Analysis of H-Plane Tee Junction Formed ByS and X Band Wave Guides

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Abstract: Many researchers investigated admittance characteristics of standard and nonstandard rectangular wave guides with slots in one of the walls i.e. either broad wall or narrow wall. The analysis of longitudinal slots in the narrow wall of wave guide is available in literature. However, no literature is available on inclined slot in the narrow wall of coupled junction of two waveguides of different bands. From the knowledge of admittance characteristics, the new coupling method provides additional design parameters for the designer. In the present work, the analysis of admittance characteristics, coupling and VSWR as a function of frequency and antenna parameters like width and inclination of slot are presented. The self-reaction and discontinuity modal current concepts have been used to obtain admittance characteristics. The results of the theory are compared with that of practical.

Keywords: admittance, discontinuity in modal current, inclined slot, self-reaction, wave guide

I. Introduction:
Slot in a rectangular wave guide radiates depending on location and orientation. An array of slots in a wave guide are very useful in many applications due to its compact size and space occupied is less. Depending on the application requirement, longitudinal or transverse slot in the walls of wave guide have been used to produce perpendicular or parallel polarized radiation pattern. However, longitudinal slot in the broad wall or transverse slot in narrow wall will not radiate. Inclined slot in the wave guide radiate cross polarized component. But EMI problems will arise, if cross polarized component radiated into free space. Slot coupled junctions suppress these cross polarized component. This new junction provides vertical polarized waves.

With a variety of geometry, the analysis of different slots is reported by many researchers [1-4]. Results on studies of impedance characteristics of slots are reported. To obtain a desired radiation pattern using nonstandard dimensions, a wave guide array to suppress cross polarization have been designed by Raju et al [5]. Das et al [6] has developed a method to find admittance and resonant length of an inclined slot in a narrow wall of a rectangular wave guide. Also derived an expression to find admittance of the slot using angular spectrum of plane wave and discontinuity in modal current. Oliner A [7] has carried out an analysis, by using variation approach and considering stored power in wave guide, to obtain equivalent impedance parameters as seen from primary wave guide. Powen Hsu et al [8] has reported data on admittance of an inclined slot in a narrow wall of a rectangular wave guide as a function of slot length and inclination but slot enters into broad wall on both sides. Internal power stored in the evanescent modes in the wave guide is taken care. Marcuvitz et al [9] has developed the concept of discontinuity in modal current by equivalent electric and magnetic fields discontinuity. Fields will be produced whenever there is discontinuity in narrow or broad wall. John et al [10] has presented a full wave analysis method for an array comprised of edge slots. Using finite element boundary integral equation method fields in the slot are calculated and spectral domain moment method is used for the effects of external wave guide structure. Cheng - Geng Jan [11] presented method of moments analysis for slot in rectangular wave guide. It is found that for resonant slots the amplitude is sinusoidal with small tilt, were as aperture field is almost constant. From the field distribution the characteristics like conductance, susceptance and resonant length of slot can be estimated.

In the present paper two different standard wave guides are coupled through an inclined slot in the narrow wall of primary wave guide and intensive work has been done to determine admittance characteristics, coupling and VSWR as a function of slot inclination and width. The concept of self-reaction and discontinuity modal current concepts have been used to obtain admittance characteristics. Spectrum of plane waves approach has been used for analysis.

II. Formulation
As shown in fig (1) $a_1$ and $b_1$ are narrow wall and broad wall dimensions of primary rectangular wave guide, $a_2$ and $b_2$ are narrow wall and broad wall dimensions of secondary rectangular wave guide. An inclined slot in the narrow wall of coupled junction of two different standard waveguides with slot length $2L$ and width $2W$. $\theta$ is the angle of inclination of slot from vertical axis. The slots admittance characteristics are analyzed...
using s and elf-reaction and discontinuity in modal current, using TE and TM mode field concepts, slot radiators are analyzed

![Fig1 rectangular wave guide junction coupled through inclined slot in the narrow wall](image)

2.1 Self Reaction

The equivalent network parameter is given by [9] the expression of the form (8). In present work Self-reaction <a, a> is determined separately for the two guides. The self-reaction (a, a)<sub>f1</sub> in primary guide is longitudinal component of magnetic current, the self-reaction (a, a)<sub>f2</sub> in primary guide is transverse component of magnetic current, the self-reaction (a, a)<sub>f3</sub> in secondary guide, obtained from thermal expansion of the magnetic field in the coupled guide, is given by [14]. In the general case of two dissimilar guides, the total self-reaction is equal to the sum of self-reactance (a, a)<sub>f1</sub>, (a, a)<sub>f2</sub> and (a, a)<sub>f3</sub>

