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Admittance Characteristics of Inclined Slot Coupled Waveguide Shunt Tee with Non-Standard Waveguides

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***Abstract* --- Antennas are essential for all types of Radar and Communication systems. For a given application it is required to meet important specifications like polarization, impedance, VSWR and radiation pattern characteristics. In most of the applications compactness of the antennas is most important. The Tee arm is coupled to the main guide usually by a longitudinal slot. The analysis of such structures is reported in the literature. However, the coupling can be made by inclined slot 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 for non-standard waveguides. Its design requires the knowledge of admittance characteristics of the shunt Tee.**

In the present work, the analysis is made to obtain variation of conductance and susceptance as a function of frequency after determining the resonant slot length. The data presented in this chapter is extremely useful for the design of small and large arrays of H-Plane Tee junction radiators. The results are numerically obtained for varied slot widths. The analysis involves the derivations of the expressions for self reaction and discontinuity in modal currents in the main guide as well as Tee arm. The data presented is used to design the arrays of the shunt Tee arms.

***Keywords*-- Waveguides, Shunt Tees, Admittance Loading, H-Plane Tee, Slot coupled Tee Junctions**

I. Introduction

Basically the Shunt Tee is a three port device. In power division applications when the power is fed to the coupled arm, it gets divided equally in two parts of the main guide. The main guide containing two ports is in shunt with the coupled arm, that is why it is known as Shunt Tee [1]. 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 matched terminated. The power is radiated through the 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 [2] 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

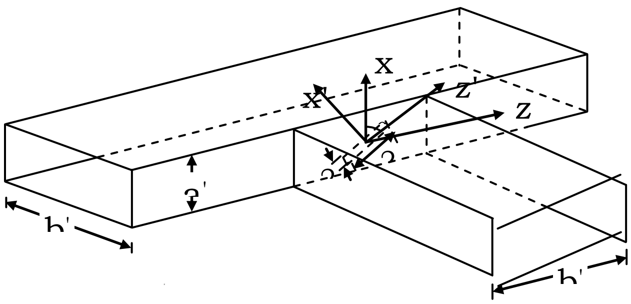

Fig.1 Inclined slot coupled waveguide shunt Tee- non-standard waveguide

Consider a H-Plane Tee junction made by non-standard waveguides coupled through an inclined slot (θ_s) of length 2L and width 2W, on the narrow wall 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].

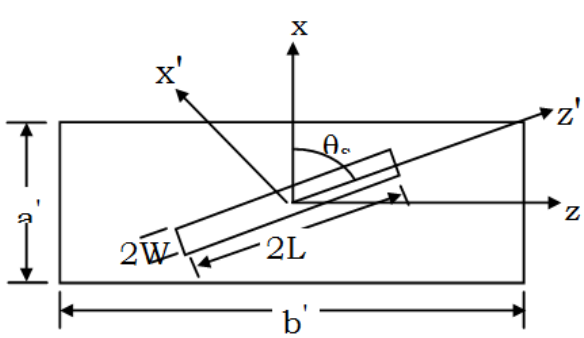

Fig. 2 Inclined slot in the narrow wall

The analysis of the H-Plane Tee junction consists : a) Evaluation of discontinuity in modal current. b) Evaluation of self-reaction in the feed waveguide. This in turn consists of evaluation of self reaction of longitudinal and transverse components of the magnetic current. c) Evaluation of self-reaction in the coupled waveguide. d) Evaluation of equivalent admittance parameter as a function of slot length for fixed frequency and width of the slot. It also consists of evaluation of equivalent admittance parameter as a function of frequency.

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)

The field radiated by a narrow slot, one half wavelength long and cut in a conducting sheet of metal is given by

$$\mathbf{H} = j\frac{V_m}{\pi\eta r}e^{-j(\omega t - k_0 r)}\ \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}a_\theta$$

(2)

$$\mathbf{E} = -j\frac{V_m}{\pi r}e^{-j(\omega t - k_0 r)}\ \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}a_\varphi$$

(3)

The field radiated by the slot is given by equations (3) in the half space y > 0 and by negative of the above equations in the half space y<0.

In a H-plane Tee junction, the coupled arm is fed with a rectangular slot either longitudinal or inclined. The slot between the feed waveguide and coupled waveguide, couples power. A slot cut in a waveguide wall in a direction transverse to the current lines produces considerable perturbation of current sheet. This results in the coupling of internal field to the space, such a slot forms a radiating element. The slots can be cut either in the narrow wall or in the broad wall of a rectangular waveguide. The vertical slots in the narrow wall do not radiate. However, the other slots like inclined slots, displaced slots and centered longitudinal slots in the narrow wall or inclined slots and displaced slots in the broad wall radiate. The amount of power coupled by slot depends on orientation of the slot and its position, dimensions of slot, internal narrow & broad wall dimensions of feed & coupled waveguides, orientation of feed waveguide, wall thickness and frequency. When the coupling slot is inclined between Tee arm and feed guide, the designer will have an additional parameter namely inclination of the slot to control admittance characteristics, coupling and VSWR.

