Studies on Slot Coupled Junction Radiator using S-Band Wave Guides

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Abstract:- In all radar and communication applications antennas plays an important role, for transmitting and receiving purpose. For certain special applications, it is required to have specifications like polarization, impedance, VSWR and radiation pattern characteristics. In H-Plane Tee junctions, the Tee arm is commonly coupled to the main wave guide by a longitudinal slot. However, the coupling can be done by inclined slot in the narrow wall of main wave guide. This structure acts as a radiator to produce vertically polarized waves. The knowledge of admittance characteristics of this new coupling system provides additional design parameters for the array designer.

In the present work, the analysis is made to obtain variation of conductance, susceptance, coupling and VSWR as a function of frequency after determining the resonant slot length of S- band H-plane Tee junction wave guide. The results are numerically obtained for varied slot width and slot inclinations. The concepts of self-reaction and discontinuity in modal currents of the main guide as well as Tee arm are used in the analysis. The data presented are extremely useful for the design of small and large arrays of S band H-Plane Tee junction radiators,useful for near and far range weather observation like National Weather Service *(NWS).*

Keywords:*H-Plane Tee junctions, self-reaction, discontinuity in modal currents, admittance characteristics.*

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1 Introduction

Basically the H-Plane Tee junction is a three port device. The main guide containing two ports and the coupled arm contains third port. The main wave guide is in shunt with the coupled arm. In power division applications Shunt Tees are usually preferred, to divide the power equally into two main ports when fed through shunt port. In the present work H-Plane Tee junctions 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 in the narrow wall of main guide. For the array designer additional design parameter will be provided by this coupling system i.e. waveguide dimensions and slot dimensions. Radiation pattern will be distorted in case of open ended slot arrays because of mutual coupling exist between the slots. In array applications, cross polarized components can be suppress by Slot coupled Shunt Tees which in turn reduces mutual coupling between slots.

The analysis of different slots is presented by many researchers[1-3]. Results on studies of impedance characteristics of slots are reported. Raju and Das have reported how To obtain a desired radiation pattern for a wave guide array by suppressing cross polarization [4] and to reduce mutual coupling between the slots [5]. Pandharipande et al [6] derived an expression for the equivalent network of long axial slot in the case of H-plane T junction coupled through longitudinal slot in the narrow wall of primary wave guide. Oliner[7] presented impedance properties of different types of slots using equivalent circuit and variational method. The results include with thickness and without thickness. Marcuvitz[8] has developed concept that Discontinuities in Waveguides walls produce fields. Discontinuity Electric and Magnetic Fields equivalent represents Discontinuity in modal Currents. Hsu. [9] obtained some admittance properties of the inclined slots in the narrow wall and investigated on the possible resonant length. Raju [10] has reported on variation of resonant length as a function of slot width and Admittance of inclined Slots in narrow wall of rectangular waveguide that are sufficiently wide as a function of frequency. Very useful investigations on slot coupled waveguide junctions and slot radiators carried out by Watson [11]. The coupled slots are either in the narrow wall or broad wall of a rectangular waveguide. Das [12] derived an equivalent circuit for waveguide T- junction using variational technique considering the slot thickness. Raju[13] and Das [14] have obtained admittance characteristics and resonant length of inclined slots in the narrow wall of a rectangular waveguide by using self-reaction and discontinuity in modal current approach . The variation of resonant length as a function of inclination of the slot is given using variational analysis as well as method of moments. Cheng-Geng Jan [15] has reported the analysis of side wall inclined slots using method of moment technique.

2.Analysis for admittance characteristics

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. In the present paper, the admittance characteristics of inclined slot in narrow wall of S-band Shunt Tee are determined from self-reaction and discontinuity in modal current [8]. 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.

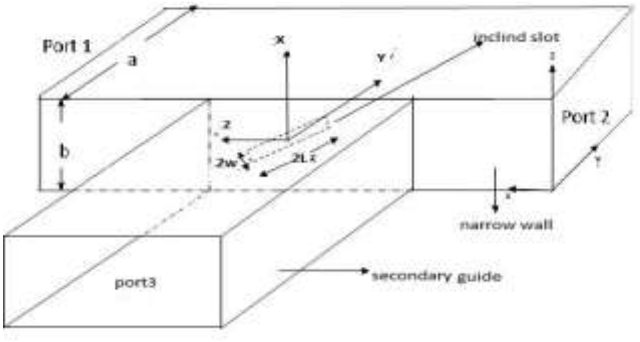

Fig.1 Inclined slot coupled waveguide shunt Tee

In the present work, the analysis is carried out to obtain variation of slot conductance and susceptance as a function of resonant slot length. The result is numerically obtained for varied slot widths and slot inclination. Consider a S-band waveguide shunt Tee coupled through an inclined slot of length 2L and width 2w, on the narrow wall as shown in Fig.1.

