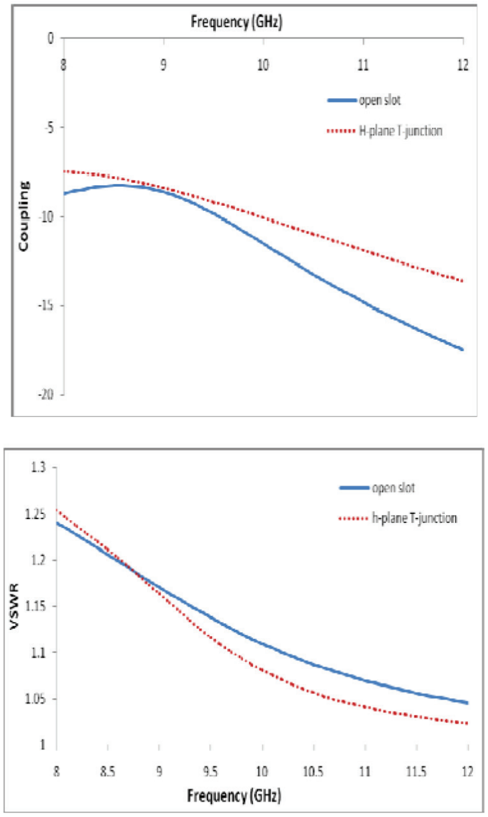

Figure 5. Variation of coupling, VSWR with frequency for a = 1.016 cm, b = 2.286 cm, 2W = 0.16 cm, α = 30^0.

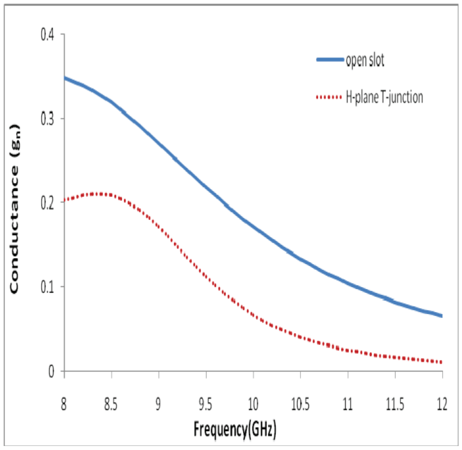

Figure 6. Variation of Conductance, Susceptance, with frequency for a=1.016 cm, b=2.286 cm, 2W=0.16 cm, α=40^0.

(*Continued*)

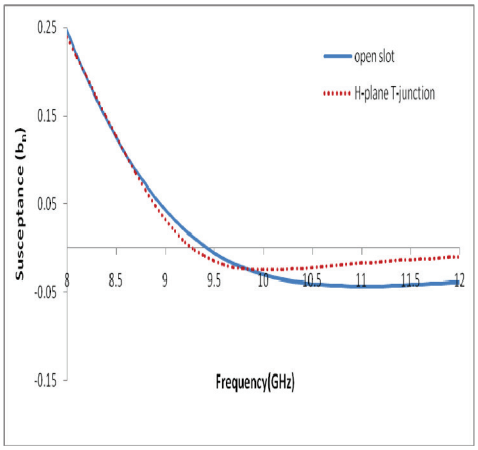

Figure 6. Variation of Conductance, Susceptance, with frequency for a=1.016 cm, b=2.286 cm, 2W=0.16 cm, α=40^0.

