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Analysis of Admittance Characteristics of unconventional slot coupled waveguide Tee junctions

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Abstract --- An unconventional slot coupled waveguide Tee junction is considered where both slot and Tee arm are inclined. In this structure, the axis of the Tee arm is neither transverse nor parallel to the axis of the feed guide. The analysis of the proposed waveguide Tee junction made by non-standard rectangular waveguides is presented . The admittance characteristics of longitudinal slot coupled waveguide junctions are controlled by the waveguide dimensions, slot dimensions, its geometry and frequency. In the present work on waveguide junction, the array designer will have two additional parameters namely inclination of slot and inclination of waveguide to control admittance characteristics which provides more flexibility for the designer. The data presented is useful for the design of arrays of such junctions for a specified type of radiation pattern.

Key Words: Unconventional Waveguides, Shunt Tees, Admittance Loading, H-Plane Tee, Slot coupled Tee Junctions

I Introduction

The mechanism of inclined slots is interpreted in terms of two modes each radiating linear polarization i.e., horizontal and vertical components. In the present work, the analysis is carried out to obtain variation of slot conductance and susceptance as a function of frequency for the resonant slot length.

The Tee arm is coupled to the main guide usually by a longitudinal slot. However, the coupling can be made by inclined slot [1] in the narrow wall of main guide. This structure is also useful to produce vertically polarized waves. Longitudinal slot coupled Shunt Tees are analyzed by few researchers [3], but inclined slot coupled non-standard wave guide Shunt Tees are not reported in open literature.

Shunt Tee is used as array element. Array antennas are popular in different radar and communications applications. They are preferred for both scan and non-scan applications. Arrays of slots cut in one of the walls of the rectangular waveguides are extensively used due to their compactness. In conventional open ended slot arrays, there exists mutual coupling between the slots [4] causing distortion in radiation patterns. 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.

The mechanism of inclined slots is interpreted in terms of two modes 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. No one has attempted to present data on such inclined coupled waveguide 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 narrow wall of Shunt Tee is determined from self reaction and discontinuity in modal current [5]. The analysis consists of two parts: 1st 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.

In the present work, the analysis is carried out to obtain variation of slot conductance [6] and susceptance as a function of frequency after determining the resonant slot length. The result is numerically obtained for varied slot widths.

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II. Analysis for admittance characteristics

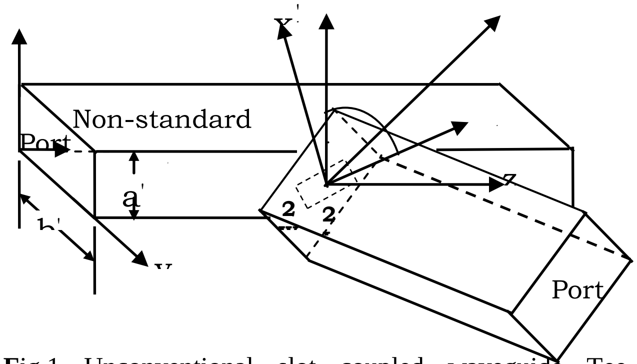

Fig.1 Unconventional slot coupled waveguide Tee junction- non-standard waveguide

Consider a waveguide Tee junction coupled through an inclined slot (θ_s) of length 2L and width 2W, on the narrow wall with Tee arm twisted by angle θ_{ta} as shown in fig. 4.1. In the proposed junction, coupling takes place through an inclined slot in the narrow wall of the feed waveguide as shown in fig. 1. Inclined Slot orientation is shown in fig 2. The slot radiator is analysed for its admittance characteristics using self-reaction and discontinuity in modal current. The admittance characteristics in the coupled waveguide radiator are evaluated using TE and TM mode field concepts. In the present work the equivalent network parameter is obtained [7].

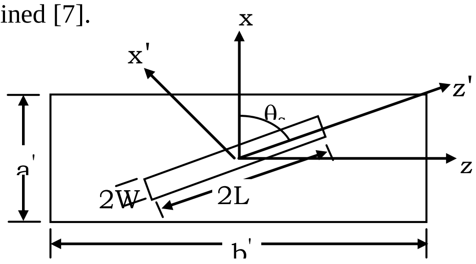

Fig. 2 Inclined slot in the narrow wall

The admittance characteristics of the proposed waveguide junction is determined from self-reaction and discontinuity in modal current. The analysis of present waveguide junction consists of 2 parts : 1st part consists of evaluation of self-reaction in the feed guide. This in turn consists of the evaluation of self-reaction of horizontal and vertical components of the magnetic current. The second part consists of the evaluation of self-reaction in the Tee arm.