The analysis for admittance characteristics is obtained 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 [14]. It is assumed that slot is inclined at an angle θ from the vertical axis and coupling takes place through inclined slot in narrow wall of the primary feed waveguide.

As shown in fig(1) a and *b* are narrow wall and broad wall dimensions of primary and 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 .θ is the angle of inclination of slot from vertical axis.The slots admittance characteristics are analyzed using self-reaction and discontinuity in modal current.Using TE and TM mode field concepts, slot radiators are analyzed.

*2.1 Self-reaction equations in H plane Tee junction coupled through inclined slot***:**

The Electric field in aperture plane of slot is replaced by an equivalent magnetic current, the total self-reaction $\langle p,p\rangle$of this magnetic current, with magnetic Fields produced bythis magnetic current. The admittance seen by primary guide can be expressed as

$$\mathrm{Y_T} = -\frac{(\mathrm{I_s I_s})}{\langle p,p\rangle}(1)$$

where$I_s$is discontinuity in modal current.

Expression for self- reaction is given by [3]

$$\langle p,p\rangle = -\int \overline{\mathrm{H}}.\overline{\mathrm{M}}\ \mathrm{dv}.(2)$$

where$\overline{\mathrm{H}}$ismagnetic field and $\overline{\mathrm{M}}$is magnetic current. V is the coupled volume.

In present work Self-reaction $\langle p,p\rangle$ is determined separately for the two guides. The self -reaction $\langle p,p\rangle_1$in primary guide is longitudinal component of magnetic current, the self-reaction $\langle p,p\rangle_2$in primary guide is transverse component of magnetic current, the self-reaction $\langle p,p\rangle_3$in secondary guide, obtained from the modal expansion of the magnetic field in the coupled guide, is given by [14]., The shunt admittance loading on the primary guide due to the slot coupled shunt Tee can be expressed as the total self-reaction is equal to the sum of self-reactance$\langle p,p\rangle_1$, $\langle p,p\rangle_2$and $\langle p,p\rangle_3$.Hence, the equivalent network parameter will be

$$\langle p,p\rangle = \langle p,p\rangle_1 + \langle p,p\rangle_2 + \langle p,p\rangle_3 (3)$$

The expression for shunt admittance loading on the primary guide due to slot coupled matched terminated Tee arm will be

$$Y_T = -\frac{I_S I_S}{\langle p,p\rangle} = -\frac{I_S I_S}{\langle p,p\rangle_1} - \frac{I_S I_S}{\langle p,p\rangle_2} - \frac{I_S I_S}{\langle p,p\rangle_3}(4)$$

$$Y_T = Y_1 + Y_2 + Y_3$$

2.2 Self-reaction due to longitudinal component of magnetic current in primary wave guide$\langle p,p\rangle_1$:

The Electric field $\overline{E_S}$ in aperture plane of slot of fig 1 is related to equivalent magnetic Current $\overline{M_S}$ by the relation

$$\overline{M_S} = \overline{E_S}\ X\overline{a_n}(5)$$

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

The field distribution in the slot is assumed to be of form given by [6]

$$\overline{E_S} = \overline{a_x} E_m\ sink(L - |z'|)(6)$$

for$\frac{a}{2} - W \leq |x'| \leq \frac{a}{2} + W$ and $-L \leq |z'| \leq L$

where E_m is maximum Electric field, $\overline{a_x}$ is unit vector along x direction and K=2π/λ. λ is wave length. 2L is length of slot and 2W is width of slot.

From the fig.1 that $\overline{a_n} = \overline{a_y}$. Hence the magnetic current due to slot is in z direction. From the knowledge of magnetic field and magnetic current, it is possible to evaluate self -reaction required for obtaining expression for equivalent network. The self -reaction has been defined in (2) in the form of volume integral. Since magnetic current is distributed over the surface, the volume integral in the self–reaction reduced to surface integral. Taking the image in the wall y=b into account, the expression for self-reaction

Takes the form $\langle p,p\rangle_1 = -\int \bar{H}_S.\overline{2M_S}\, ds$

By integrating and simplifying the above expression,

$\langle p,p\rangle_1 =$
$\sum_m^\infty \sum_n^\infty \frac{\epsilon_m \epsilon_n \lambda}{j40\gamma_{mn}\, ab\pi^2} E_m^2\, 2w\, cos^2 m\pi \cos\frac{n\pi}{2} \frac{\sin\left(\frac{n\pi\omega}{a}\right)}{\frac{n\pi\omega}{a}} \int_{\frac{\pi}{2}-w}^{\frac{\pi}{2}+w} \cos\left(\frac{n\pi x}{a}\right) dx \left[\cos \int_{-L}^{L} e^{-\gamma_{mn}} |z| sink(L -\right.$
$z')dz{-}e{-}\gamma mnz{-}LL\cosh \gamma mnsink(L{-}z')$ (8)

