ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2015

Contribution of Feed Waveguide on the Admittance Characteristics Of Coplanar Slot Coupled E-H Tee Junction

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ABSTRACT: H and E plane Tee junctions are the most common junctions in microwave communication and radar systems. They are extensively analyzed as evident from the literature. However co-planar E-H plane Tee junction is derived from H plane Tee junction. In this type of junction, T- arm is rotated by 90° and coupling takes place through inclined slot in the narrow wall of primary guide. Vertical slot in the narrow wall does not radiate and hence it is not used as slot antenna. Inclined open slot radiators are used to produce horizontally polarized fields. But due to the inclination the slot radiated fields contain cross polarized components. In order to suppress such cross polarized fields co-planar E-H junctions are extremely useful. An analysis of a T –Junction which differs from conventional H-plane T – junctions in that the T arm is rotated by 90^0 and coupling takes place through an inclined slot is presented. The variations of conductance, susceptance, coupling and VSWR with the angle of inclination of the slot, and with frequency, are presented and results have been verified practically.

KEYWORDS: admittance, coupling, resonance length, VSWR.

I. INTRODUCTION

Investigations of H – plane T – junctions have already been reported [1-3].However a new waveguide junction which is neither E nor H plane T-junction fig 1.1 in which the coupling slot is in the narrow dimension of the coupled guide is oriented along the axis of the primary guide. As a result, the E field of the coupled guide and the H field of the primary guide are coplanar and hence this type of T – junction is designated as a coplanar E – H plane T – junction is considered for analysis. The power is coupled to the T – arm through an inclined slot in the narrow wall of the primary guide. It can be noted that in this type of T – junction no power can be coupled using either a longitudinal or a vertical slot.

In the present work, investigations have been carried out to find the waveguide dimensions necessary for slots which resonate around 3GHz and it is analyzed and computed results are presented for a slot angle at 30^0,45^0 and 60^0 for coplanar E-H plane Tee junction using identical waveguides having standard dimensions (a= 3.4036cm, b = 7.2136cm) for admittance characteristics.

The more general form of coplanar E-H plane Tee junction and its impedance loading is evaluated using the analysis described in the eq. 12. The total self reaction due to the magnetic current in the slot and discontinuity in modal current [4] in the primary guide due to inclined slot in the narrow wall are evaluated and the absolute admittance loading on the primary guide is found out. Subsequently, this admittance is normalized by the characteristic wave admittance of the primary feed waveguide. This normalized admittance data is used to evaluated VSWR coupling and by making use of the formulas from the eq.16 and 17 respectively. Theoretical and practical results on normalized admittance loading, coupling, and VSWR as a function of frequency with the angle of inclination of the slot as parameter are presented.

II. EXPRESSION FOR IMPEDANCE LOADING

Fig.1 represents coplanar E-H plane Tee junction in which the two rectangular waveguides forming the junction have different broad and narrow wall dimensions. Coupling takes place through an inclined slot in the narrow wall of guide 1.In order to estimate the shunt impedance loading on the primary guide (guide 1) due to the slot coupled

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matched terminated Tee arm, expression for the total self reaction <a,a> due to the equivalent magnetic current is found by following the procedure . The expression for the shunt impedance loading is obtained by using the equations

$$\langle a,a\rangle = \langle a,a\rangle_1 + \langle a,a\rangle_2 + \langle a,a\rangle_3 \tag{1}$$

$$\begin{aligned} Z &= -\frac{\langle a,a\rangle}{II} \\ &= -\frac{\langle a,a\rangle_1}{II} - \frac{\langle a,a\rangle_2}{II} - \frac{\langle a,a\rangle_3}{II} \\ &= Z_1 + Z_2 + Z_3 \end{aligned} \tag{2}$$

Expressions for $<a,a>_1$ (self reaction of the longitudinal component of the magnetic current in primary guide), $<a,a>_2$ (self reaction of the transverse component of the magnetic current in primary guide) and $<a,a>_3$ (self reaction of the equivalent magnetic current in the coupled guide) are given in the following sections.