The expression for discontinuity in modal current I, due to an inclined slot in the narrow wall of the excited guide (guide1) is given by

$$I = -2jY_{01}V_0\sin\theta.\frac{\sin(W\beta_{01}\cos\theta)}{W\beta_{01}\cos\theta}.\left(\frac{2}{ab}\right)^{\frac{1}{2}}\frac{\pi}{b\beta_{01}}.\frac{K}{(\beta_{01}\sin\theta)^2-K^2}\left[\cos(\beta_{01}L\sin\theta)-\cos KL\right]$$

(1)

From knowledge of the magnetic field it is possible to evaluate self-reaction As the magnetic current is confined over the surface, the volume integral becomes surface integral. Magnetic cuurent due to slot is z-directed. Taking the effect of image in the wall y = b' into account, the expression for the self- reaction takes the form

$$\langle q,q\rangle_h = -\int_s H_z \; 2M_z \; ds \qquad (2)$$

where **H** is magnetic field, **M** is magnetic current.

The magnetic field H_z, is obtained from Maxwell's equation in terms of vector potential.

i.e.
$$H_z = \frac{1}{j\omega\mu_0}\left(\beta^2 + \frac{\partial^2}{\partial z^2}\right)F_z \qquad (3)$$

where F_z is z-component of vector electric potential and $\beta = \frac{2\pi}{\lambda}$, λ being wavelength.

Here, F_z has only z-component as the slot is z-directed. The relation between the electric field distribution in the slot, vector electric potential and Helmholtz equations are given by

$$\mathbf{E}_t = -\nabla \times \mathbf{F} \qquad (4)$$

$$\nabla^2\mathbf{F} + \beta^2\mathbf{F} = -\mathbf{M} \qquad (5)$$

and
$$\mathbf{M} = \mathbf{E}_t \times \mathbf{a}_n \qquad (6)$$

where $\mathbf{a}_n$ is unit vector normal to the aperture plane.

Here, the electric field in the aperture plane of the slot in fig. 4.1 can be assumed as

$$\mathbf{E}_t = \mathbf{a}_{x_1'} E_0 \sin\beta(L - |z_1'|) \qquad (7)$$

where E_0 is the maximum electric field distribution in the aperture plane of the slot.

F is evaluated for the sinusoidal distribution of electric field and using the standard boundary conditions on the walls of the waveguide. The expression for **F** = F_z $\mathbf{a}_z$ appears in the following simplified form

$$\mathbf{F} = \sum_{m}^{\infty}\sum_{n}^{\infty}\frac{\in_m \in_n}{\gamma_{mn} a'b'}(2W)E_0 \cos\left(\frac{m\pi y}{b'}\right)\cos\left(\frac{n\pi x}{a'}\right)\cos m\pi \cos\frac{n\pi}{2} \frac{\sin\left(n\pi W/a'\right)}{\left(n\pi W/a'\right)}\left(\frac{\beta}{\beta^2+\gamma_{mn}^2}\right)\left[e^{-\gamma_{mn}L}\cosh\gamma_{mn}z + \frac{\gamma_{mn}}{\beta}\sin\beta\left(L-|z|\right)-\cos\beta L\, e^{-\gamma_{mn}|z|}\right]\mathbf{a}_z \tag{8}$$

Here,

$$\gamma_{mn} = \left[\left(\frac{m\pi}{b'}\right)^2+\left(\frac{n\pi}{a'}\right)^2-\beta^2\right]^{\frac{1}{2}} \tag{9}$$

Substituting F_z in equation (3), H_z can be written as

$$H_z = -\frac{1}{j\omega\mu_0}\sum_{m}^{\infty}\sum_{n}^{\infty}\frac{\in_m\in_n}{\gamma_{mn}a'b'}(2W)E_0\cos\left(\frac{m\pi y}{b'}\right)\cos\left(\frac{n\pi x}{a'}\right)\cos m\pi\cos\frac{n\pi}{2} \frac{\sin\left(n\pi W/a'\right)}{\left(n\pi W/a'\right)}\beta\left[\cos\beta L\, e^{-\gamma_{mn}|z|} - e^{-\gamma_{mn}L}\cosh\gamma_{mn}z\right] \tag{10}$$

where ε_m , ε_n = 1 for m, n = 0 ; ε_m , ε_n = 2 for m, n > 0
From the equations , (4 – 10), the self-reaction is simplified to the following form

$$\langle q,q\rangle_h = \frac{16E_0^2W^2\beta^2}{j\mu_o\omega a'b'}\sum_{m}^{\infty}\sum_{n}^{\infty}\frac{\in_m\in_n}{\gamma_{mn}\left(\beta^2+\gamma_{mn}^2\right)}\cos^2 m\pi\cos^2\frac{n\pi}{2}\left[\frac{\sin(n\pi W/a')}{(n\pi W/a')}\right]^2\times \left[\cos(\beta L)\left\{2e^{-\gamma_{mn}L}-\cos(\beta L)+\frac{\gamma_{mn}}{L}\sin(\beta L)\right\}-0.5\left(1+e^{-2\gamma_{mn}L}\right)\right] \tag{11}$$