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

$$\langle p,p\rangle_1 = 2Qsin^4\theta \sum_{m=0}^{\infty}\sum_{n=1}^{\infty} \frac{\epsilon_m \epsilon_n}{\gamma_{01}(k^2+\gamma_{01}{}^2)} cos^2 m\pi . cos^2\frac{n\pi}{2}\left[\frac{\sin(nR)}{(nR)}\right]^2$$

$$\Big[0.5\left(1+e^{-2\gamma_{01}L\sin\theta}\right) - \cos(kLsin\theta)\,\langle 2e^{-\gamma_{01}L\sin\theta} - \cos(kL\sin\theta) + \frac{\gamma_{01}}{k}\sin(kL\sin\theta)\rangle\Big]$$

Where $R = \frac{\pi W \sin\theta}{a}$, $Q = \frac{j2k^2 V_m{}^2}{\mu_0\omega a \quad b}$, and $\gamma_{01} = \left[\left(\frac{m\pi}{b}\right)^2 + \right.$
$n\pi a2{-}k212$ (7)

Similarly, the expression for the self-reaction for the transvers component of the slot magnetic current in primary wave guide will be
$\langle p,p\rangle_2 =$
$Qcos^2\theta \sum_{m=0}^{\infty}\sum_{n=1}^{\infty} \frac{\epsilon_m}{(\gamma_{01}{}^2)} cos^2 m\pi . sin^2\frac{n\pi}{2}\left[\frac{1}{k^2-\left(\frac{n\pi}{a}\right)^2}\right]^2 \left[cos\left(\frac{n\pi Lcos\theta}{a}\right) - \right.$
$\cos kLsin\theta 22cos\theta{+}e{-}2\gamma wcos\theta\gamma 01w{-}1\gamma 01w$(8)

The expression for the self-reaction in coupled wave guide reduced to
For the coordinates shown in fig.1 the variables are related as

$x=x' + \left(\frac{a}{2}\right)$ and $z=z' + \left(\frac{b}{2}\right)$; k=2π/λ.

From formulation given by [3] and using the relations above the normalized vectors for electric $(\bar{E}_{mn}^e)$ and magnetic $(\bar{E}_{mn}^m)$ are found. The electric and magnetic voltages are given

$$V_{mn}^e = \int_{-w}^{w}\int_{-L}^{L} \bar{E}_S \bar{E}_{mn}^{-e}\, dx'\, dz'$$

$$V_{mn}^m = \int_{-w}^{w}\int_{-L}^{L} \bar{E}_S \bar{E}_{mn}^{-m}\, dx'\, dz'$$

where E_m is maximum Electric field, and K=2π/λ . λ is wave length. a and b are narrow wall and broad wall dimensions of feed and coupled guide. From the knowledge of [6] the expressions for modal voltages are obtained.

The field distribution in the aperture plane of slot is assumed having length 2_{Lt} and width $2w_t$ given by

$$\overline{E_S} = \overline{a_x} E_m\, sink(L_t - |z'|)$$

for -L≤ $|z'| \leq L$ and -W≤ $|x'| \leq W$

where E_m is maximum Electric field, $\overline{a_x}$ is unit vector along x direction and K=2π/λ. λ is wave length. 2L is length of slot and 2W is width of slot and $V=2WE_m$

The transvers component of magnetic field in y=0 plane of guide 2 is of the form

$\bar{H}_s = \sum_m^\infty \sum_n^\infty \left[(Y_0)_{mn}^e V_{mn}^e \bar{h}_{mn}^e + (Y_0)_{mn}^m V_{mn}^m \bar{h}_{mn}^m\right]$(9)

Here $(Y_0)_{mn}^e$ *and* $(Y_0)_{mn}^m$ are characteristic admittance of TE and TM modes.$\bar{h}_{mn}^e$ and$\bar{h}_{mn}^m$ are modal vector functions for transvers component of magnetic field .