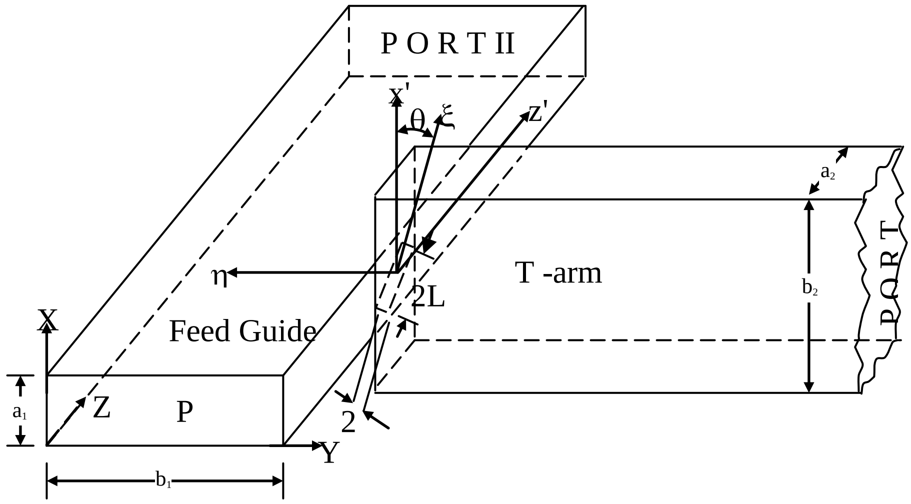

Fig.1: Geometry of coplanar EH T-Junction for S-band.

III. EXPRESSIONS FOR SELF REACTIONS

Self reaction, $<a, a>_1$ of the longitudinal component of equivalent magnetic current is obtained using the following. The corresponding expression for self reaction assumes the form

$$< a,a >_1 = \frac{j\,4\,K^2 V_0^2 \sin^4\theta}{\omega\mu\, a_1 b_1} \sum_n^{\infty} \sum_m^{\infty} \frac{\varepsilon_n\, \varepsilon_m}{(\gamma_1)_{mn}\,\left(K^2 + (\gamma_1)_{mn}^2\right)} \cos^2 m\pi \cdot \cos^2\frac{n\pi}{2} \left(\frac{\sin nF_1}{nF_1}\right)^2 \Big[\,0.5\left(1 + e^{-2(\;)_{mn} L \sin\theta}\right) - \cos(KL\,\sin\theta)\,\{2e^{-(\gamma^1)_{mn} L \sin\theta} - \cos(KL\,\sin\theta) + \frac{(\gamma_1)_{mn}}{K}\sin(KL\,\sin\theta)\,\}\Big] \quad \ldots (1.2)$$

Where

$$F_1 = \frac{\pi\, w\, \sin\theta}{a_1} \tag{3}$$

$$(\gamma_1)_{mn} = \left[\left(\frac{m\pi}{b_1}\right)^2 + \left(\frac{n\pi}{a_1}\right)^2 - K^2\right]^{1/2} \tag{4}$$

The expression for self reaction, $<a, a>_2$ of the transverse component of the equivalent magnetic current is found. The slot is located in the narrow wall of the primary guide whose internal narrow and broad dimensions respectively are a_1 and b_1. The expression for $<a, a>_2$ in the present configuration is of the same form as equation (2). With the modified dimensions of the primary guide, its expression is written as

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$$< a,a >_2 = \frac{j\,2K^2V_0^2\cos^2\theta}{\omega\,\mu\,a_1 b_1 w}\sum_m^\infty\sum_n^\infty \frac{\varepsilon_m}{(\gamma_1)_{mn}^2}\cdot\left[\frac{1}{K^2-(n\pi/a_1)^2}\right]\cos^2 m\pi\,\sin^2\frac{n\pi}{2}\cdot \cdot\left[\cos\left(\frac{n\pi L\cos\theta}{a_1}\right)-\cos(KL\cos\theta)\right]^2\cdot \cdot\left[2\cos\theta+\frac{e^{-2(\gamma_1)_{mn} w\cos\theta}}{(\gamma_1)_{mn} w}-\frac{1}{(\gamma_1)_{mn} w}\right] \quad (5)$$

Where $(\gamma_1)_{mn}$ is given by the equation (4). In the summation appearing in (2) and (5), the terms for m = 0, n = 0 and m = 1, n = 0 are excluded.