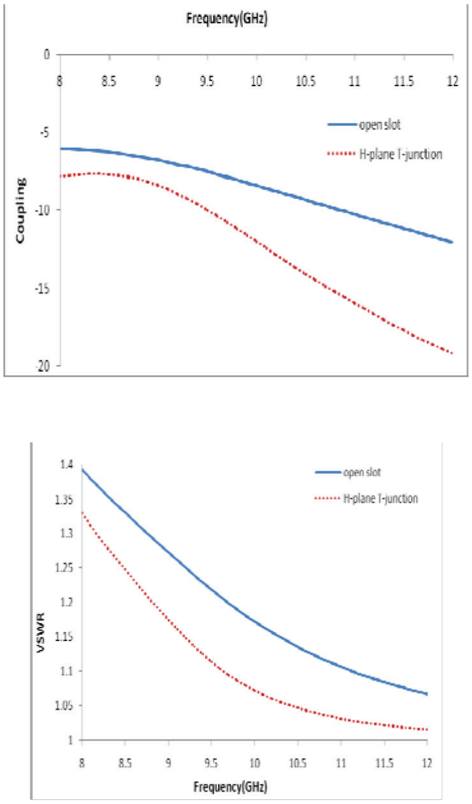

Figure 7. Variation of Coupling, VSWR with frequency for a=1.016 cm, b=2.286 cm, 2W=0.16 cm, α=40^0.

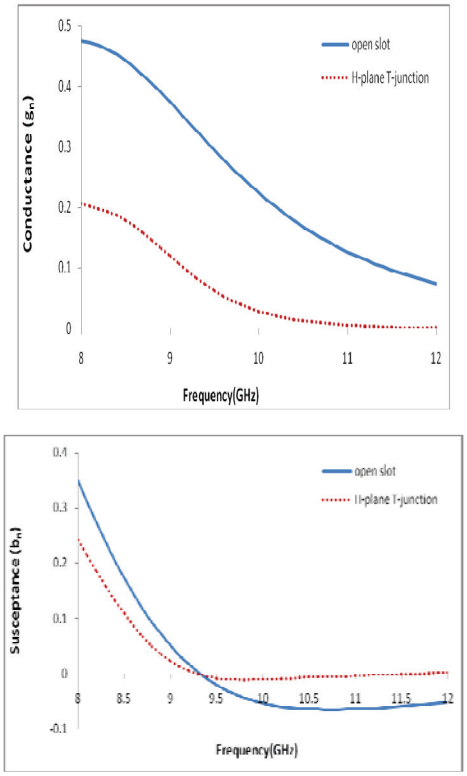

Figure 8. Variation of Conductance, Susceptance, with frequency for a = 1.016 cm, b = 2.286 cm, 2W = 0.16 cm, α = 50^0.

resonant length of the slot. The resonant length is evaluated from the variation of normalized conductance (g_n), normalized susceptance (b_n), VSWR and coupling for the center frequency of X-band.

5. Conclusions

It is evident from the results that the resonant length is found to vary with frequency, Slot width, slot inclination and waveguide dimensions. The Conductance peak appears away from the resonant length to the left. The susceptance as a crossover from positive to negative at resonant length. The resonant frequency from open slot radiator is found to be different from that of H-Plane Tee junction. It is the case with coupling and VSWR; Coupling varies over a range of -7 to -17dB. Coupling is higher in case of H-plane Tee junction, VSWR is found to change between 1.05 and 1.25. The data presented in the present work is useful for the design of arrays of open slot and H-Plane Tee junction.

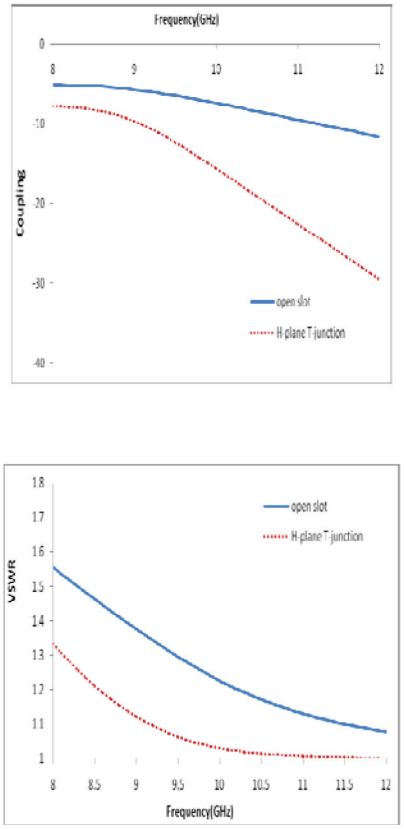

Figure 9. Variation of Coupling, VSWR with frequency for a = 1.016 cm, b = 2.286 cm, 2W = 0.16 cm.

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