Since magnetic current is in ground plane y'=0, the total magnetic current considering its image in the ground plane is given by

$\bar{M}_S = 2\bar{E}_s X \bar{a}_y$

The electrical field distribution in the aperture plane of slot can represent by an equivalent magnetic current. The self-reaction$\langle p,p\rangle_3$of the magnetic current.$\bar{M}_S$in coupled guide given by

$$\langle p,p\rangle_3 = -\iint \bar{H}_s . \bar{M}_S\, dx'\, dz'$$

The self- reaction$\langle p,p\rangle_3$is reduced to

$\langle p,p\rangle_3 =$
$2\sum_{m=0}^{\infty}\sum_{n=1}^{\infty}(Y_0)_{mn}^e\ (V_{mn}^e)^2 +$
$2\sum_{m=0}^{\infty}\sum_{n=1}^{\infty}(Y_0)_{mn}^m\ (V_{mn}^m)^2$(10)

where$(Y_0)^e_{mn} = \frac{\gamma_{mn}}{j\omega\,\mu_0}$; $(Y_0)^m_{mn} = \frac{j\omega\,\epsilon}{\gamma_{mn}}$

2.3 Expressions for modal discontinuity current:

The expression for discontinuity in modal current [9] can be reduces to

$$I_S = -2jY_{01}V_m\left(\frac{2}{ab}\right)^{1/2}\frac{\pi}{b\beta_{01}}\frac{k}{\beta_{01}^2-k^2}\left(\cos\beta_{01}\frac{L}{2}-\cos k\frac{L}{2}\right)\frac{\sin\beta_{01}\,w/2}{\beta_{01}\,w/2} \quad (11)$$

Here $Y_{01} = \frac{\beta_{01}}{\omega\mu_{01}}$ and $\beta_{01} = \sqrt{k^2-\left(\frac{\pi}{b}\right)^2}$

2.4Expressions 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

The normalized admittance is given by

$$Y = \frac{Y_T}{Y_{01}}$$

whereY_{01} is characteristic wave admittance for dominant mode.

$$Y = g_n + jb_n = \frac{1}{z} \quad (12)$$

whereg_n is the normalized conductance and b_n is the normalized susceptance

2.5 *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

$$\begin{bmatrix} c_1^+ \\ c_1^- \end{bmatrix} = \begin{bmatrix} 1+Y/2 & Y/2 \\ -Y/2 & 1-Y/2 \end{bmatrix} \begin{bmatrix} c_2^+ \\ c_2^- \end{bmatrix}$$

When port2 of guide1is terminated with matched load c_2^-=0

The reflection coefficient seen by port1 is given by

$$\tau = \frac{\mathbf{1}-\boldsymbol{Y_{LN}}}{\mathbf{1}+\boldsymbol{Y_{LN}}}$$

where

$$Y_{LN} = 1+Y$$

Using power balanced condition the radiated power coupled to free space is given by

$$C_0 = \frac{4g_n^2}{[(2+g_n)^2+b_n^2]} (13)$$

The VSWR in terms of reflection coefficient is given by

$$VSWR = \frac{1+|\tau|}{1-|\tau|} \quad (14)$$

3. Results

Using the expression (12) normalized admittance presented above, the variations of normalized conductance, normalized susceptance numerically computed at the central frequency of S-band wave guide. For the slot inclination of θ=30^0,35^0, 40^0,45^0,50^0 the resonant lengths of the slot 2L=4,8 cm,5.2cm,5.4cm,5.6cm and 5.8cm for S-band are obtained respectively. The variation of conductance, susceptance as a function of frequency for slot width of 0.05cm,0.1 cm ,0.15cm,0.2 cm,0.25 cm,0.3 cm are presented in figs.2, 5, 8, 11,14,17.Using the expression (13),The variation of coupling as a function of frequency for slot width of 0.05cm, 0.1 cm ,0.15cm,0.2 cm,0.25 cm,0.3 cm are presented in figs.3, 6, 9, 12,15,18. Using the expression(14),The variation of VSWR as a function of frequency for slot width of 0.05cm, 0.1 cm ,0.15cm,0.2 cm,0.25 cm,0.3 cm are presented in figs.4, 7, 10, 13,16,19.