In order to obtain the expression for the self reaction $<a, a>_3$ in guide 2, the configurations of Fig. 1.1 is considered. The internal narrow and broad dimensions of the coupled guide are represented by a_2 and b_2 respectively. Substituting these dimensions of the coupled guide in the expression for self reaction, $<a, a>_3$ due to the equivalent magnetic current in the coupled guide of the present configuration is obtained. The expressions for V_{mn}^e and V_{mn}^m given as

$$V_{mn}^e = \frac{V_0}{2\pi}\left[\frac{a^2b^2\varepsilon_m\,\varepsilon_n}{(ma_2)^2+(nb_2)^2}\right]^{1/2}\left[\left(\frac{m\pi}{b_2}\cos\theta+\frac{n\pi}{a_2}\sin\theta\right)\cdot \cdot(\cos KL-\cos AL)\frac{2K}{K^2-A^2}\frac{\sin BW}{BW}\sin\overline{m+n}\,\frac{\pi}{2} + \left(\frac{m\pi}{b_2}\cos\theta-\frac{n\pi}{a_2}\sin\theta\right)(\cos KL-\cos CL)\cdot \cdot\frac{2K}{K^2-C^2}\frac{\sin DW}{DW}\sin\overline{m-n}\,\frac{\pi}{2}\right] \quad (6)$$

$$V_{mn}^m = -\frac{V_0}{\pi}\left[\frac{a_2\,b_2}{(ma_2)^2+(nb_2)^2}\right]^{1/2}\left[\left(\frac{n\pi}{a_2}\cos\theta-\frac{m\pi}{b_2}\sin\theta\right)\cdot \cdot(\cos KL-\cos AL)\frac{2K}{K^2-A^2}\frac{\sin BW}{BW}\sin\overline{m+n}\,\frac{\pi}{2} + \left(\frac{n\pi}{a_2}\cos\theta+\frac{m\pi}{b_2}\sin\theta\right)(\cos KL-\cos CL)\cdot \cdot\frac{2K}{K^2-C^2}\frac{\sin DW}{DW}\sin\overline{m-n}\,\frac{\pi}{2}\right] \quad (7)$$

Where,

$$A = \frac{m\pi}{b_2}\cos\theta+\frac{n\pi}{a_2}\sin\theta$$
$$B = \frac{m\pi}{b_2}\sin\theta-\frac{n\pi}{a_2}\cos\theta$$
$$C = \frac{m\pi}{b_2}\cos\theta-\frac{n\pi}{a_2}\sin\theta$$
$$D = \frac{m\pi}{b_2}\sin\theta+\frac{n\pi}{a_2}\cos\theta \quad (8)$$

The corresponding expressions for $(Y_0)_{mn}^e$ and $(Y_0)_{mn}^m$ are given by

$$(Y_0)_{mn}^e = \frac{(\gamma_2)_{mn}}{j\,\omega\,\mu} \quad (9)$$

And

$$(Y_0)_{mn}^m = \frac{j\,\omega\,\varepsilon}{(\gamma_2)_{mn}} \quad (10)$$

Where

$$(\gamma_2)_{mn} = \left[\left(\frac{m\pi}{b_2}\right)^2+\left(\frac{n\pi}{a_2}\right)^2-K^2\right]^{1/2} \quad (11)$$

IV. DISCONTINUITY IN MODAL CURRENT

The expression for the discontinuity in modal current, I due to an inclined slot in the narrow wall of the primary guide is derived for the dimension of the primary guide of Fig.1, the expression for I is given by equation (12).

$$I = -2jY_{01}V_0\,\sin\theta\,\frac{\sin(W\beta_{01}\sin\theta)}{W\beta_{01}\sin\theta}\left(\frac{2}{a_1b_1}\right)^{1/2}\frac{\pi}{b_1\beta_{01}}\cdot\frac{K}{(W\beta_{01}\sin\theta)^2-K^2}\left[\cos(\beta_{01}L\sin\theta-\cos KL)\right] \quad (12)$$