Hence, the equivalent network parameter will be

\[
<\text{s, s}> = (a, a)<f1> + (a, a)<f2> + (a, a)<f3>
\]

The expression for the self-reaction for the longitudinal component of the slot magnetic current in primary wave guide will be

\[
(a, a)<f1> = \frac{j4k^2V^2 \sin^4 \theta}{\mu_0 \omega a_1 b_1} \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} \frac{\epsilon_m \epsilon_n}{\gamma_{01} (k^2 + \gamma_{01}^2)} \cos^2 m\pi \cos^2 \frac{n\pi}{2} \left[ \sin (nP) \right]^2
\]

\[
\left[ 0.5(1 + e^{-2\gamma_1 L \sin \theta}) - \cos (kL \sin \theta) (2e^{-2\gamma_1 L \sin \theta} - \cos (kL \sin \theta)) + \frac{\gamma_{01}}{k} \sin (kL \sin \theta) \right]
\]

Where \( P = \frac{n\omega \sin \theta}{a_1} \)  

The expression for the self-reaction for the transverse component of the slot magnetic current in primary wave guide will be

\[
(a, a)<f2> = \frac{j2k^2V^2 \cos \theta}{\mu_0 \omega a_1 b_1} \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} \frac{\epsilon_m \epsilon_n}{\gamma_{01} (\gamma_{01}^2 + \gamma_{01}^2)} \cos^2 m\pi \sin^2 \frac{n\pi}{2} \left[ \cos \left( \frac{m\pi \cos \theta}{a_1} \right) - \cos (kL \sin \theta) \right]^2 \left[ 2 \cos \theta + e^{-2\gamma_1 L \sin \theta} - 1 \right] \]

The expression for the self-reaction in coupled wave guide reduced to

\[
(a, a)<f3> = 2 \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} (I)_{mn, E_{mn}}^2 + 2 \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} (I)_{mn, E_{mn}}^2 \left( (I)_{mn, E_{mn}}^m \right)^2
\]

Where \( (I)_{mn} = \frac{\gamma_{01}}{\mu_0 \omega a_1 b_1} \) and \( y_{01} = \left( \frac{\gamma_{01}}{\gamma_{01}^2} \right)^2 - (k)^2 \)

And modal voltages are given by [6]
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\[ E_{mn}^{e} = \frac{V}{2\pi} \left[ \frac{a_{2}b_{2}}{m a_{2}^{2} + n b_{2}^{2}} \right]^{\frac{1}{2}} \left[ \left( \frac{m \pi}{b_{2}} \cos \theta - \frac{n \pi}{a_{2}} \sin \theta \right) (\cos kL - \cos AL) \frac{2k}{k^{2} - A^{2}} Bw \sin \frac{\pi}{2} \right] \]

\[ E_{mn}^{m} = -\frac{V}{\pi} \left[ \frac{a_{2}b_{2}}{m a_{2}^{2} + n b_{2}^{2}} \right]^{\frac{1}{2}} \left[ \left( \frac{n \pi}{a_{2}} \cos \theta - \frac{m \pi}{b_{2}} \sin \theta \right) (\cos kL - \cos CL) \frac{2k}{k^{2} - C^{2}} Dw \sin -\frac{\pi}{2} \right] \]

Where
\[ A = \frac{m \pi}{b_{2}} \cos \theta + \frac{n \pi}{a_{2}} \sin \theta \]
\[ B = \frac{n \pi}{a_{2}} \cos \theta - \frac{m \pi}{b_{2}} \sin \theta \]
\[ C = \frac{n \pi}{a_{2}} \cos \theta - \frac{m \pi}{b_{2}} \sin \theta \]
\[ D = \frac{n \pi}{a_{2}} \cos \theta + \frac{m \pi}{b_{2}} \sin \theta \]

2.2 Expressions for modal discontinuity Current:
The expression for discontinuity in modal current [9] can be reduced to
\[ I_{c} = -2jY_{00} V \frac{2}{(a_{b_{1}}^{2})^{\frac{1}{2}}} \frac{\pi}{2} \frac{k}{\beta_{01}} - \frac{L}{2} - \cos \frac{L}{2} \sin \frac{\beta_{01}}{\beta_{01}}^{\frac{k}{2}} \]

\[ \frac{\beta_{01}^{2}}{k} \]