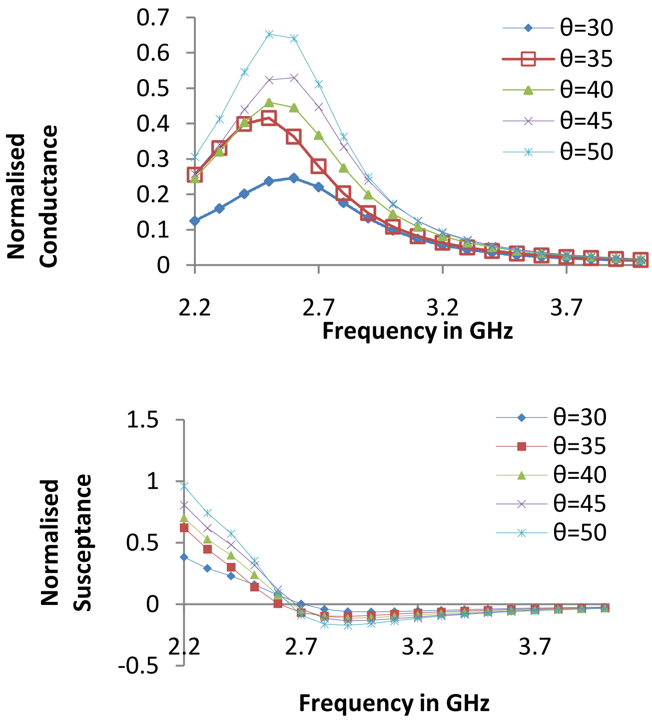

Fig.2. Variation of conductance, susceptance as a function of frequency for slot width 2w=0.05 cm

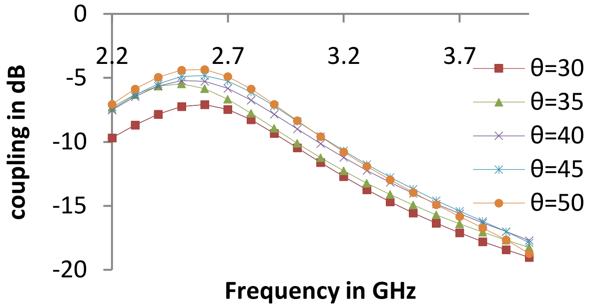

Fig.3.Variation of coupling as a function of frequency for slot width 2w=0.05 cm

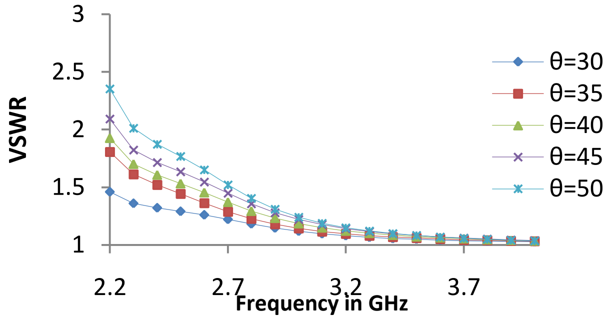

Fig.4.Variation of VSWR as a function of frequency for slot width 2w=0.05 cm

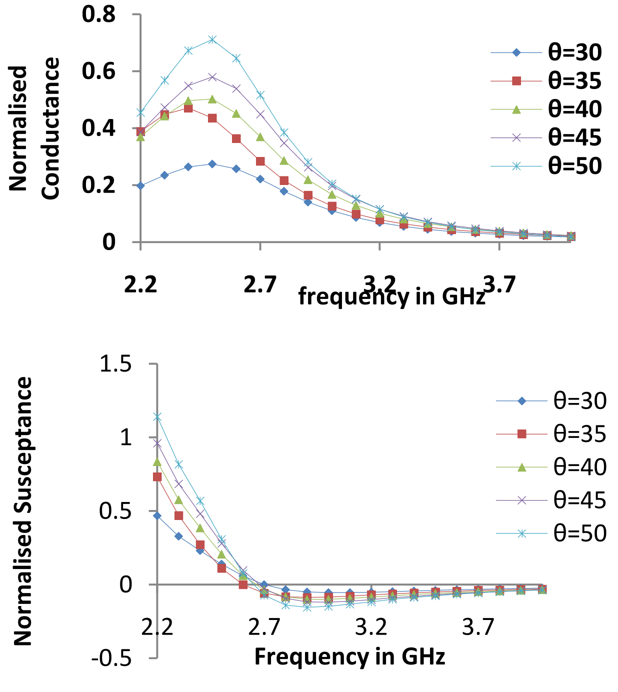

Fig.5.Variation of conductance, susceptance as a function of frequency for slot width 2w=0.1 cm