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Vol. 3, Issue 3, March 2015

Where

$$Y_{01} = \frac{\beta_{01}}{\omega\,\mu} = \frac{1}{z_{01}}$$

And

$$\beta_{01} = \left[K^2 - \left[\frac{\pi}{b_1}\right]^2\right]^{1/2}$$

V. DERIVATION OF EXPRESSION FOR COUPING AND VSWR

Expression for the impedance loading on the primary guide is derived from the equations (1) , (2) the result is divided by Z_{01}, the characteristic wave impedance of the primary guide to obtain the normalized impedance

$$z = \frac{Z}{Z_{01}} \tag{13}$$

The reciprocal of z gives the normalized admittance, y and is given by

$$Y = \frac{1}{z} = g_n + jb_n \tag{14}$$

Where g_n is the normalized conductance and b_n is the normalized susceptance.
The reflection coefficient seen by guide 1 of fig 1.1 to be of form

$$\Gamma = \frac{1 - y_{LN}}{1 + y_{LN}}$$

where $y_{LN} = 1 + y$ (15)

The corresponding VSWR is of the form

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

The coupling in dB is given by

$$C_{dB} = 10\log_{10}\left[\frac{4g_n}{(2 + g_n)^2 + b^2{}_n}\right] \tag{17}$$

VI. NUMARICAL AND EXPERIMENTAL RESULTS

Using the equations 14, 16 and 17, variation of $\mathbf{g_n, b_n}$ coupling and VSWR with the resonance length, 2L where the resonance length is determined from the point of zero crossing of susceptance curve, the resonant length is determined for the slot is evaluated for f=3 GHz , 2w=0.3cm $a_1 = a_2$ =3.4036 cm , $b_1 = b_2$ =7.2136 cm at slot inclination angle 30^0, 45^0 and 60^0. The results are presented in fig 3 variation of normalized conductance g_n for 2L=1.926 cm , 1.969 cm and 2.57 cm at slot inclination angle 30^0 , 45^0 and 60^0 respectively other parameters remaining same as above with frequency.

The results are presented in fig 4 variation of normalized susceptance b_n for 2L=1.926 cm , 1.969 cm and 2.57 cm at slot inclination angle 30^0 , 45^0 and 60^0 respectively other parameters remaining same as above with frequency.

The results are presented in fig 5 variation of coupling for 2L=1.926 cm , 1.969 cm and 2.57 cm at slot inclination angle 30^0 , 45^0 and 60^0 respectively other parameters remaining same as above with frequency.

The results are presented in fig 5 variation of VSWR for 2L=1.926 cm , 1.969 cm and 2.57 cm at slot inclination angle 30^0 , 45^0 and 60^0 respectively other parameters remaining same as above with frequency.

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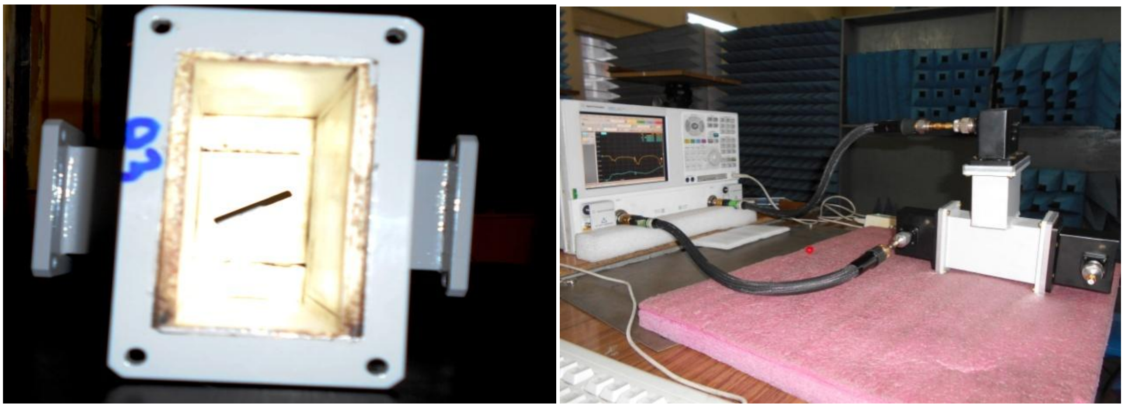
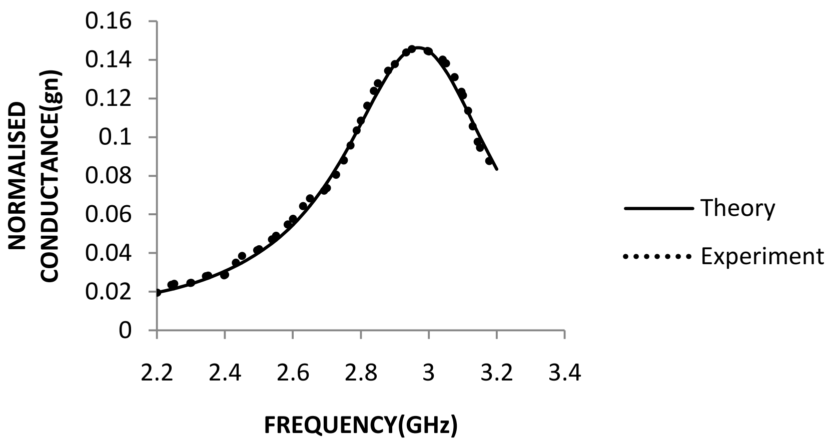