In the above equation (11), summation is taken for all combinations of m and n excluding m = 0, n = 0 and m = 1, n = 0.
The total self-reaction is given by

$$\langle q,q\rangle = \langle q,q\rangle_h + \langle q,q\rangle_v + \langle q,q\rangle_{cg} \tag{12}$$

The impedance Z is given by

$$Z = -\frac{\langle q,q\rangle}{II} \tag{13}$$

Here, I = discontinuity in modal current
The admittance loading of the slots of the present is given by

$$Y = \frac{1}{Z}$$

The normalized admittance is

$$y_n = \frac{Y}{Y_{01}} = g_n + jb_n \tag{14}$$

Where Y_{01} is the characteristic wave admittance for the dominant mode, g_n is the normalized conductance and b_n is the normalized susceptance
The expression for coupling is given by

$$P_c = \left[\frac{4g_n}{(2+g_n)^2+(b_n)^2}\right] \tag{15}$$

The expression for VSWR is given by

$$VSWR = \frac{1+|\rho|}{1-|\rho|} \tag{16}$$

where ρ is reflection coefficient which is basically complex in nature.

III. Results & Conclusions

Using the above expressions , the variation of normalized admittance characteristics as a function of slot length for different slot widths , slot inclinations and Tee arm inclinations are numerically computed. The characteristics include the variation of normalized conductance and normalized susceptance. Resonant slot length is determined from the point at which the susceptance changes from positive to negative in susceptance curve. Subsequently , the variation of normalized conductance and susceptance with frequency is numerically computed for the resonant slot length. From these values, variation of coupling and VSWR as a function of frequency for the above parameters is computed. The results are presented in figs.
Using the above equations, variation of normalized conductance (g_n), normalized Susceptance (b_n), Coupling and VSWR is numerically obtained as a

function of frequency for slot widths 2w=0.1, 0.2, 0.3cm and θ with slot inclinations of 40^0 are presented in following figures (3-6).

The variation of normalized conductance, susceptance, coupling and VSWR is evaluated as a function of slot length for f = 9.375 GHz , 2 W = 0.2 cm , a = 1.6 cm , b = 2.286 cm for slot inclinations of 10^0 & 20^0 and for tee arm inclinations of 10^0 to 30^0 . Resonant slot length is determined from the susceptance curve. The variation of normalized conductance, susceptance , coupling and VSWR is numerically computed over the frequency range of 8 – 10.5 GHz for the respective slot lengths. In order to investigate the effect of orientations of the Tee arm, the above computations are repeated for $\theta_{ta} = 30^0$ & 45^0 and for slot inclinations of 30^0 to 60^0 · The results are presented in figs. (3 – 6).

It is evident from the results that the conductance peak is occurring at a frequency slightly away from resonant frequency. This is in accordance with the change in partial distributed components of the radiators with the frequency.

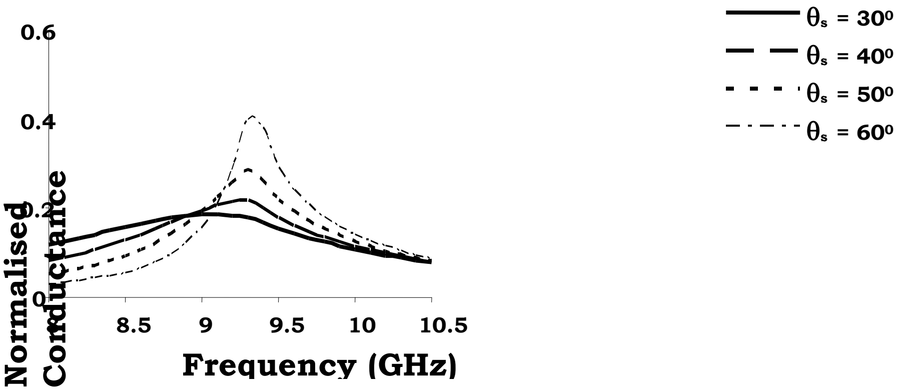

Fig.3 Variation of normalized conductance with frequency for Slot Width = 0.2 cm , $\theta_{ta} = 30^0$

