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Research Article

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Intensive study report and Modeling of Waveguide Coupled Microstrip Patch Antenna Using Effective Fringing Area and Parallel Loading Method

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ABSTRACT

An entirely new technique has been designed to couple the advantages of both the microstrip patch antenna and rectangular waveguide. Patch antenna consists of two patches, one radiator patch which faces outside, and the other faces mouth of the rectangular waveguide. Antenna parameters like return loss, gain, bandwidth, polarization and radiation pattern were studied in detail by changing geometrical features of antenna like length of patch facing waveguide side, by varying the feed point distance that is the distance from the corner of rectangular patch to centre of the circular patch, by different orientation of circular patch from the corner of rectangular patch where it is connected to radiating side circular patch through PTH(plated through hole),by placing the patch on different points on the rectangular patches. The obtained results were discussed in detail and explained. In part 2 detail mathematical analyzing steps were discussed. In part 3 moment's method along with its application to waveguide coupled microstrip patch antenna discussed In this paper a new mathematical tool is worked out which explains the observed the return loss graph effectively. This tool is called effective fringing area method. First we considered here waveguide coupled Microstrip patch antenna as the parallel load comprising of four elements .Along with this observed return loss graph and radiation pattern graph is provided.

Key words: Waveguide coupled microstrip patch antenna, effective fringing method

INTRODUCTION

In many wireless communication systems there is a requirement for low –profile antennas. The reason is that these antennas are less obstructive than traditionally used parabolic reflector. In addition, snow, rain, or wind has less effect on their performance. Microstrip patch antennas are an example of low profile antenna. In order to make this patch antenna an effective radiator, patch has to be suitably fed. Different methods can be used to achieve this goal. To couple power from the feed network to the patches different coupling mechanisms can be employed. One possible way is to a direct connection between feed network and the patches by employing the edge feed method [1]. One disadvantage of this method is that the feed network appears in the same layer as in the radiating elements, and produces residual radiation. Alternative to the edge feed are co-axial probes and electromagnetically coupled microstrip lines. The coaxial probe requires a hybrid connection is unattractive in large arrays, as it is labour intensive to implement.

The electromagnetic coupling (em) coupling methods include proximity coupling and aperture coupling from microstrip or strip line to the patches. One drawback of the aperture coupled microstrip patch antenna is its backward radiation, due to slots (aperture) in the ground plane [2]. In addition to this all these methods of coupling suffer from poor power handling capacity and poor band width.

In this paper, a new design of waveguide coupled microstrip patch antenna is proposed, which incorporates attractive features of microstrip antenna like low in profile, light weight, compact and conformable in structure, easy to fabricate and good features of waveguide, like high power handling capability, lower losses (resistive), frequency and band pass response stability, ease of tuning after manufacture and robustness. For the proposed patch earlier works were referred [3-6].The radiating patch in the proposed design is a simple circular patch. The proposed patch antenna has two patterns on either side. One is radiating patch which is circular which faces outside and the other which faces mouth of the waveguide plays an important role in the designing of the patch antenna. Here first we want to present mathematical formulas with comparison graph for 2results .Patch no 19 is taken for demonstration. It has four dips in return loss graph. But when 10 db is considered for valuation of band width all the four peaks will be in one band thus increasing band with more than 1GHz. For analyzing parallel load modelling is described along with all the formulas .Next effective area fringing method is described. Results obtained from effective area fringing method are plotted for comparison.

BEGINNING OF THE STUDY

Since this is new type of antenna so information is nowhere in the literature, so work started as to know whether such type of antenna can radiate. For this lot of antennas with various kinds of patches tried. One thing observed that radiation is much affected by the patches on the waveguide side. In this study microstrip is made up of double sided glass epoxy printed circuits board. The size of patch is such that it fits perfectly on the face of the waveguide matching all the four holes. It has two patches, one on the radiating side and the other on the waveguide side. Lots of literature is available for radiating side patches of various shapes. In this work circular patch is selected for the construction of the waveguide coupled microstrip patch antenna. Literature is not available for the other side of the patch which is facing mouth of the waveguide. So we started with various shapes of patches on the waveguides side and in one type very interesting result observed. That patch was rectangular shape which when searched further in literature came to know that it resembles that of iris type which was proposed by J.C.SLATTER [7], So in the further study this pattern was retained and the systematic study is performed on this type of waveguide coupled microstrip patch antenna.