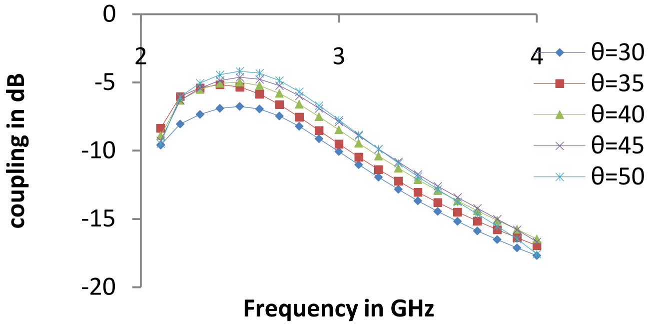

Fig.6.Variation of coupling as a function of frequency for slot width 2w=0.1 cm

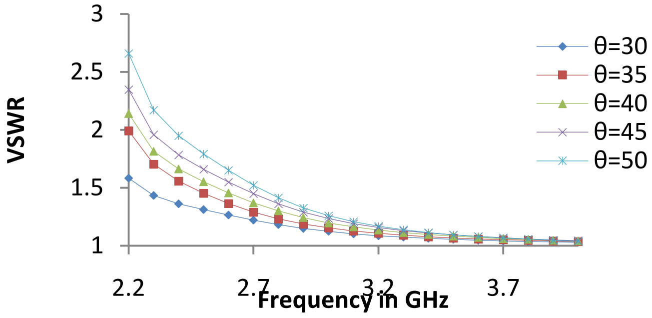

Fig.7.Variation of VSWR as a function of frequency for slot width 2w=0.1 cm

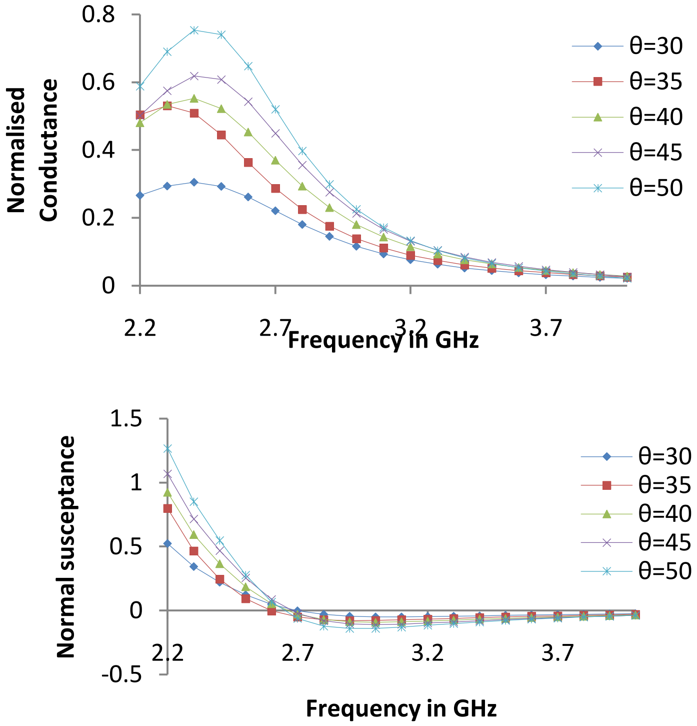

Fig.8.Variation of conductance, susceptance as a function of frequency for slot width 2w=0.15 cm