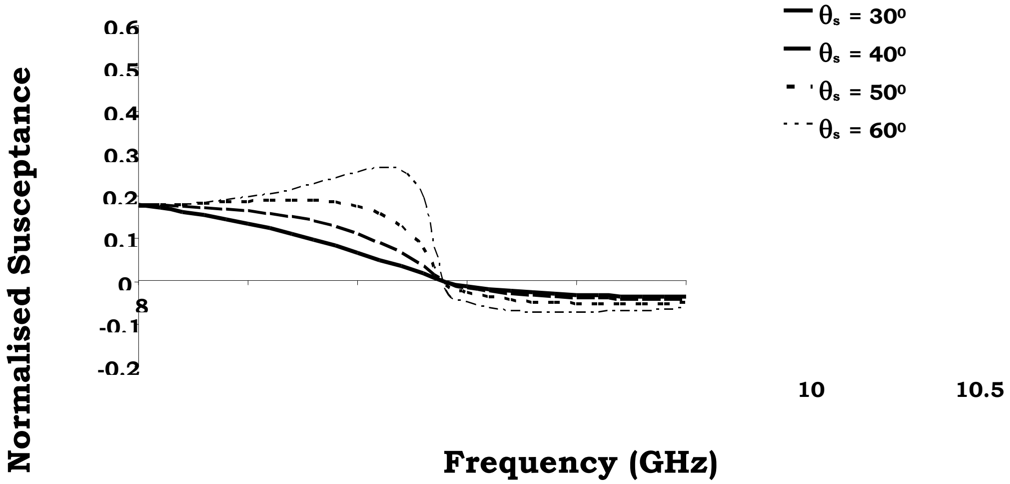

Fig.4.Variation of normalized susceptance with frequency for Slot Width = 0.2 cm , $\theta_{ta} = 30^0$

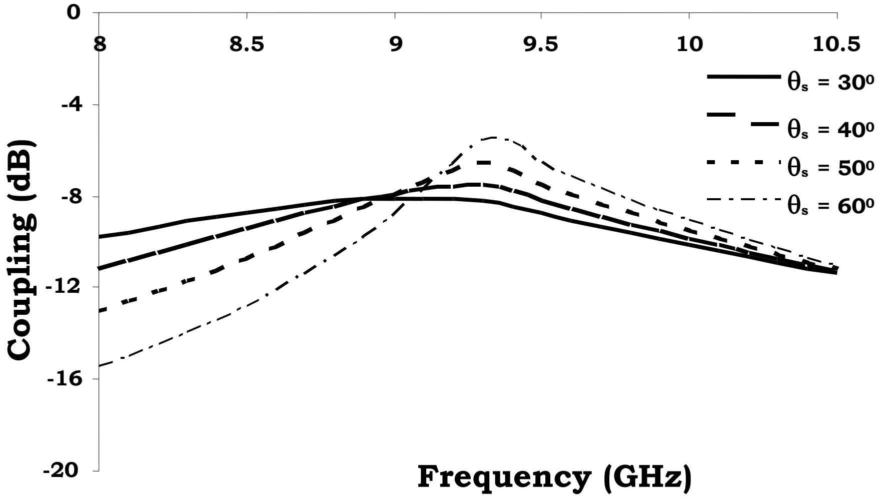

Fig.5 Variation of coupling with frequency for Slot Width = 0.2 cm , $\theta_{ta} = 30^0$

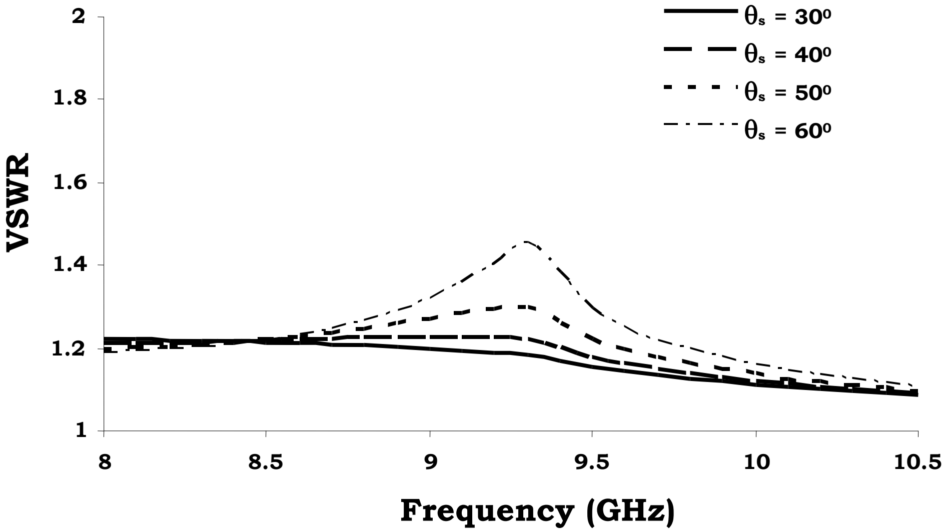

Fig.6 Variation of VSWR with frequency for Slot Width = 0.2 cm , $\theta_{ta} = 30^0$

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