Fig 2 (a) Photograph of Fabricated E-H T-Junction. (b) Photograph of experimental set-up for measuring s-parameters



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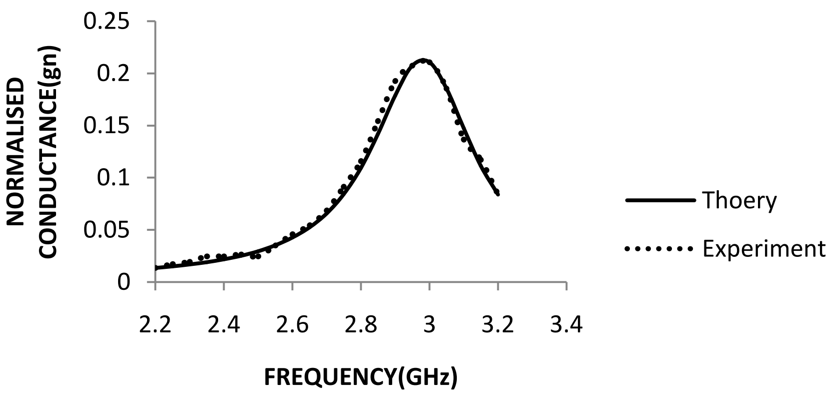

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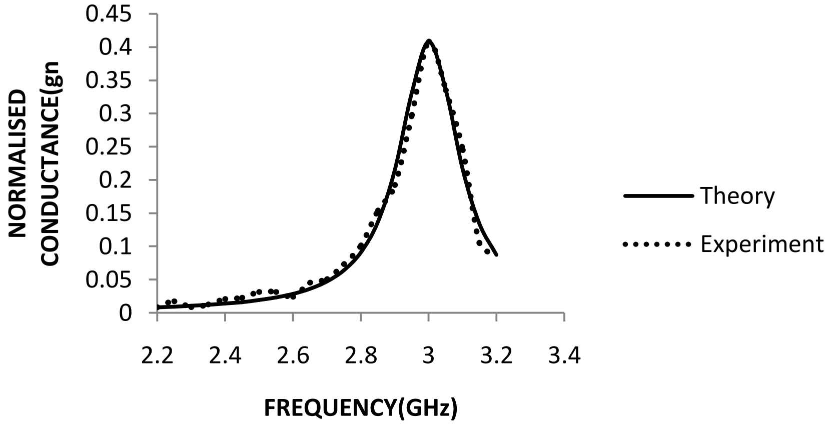
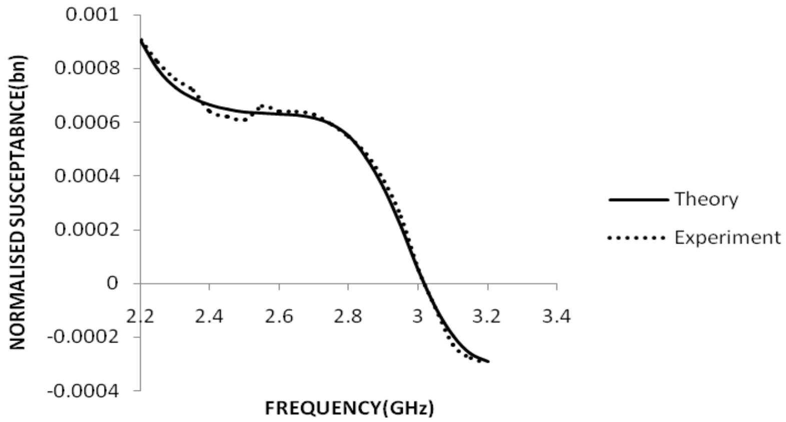