Construction

Patch dimensions is 40.785mm x 40.73mm and cad points are (10, 10), (50.785, 10), (10, 50.73) and (50.78,50.73). Mounting hole co-ordinates is 30.90mm x 32.70 mm and cad points are (14.94,46.715), (44.845,46.71), (14.94,14.013) and(45.84,14.013). Waveguide dimension is 22.82mm x 10.016mm and cad points are (18.84,25.36), (41.66,25.36), (18.84,35.36) and (41.66,35.36). Iris type rectangular ring dimension is 7.60 mm x 7.32 mm and cad points are (26.69, 27.76), (33.01, 27.16), (26.69, 32.96) and (33.01, 32.96).The circular disk antenna mounting co-ordinates on radiating side of the patch is (26.68, 36.76).The radius of the circular disk patch antenna is 4.575mm.The feed point co-ordinates is (26.69, 32.96). The distance from feed point to centre of circular disk is 1.4mm.P.T.Hole diameter is 0.8mm. Preparation method is photo etching method.

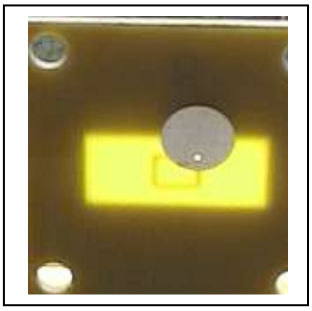

Fig. 1Radiating side of antenna

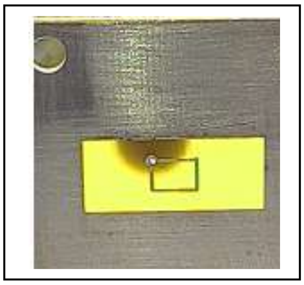

Fig. 2 Waveguide side of antenna

Microstrip antenna was constructed for 10 GHz. For this frequency duroid material was preferred, since this material is not freely available in India, double sided glass epoxy, and dielectric constant of 4.2 was used. Dimensions were taken from microwave hand-book. CAD software was used for designing microstrip patch antenna. Waveguide coupled microstrip patch antenna was prepared using PTH (plated through hole) method and both sides of the copper were tin coated. Thickness of the dielectric is 1.6 mm and copper thickness is 35 micron. Minimum line thickness possible is 0.25 mm.

Study Planning

The study was performed for five different geometries.

I. For different length (a’) and width (b’) of rectangular patch which faces the mouth of the waveguide.

II. For different feed point distances. It is the distance from the centre of the circular radiating patch to the left corner of the rectangular patch.