Here \[ Y_{00} = \frac{\beta_{01}}{\omega \mu_{01}} \] and \[ \beta_{01} = \sqrt{\left( \frac{\pi}{b_{1}} \right)^{2}} \]

2.3 Expression for Admittance loading:
The normalized shunt admittance is related to normalized impedance by the relation and can be calculated from the knowledge of self-reaction and discontinuity in modal current
\[ Y = g_{n} + j b_{n} = \frac{1}{z_{r}} = \frac{1}{r + j x} \]

2.4 Expression for Coupling and VSWR:
A slot in the waveguide wall produces a discontinuity in modal current, giving rise to shunt type of equivalent giving rise to admittance parameters. The transmission matrix of the shunt admittance parameters [3] is given by
\[ \begin{bmatrix} c_{1}^{+} \\ c_{1}^{-} \end{bmatrix} = \begin{bmatrix} 1 + Y/2 & Y/2 \\ -Y/2 & 1 - Y/2 \end{bmatrix} \]

When port 2 of guide 1 is terminated with matched load \[ c_{2} = 0 \]
The reflection coefficient seen by port 1 is given by
\[ \tau = \frac{1 - Y_{LN}}{1 + Y_{LN}} \] Where \[ Y_{LN} = 1 + Y \]

Using power balanced condition the radiated power coupled to free space is given by [12]
\[ C = g_{n}^{2}/[(2 + g_{n})^{2} + b_{n}^{2}] \]

The coupling in dB taking correction into account

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\[ C_{db} = 10 \log_{10} \left[ 4g_n^2/((2 + g_n)^2 + b_n^2) \right] - 8.686 \alpha t \]

Where correction factor \( \alpha = \left( \frac{n}{2L} \right)^2 - k^2 \) and \( t \) is wall thickness of wave guide.

The VSWR in terms of reflection coefficient is given by [5]

\[ VSWR = \frac{1 + |\tau|}{1 - |\tau|} \quad \text{--------------------------- (8)} \]

III. Results

From the obtained resonant length, normalized conductance, normalized susceptance, coupling and VSWR are numerically computed as a function of frequency, from expressions (1),(6),(7) and (8). Results are shown for \( a_1 = 3.48 \text{ cm}, b_1 = 7.24 \text{ cm}, a_2 = 1.016 \text{ cm}, b_2 = 2.286 \text{ cm}, \) for slot length \( 2L_1 = 1.6 \text{ cm}, \) for slot width \( 2W = 0.05, 0.1, 0.15, 0.2, 0.3 \) for slot inclinations \( \theta = 30^0, 35^0, 40^0, 45^0 \) and \( 50^0 \) in fig (2), fig(3), fig(4), fig(5), fig(6) respectively.

![Graphs showing variations of conductance, susceptance, coupling and VSWR](image)

Fig (2) Variation of conductance, susceptance, coupling and VSWR as a function of frequency with slot length \( 2L_1 = 1.6 \text{ cm}, \) slot width = 0.05 cm and slot inclination \( \theta = 30^0, 35^0, 40^0, 45^0, 50^0 \)
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Fig (3) Variation of conductance, susceptance, coupling and VSWR as a function of frequency with slot length 2L=1.6 cm, slot width=0.1 cm and slot inclination $\theta = 30^0, 35^0, 40^0, 45^0, 50^0$
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Fig (4) Variation of conductance, susceptance, coupling and VSWR as a function of frequency with slot length $2L = 1.6\,\text{cm}$, slot width $= 0.15\,\text{cm}$ and slot inclination $\theta = 30^\circ, 35^\circ, 40^\circ, 45^\circ, 50^\circ$

Fig (5) Variation of conductance, susceptance, coupling and VSWR as a function of frequency with slot length $2L = 1.6\,\text{cm}$, slot width $= 0.2\,\text{cm}$ and slot inclination $\theta = 30^\circ, 35^\circ, 40^\circ, 45^\circ, 50^\circ$. 

DOI: 10.9790/2834-11210108
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IV. Conclusions
It is evident from the results waveguide junction made of s band and x band wave guide. The results are found to be very interesting. Using MATLAB the variation of normalized conductance and normalized susceptance is found to depend on frequency, slot length, slot width and slot inclination. The results on coupling indicate that power coupled from primary to secondary at around mid-frequency of band. VSWR found to exhibit small variation over the entire frequency. Slot inclination also found to influence. The results presented in this paper make it possible to design such junctions very easily.

References