(c)

Fig 3: Variation of normalized conductance (g_n) with frequency for 2W=0.3cm, a=3.4036cm, b=7.2136cm at (a) θ=30^0, (b) 45^0 and (c) 60^0 respectively



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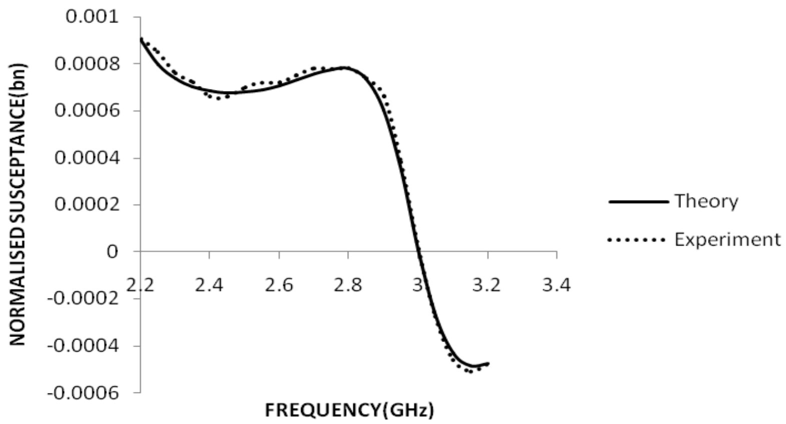

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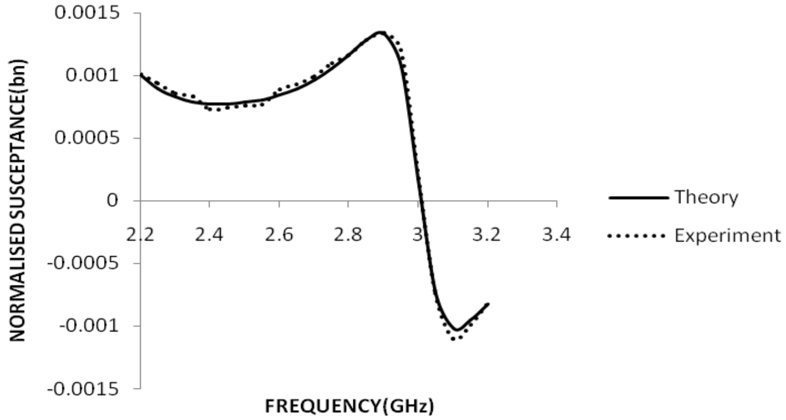
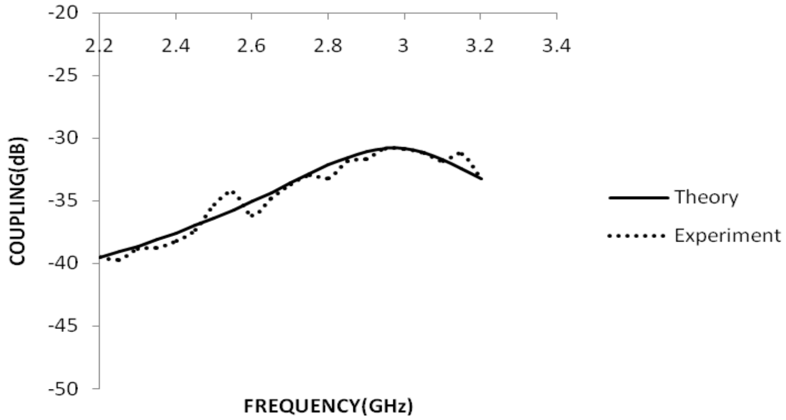


(c)

Fig 4: Variation of normalized Susceptance (b_n) with frequency for 2W=0.3cm, a=3.4036cm, b=7.2136cm at (a) $\theta=30^0$, (b) 45^0 and (c) 60^0 respectively