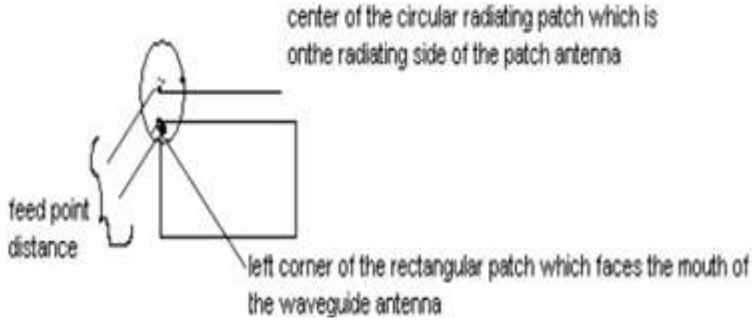

Fig. 3 Study planning 1and 2

III. For various orientation of radiating patch from the feed point. It is at the left corner of the rectangular patch.

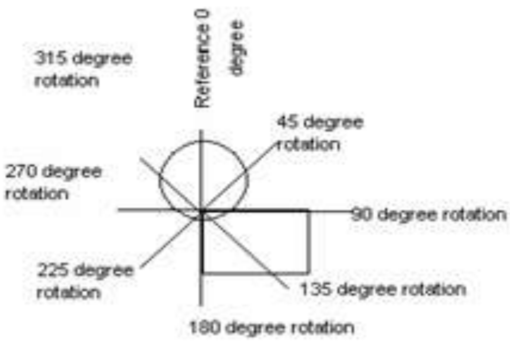

Fig. 4 Study planning 3

IV. For radiating patch placed at different locations on the rectangular patch.

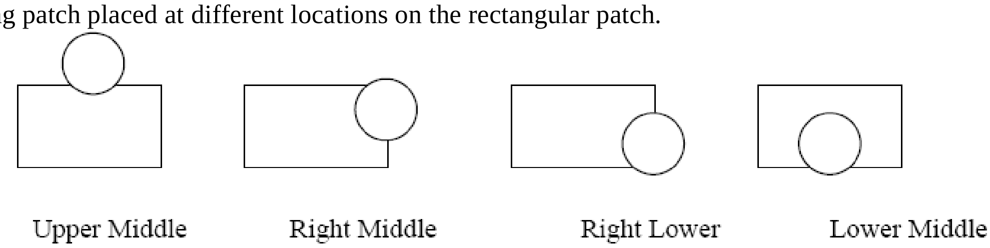

Fig. 5 Study planning 4

V. For various thicknesses of the rectangular sides of the rectangular patch.

Fig. 6 Study planning 5

EXPERIMENTAL SETUP

10GHz microwave bench (GUNN diode oscillator) is used for the study of waveguide-coupled microstrip patch antenna. The antenna is mounted on the mouth of the waveguide. Radiation pattern measurements were carried out with help of the horn antenna mounted on arm of the spectrometer. The readings were taken from the horizontal field for every 5 degrees using detector diode .The results were plotted on the polar graph. For return loss measurement, direction couplers of 3db each were used in reflectometer [8] method. For the entire measurement 0-20 micro ammeter used so that square law is obeyed. Totally 12 discrete frequencies were used. By varying micrometer of gunn diode 12 frequencies obtained (11.335GHz, 11.335GHz, 10.945GHz, 10.746GHz, 10.525GHz, 10.354GHz, 10.288GHz, 10.102 GHz, 9.9GHz, 9.741GHz, 9.716GHz, and 9.499GHz).

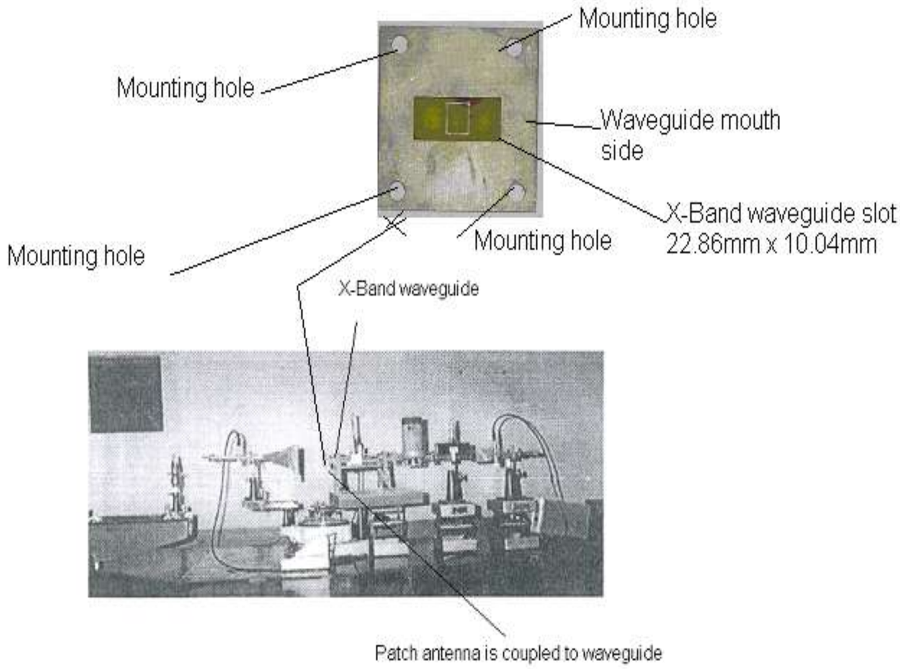

Fig. 7 Experimental Setup

Summary of Study Report

Study is performed as to find out how return loss varies for 29 patches grouped in five batches making each group varies in one parameter and the summary of the five group (10 patches)is presented here. Return loss is studied using the 3-db directional coupler.