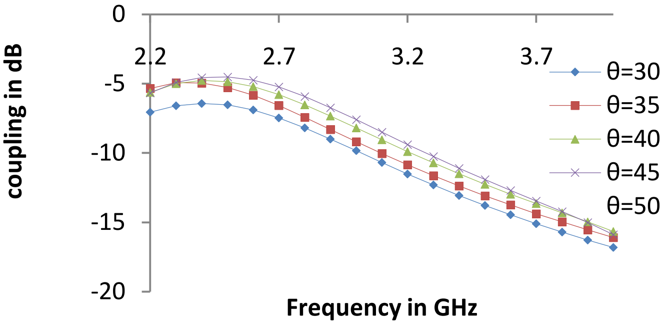

Fig.9.Variation of coupling as a function of frequency for slot width 2w=0.15 cm

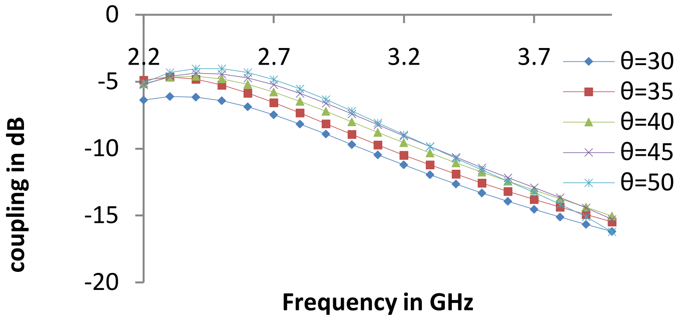

Fig.12.Variation of coupling as a function of frequency for slot width 2w=0.2 cm

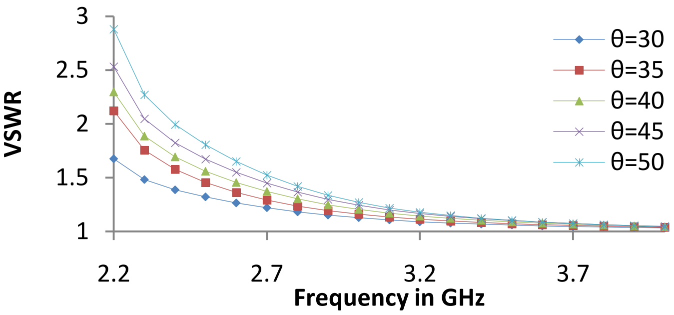

Fig.10.Variation of VSWR as a function of frequency for slot width 2w=0.15 cm

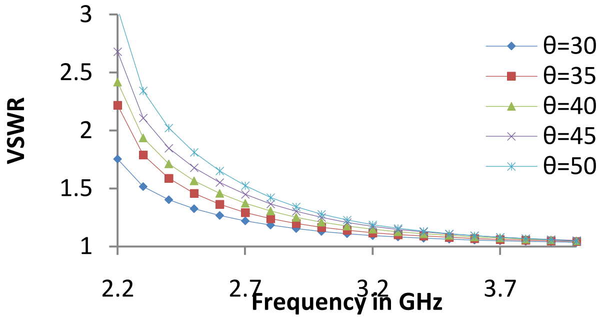

Fig.13.Variation of VSWR as a function of frequency for slot width 2w=0.2 cm

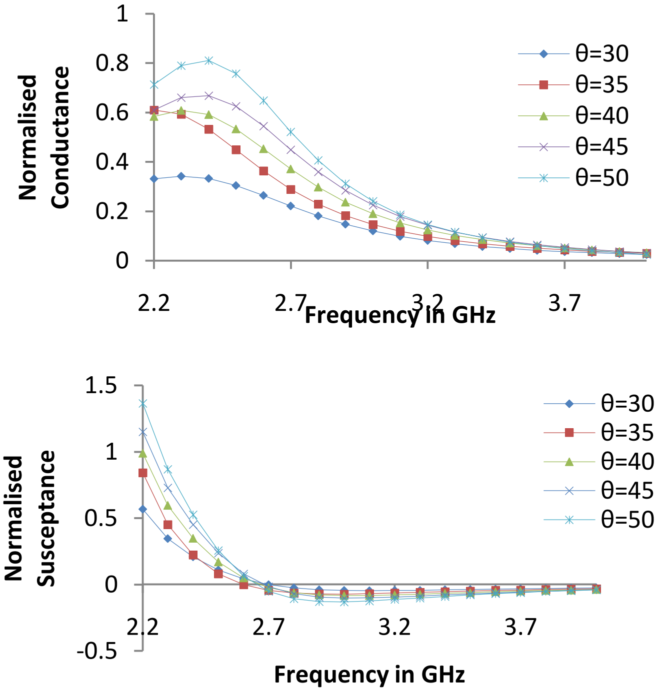

Fig.11.Variation of conductance, susceptance as a function of frequency for slot width 2w=0.2 cm

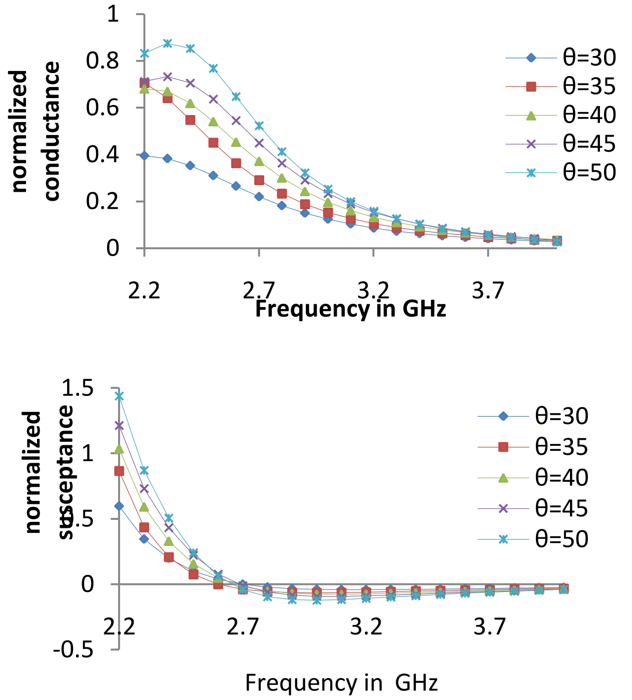

Fig.14.Variation of conductance, susceptance asa function of frequency for slot width 2w=0.25 cm

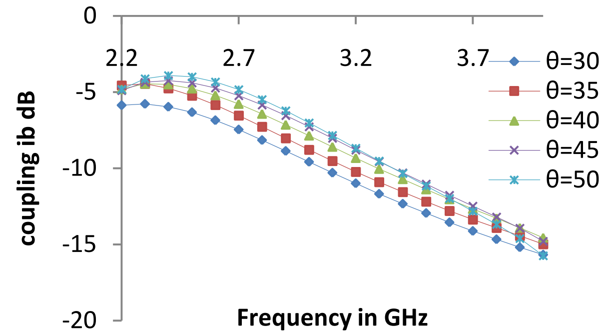

Fig.15. Variation of coupling as a function of frequency for slot width 2w=0.25 cm