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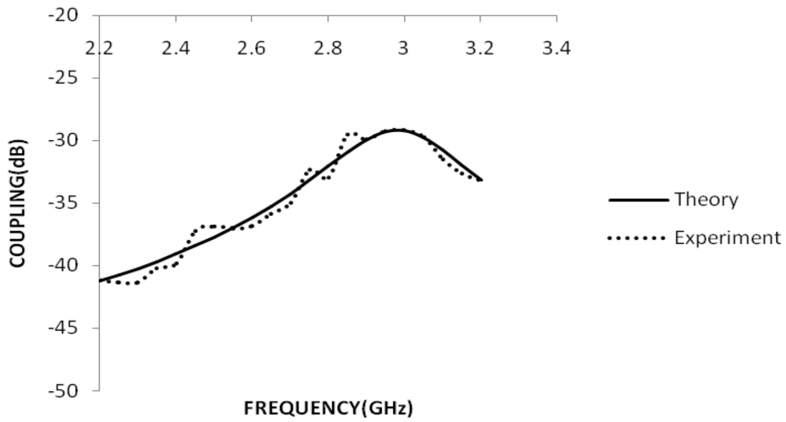

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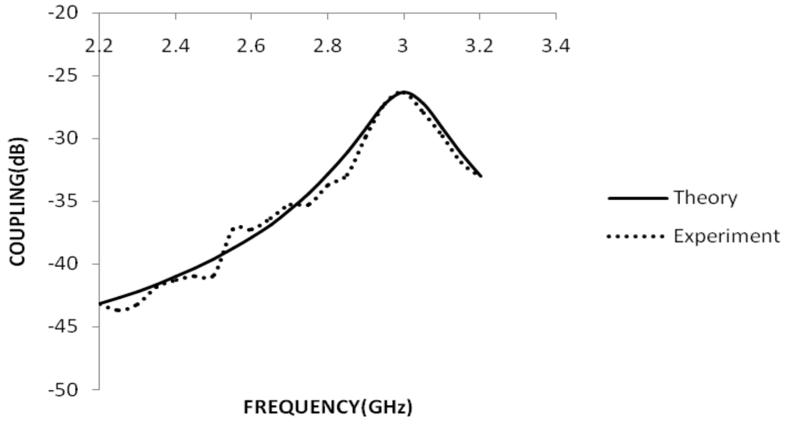
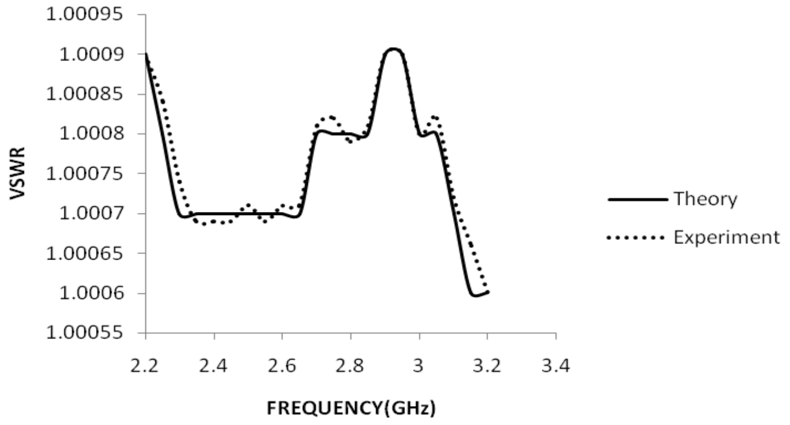
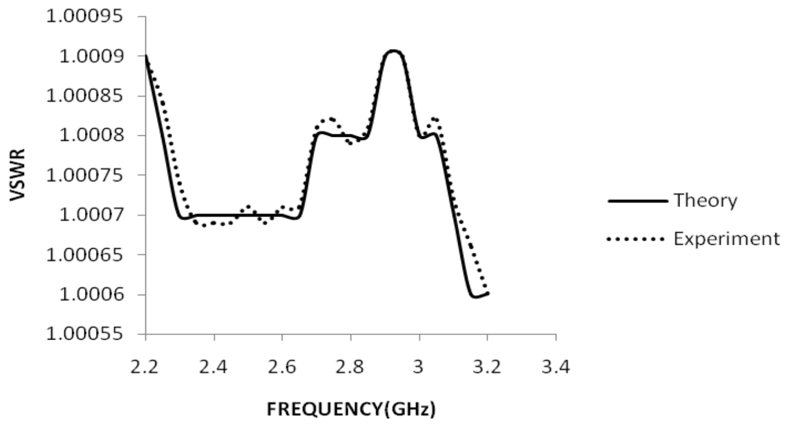