The field distribution in the slot having length $2L_\ell$ and width $2W_\ell$ is assumed in the form

$$\mathbf{E}_s = \mathbf{a}_x E_0 \sin\beta(L_\ell - |z|) \qquad (4)$$

for $\frac{a'}{2} - W_\ell \le x \le \frac{a'}{2} + W_\ell$

and $-L_\ell \le z \le L_\ell$

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Here, a' and b' are narrow and broad dimensions of the waveguide, E_0 is maximum electric field, $\beta = \frac{2\pi}{\lambda}$, λ being wavelength.

According to Harrington [125], the vector electric potential is given by

$$\mathbf{F} = \frac{e^{-jkr}}{4\pi r}\iiint \mathbf{M}(r)dv \tag{5}$$

Here, the electric field is x-directed, the magnetic current is z-directed and **F** is z-directed. That is,

$$\mathbf{F} = \mathbf{a}_z F_z \tag{6}$$

It satisfies

$$\nabla^2 F_z + \beta^2 F_z = -M_z \tag{7}$$

As

$$\mathbf{E} = -\nabla \times \mathbf{F} \tag{8}$$

$$E_x = -\frac{\partial F_z}{\partial y} \tag{9}$$

$$E_y = \frac{\partial F_z}{\partial x} \tag{10}$$

The boundary conditions are

$$\left.\begin{aligned} \frac{\partial F_z}{\partial x} &= 0 \text{ at } x = 0,\ x = a' \\ \frac{\partial F_z}{\partial y} &= 0 \text{ at } y = 0,\ y = b' \end{aligned}\right| \tag{11}$$

Simplified expression for self-reaction $\langle p, p\rangle_l$ is given by

$$\langle p, p\rangle_\ell = \frac{16 E_0^2 W_\ell^2 \beta^2}{j\mu_o \omega a' b'} \sum_m^\infty \sum_n^\infty \frac{\epsilon_m \epsilon_n}{\gamma_{mn}\left(\beta^2+\gamma_{mn}^2\right)} \cos^2 m\pi \cos^2 \frac{n\pi}{2}\left[\frac{\sin(n\pi W_\ell/a')}{(n\pi W_\ell/a')}\right]^2 \times \left[\cos(\beta L_\ell)\left\{2e^{-\gamma_{mn}L_\ell} - \cos(\beta L_\ell) + \frac{\gamma_{mn}}{\beta}\sin(\beta L_\ell)\right\} - 0.5\left(1+e^{-2\gamma_{mn}L_\ell}\right)\right] \tag{12}$$

III. Results & Conclusions

Using the above expressions , the variation of normalized admittance characterestics as a function of slot length for different slot widths and slot inclinations are numerically computed. The characteristics include the variation of normalized conductance and normalized susceptance. For this resonant length , the variation of normalized conductance and susceptance with frequency is numerically computed. 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. (3-4).

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)

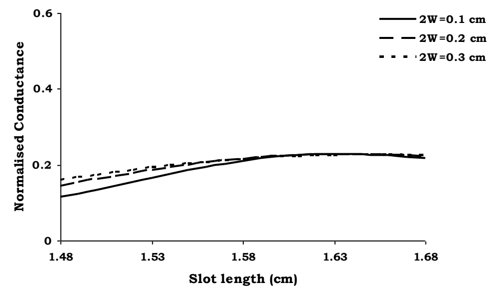

Fig.3 Variation of normalized conductance with slot inclination $\theta_s = 40^0$

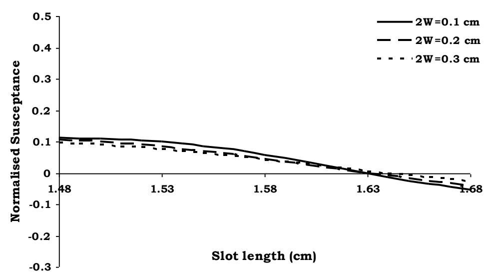

Fig.4 Variation of normalized susceptance with slot inclination $\theta_s = 40^0$

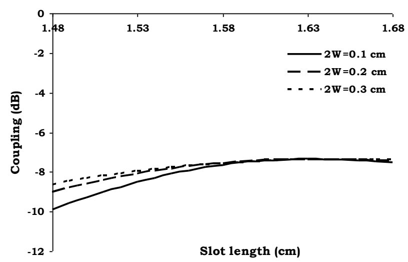

Fig.5 Variation of coupling with slot inclination $\theta_s = 40^0$

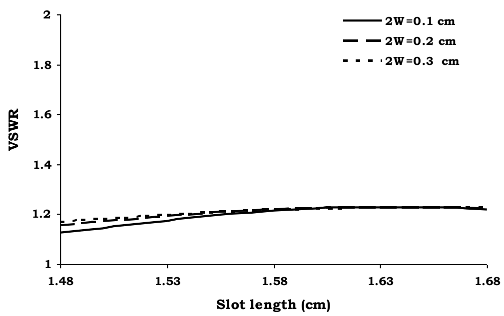

Fig.6 Variation of VSWR with slot inclination $\theta_s = 40^0$

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.

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