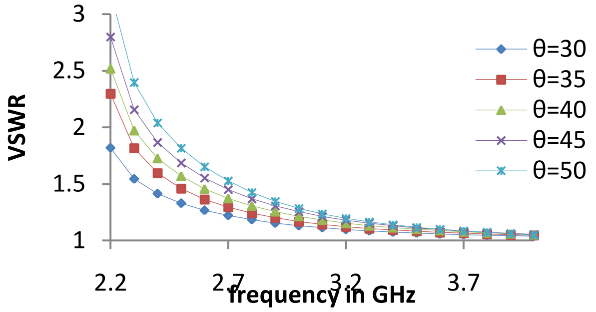

Fig.16.Variation of VSWR as a function of frequency for slot width 2w=0.25 cm

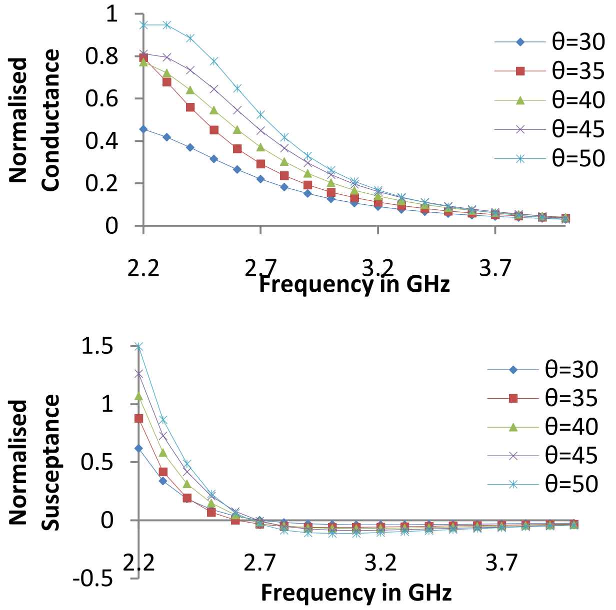

Fig.17.Variation of conductance, susceptance as a function of frequency for slot width 2w=0.3 cm

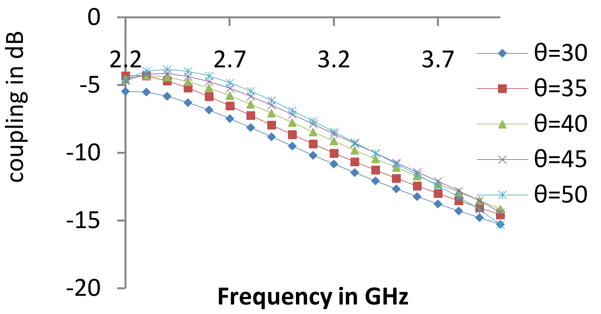

Fig.18.Variation of coupling as a function of frequency for slot width 2w=0.3 cm

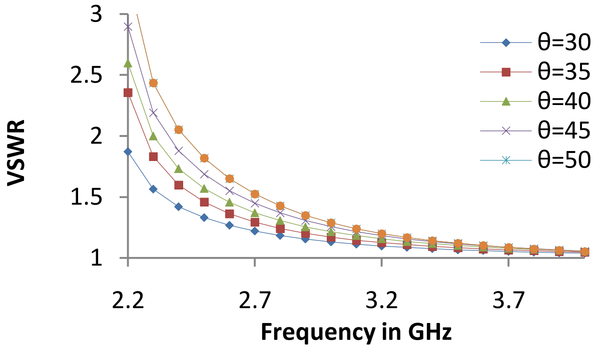

Fig.19.Variation of VSWR as a function of frequency for slot width 2w=0.3 cm

4. Conclusion

It is evident from the results that the conductance as a function of frequency in S-band range exhibits its peak close to the resonant frequency. The peak is shifted to the left of resonant frequency. This it-self indicatesthat the equivalent circuit of the junction contains distributed components R, L and C, where all the parameters vary with the frequency. This is against the behavior of lumped circuits. The susceptance has a change in sign and the sign changes at resonant frequency.

Coupling and VSWR are influenced by the admittance parameters containing conductance and susceptance. On the other hand, the conductance and susceptanceare dependent on wave guide dimensions and slot parameters. The results presented in this paper are extremely useful for the design of arrays of wave guide junctions made of S-band wave guides.

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