(c)

Fig 5: Variation of Coupling with frequency for 2W=0.3cm, a=3.4036cm, b=7.2136cm at (a) θ=30^0, (b) 45^0 and (c) 60^0 respectively



(a)



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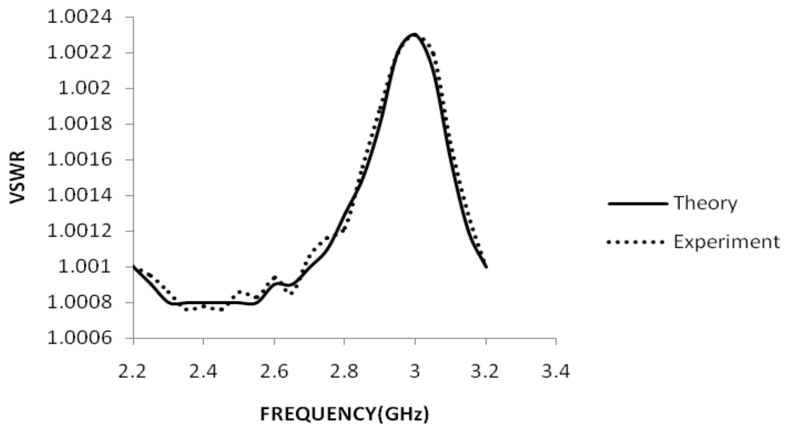

(c)

Fig 6: Variation of VSWR with frequency for 2W=0.3cm, a=3.4036cm, b=7.2136cm at (a) θ=30^0, (b) 45^0 and (c) 60^0 respectively.

VII. CONCLUSION

Results of the analysis reveal that it is possible to obtain resonance at f =3 GHz in the junction having a waveguide with internal dimensions a=3.4036cm, b=7.2136cm.It is clear from the results there is excellent agreement between theoretical and experimental results on coupling and VSWR round resonance. There exists a deviation at frequencies far away from resonance. Resonant conductance has been brought down to the order of 0.005 by suitable reduction of slot inclination. The conductance is quite high compared to susceptance, further reduction in g_r has been achieved by increasing the broad dimension of the feed waveguide.

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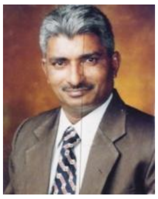
BIOGRAPHY

M. Murali received the Bachelor of Technology in Electronics and Communication Engineering in the year of 1998 from Nagarjuna University and Master of Engineering in Control System from Andhra University College of Engineering (A) in the year 2000. Currently, he is working in BABA Institute of Technology and Sciences in the department of Electronics and Communication Engineering ,Visakhapatnam. His Research interests include Array Antennas, EMI/EMC and Soft Computing. He is a life member of SEMCE (India).



Dr. G.S.N. Raju received his B.E., M.E. with distinction and first rank from Andhra University and Ph.D. from IIT, Kharagpur. At present, he is the Vice – Chancellor of Andhra University and a Senior Professor in Electronics and Communication Engineering. He is in teaching and research for the last 30 years in Andhra University. He guided 28 Ph.D.s in the fields of Antennas, Electromagnetics, EMI/EMC and Microwave, Radar Communications, Electronic circuits. Published about 304 technical papers in National/ International Journals/ Conference Journals and transactions. He is the recipient of The State Best Teacher Award' from the Government of Andhra Pradesh in 1999, 'The Best

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Researcher Award' in 1994, 'Prof. Aiya Memorial National IETE Award' for his best Research guidance in 2008 and Dr. Sarvepalli Radhakrishnan Award for the Best Academician of the year 2007, He was a visiting Professor in the University of Paderborn and also in the University Karlsruhe, Germany in 1994. He held the positions of Principal, Andhra University College of Engineering (A), Visakhapatnam, Chief Editor of National Journal of Electromagnetic Compatibility. Prof. Raju has published five textbooks Antennas and Wave Propagation, Electromagnetic Field Theory and Transmission Lines, Electronics Devices and Circuits, Microwave Engineering, Radar Engineering and Navigational Aids. Prof. Raju has been the best faculty performer in Andhra University with the performance index of 99.37%.