Table - 1 Summary of Study Report

patch no.	length	Rotation	position	Feed point	Return Loss db	Band width	Polarization	Main peak
1	21.62	0^0	Left top corner	3.8mm	-48.3	2.29	vertical	90^0
19	7.6	0^0	Left top corner	3.8mm	-55.04	2.72	elliptical	90^0
22	15.62	0^0	Left top corner	3.8mm	-46.93	1.92	elliptical	90^0
6	5.7	0^0	Left top corner	3.01mm	-45.33	2.11	vertical	130^0
11	5.7	0^0	Left top corner	0.5mm	-43.79	1.48	vertical	125^0
3	5.7	45^0NE	Left top corner	3.8	-44.56	2.33	elliptical	75^0
8	5.7	90^0E	Left top corner	3.8	-44.19	2.33	elliptical	75^0
2	5.7	0^0	Right middle	3.8	-43.29	1.84	vertical	45^0
15	5.7	0^0	Lower middle	3.8	-41.83	1.21	elliptical	45^0
28	5.7	0^0	Right lower	3.8	-43.67	2.63	elliptical	75^0

Parallel Load Modeling

Patch is modelled as parallel loads in the waveguide. The admittance of the iris type rectangular patch, admittance of aperture and admittance of radiation patch are calculated using the formula .The rectangular ring pattern on the waveguide side is loaded as a resonant ring and the normalized susceptance B_f is given by the equation [9], igure of equivalent circuit of waveguide coupled microstrip patch antenna is shown below.

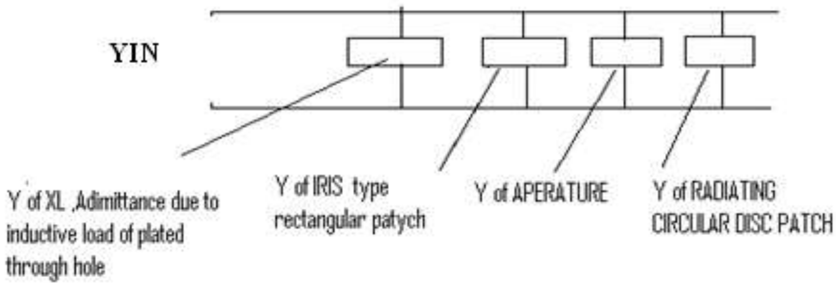

Fig. 8 Waveguide coupled microstrip patch antenna modelling as parallel loads

Y_{XL}=1/XL=admittance due to inductive load of plated through hole.

$$X_L = \left(\frac{377 \times h \times f \times \log\left(\frac{c}{\pi f r \sqrt{\varepsilon_r}} \right)}{c} \right) \qquad y(aparature) = \frac{3 \times a \times b \times \lambda_0}{16\pi r^3}$$

Y of Iris,

$$\boxed{\begin{aligned} B_f = {} & \left(\frac{-\lambda_g}{a} \right) \cot^2\left(\frac{\pi D}{2a} \right) + \left\langle \frac{\pi (a^2 - D^2)}{4AD\cos\left(\frac{\pi D}{2a} \right)} \right\rangle^2 \times \left\langle \frac{\left(1 - \frac{\lambda^2}{4D^2} \right)}{\left(1 - \frac{\lambda^2}{4a^2} \right)} \left(\frac{4bd}{\lambda_g a} \right) \ln \operatorname{cosec}\left(\frac{\pi d}{2b} \right) \right\rangle \\ & + \left(\frac{\lambda_g}{aD^2} \right) \left(\frac{b^2}{3} + \frac{d^2}{2} - \frac{8bd}{2} \right) - \left(\frac{2b^2}{\pi^2} \right) \sum_{n=1}^{\infty} \left(\frac{n\pi d}{b} \right) k \frac{\left(\frac{2n\pi (a-d)}{b} \right)}{n^2} \end{aligned}}$$

$$k(v) = \int_0^\infty dw k_0(u) du \cong e^{-v} \left(\frac{1+2v}{\pi} \right)^{-1/2}$$

Y of circular radiating disk antenna [10] $Y = \left[\frac{\frac{1}{R}}{1 + Q_T^2 \left(\frac{f}{f_r} \right)^2} \right]$

$$Q_C = \frac{h}{\pi \times f \times \mu_0 \times \sigma^{-1/2}} \qquad Q_D = \frac{1}{\tan\delta} \qquad Q_R = \frac{4 \times a \times (\alpha_{11}^2 - 1)\varepsilon r^{3/2}}{h \times \alpha_{11}^3 F\left(\frac{\alpha 11}{\sqrt{\varepsilon r}} \right)}$$

$$\frac{1}{Q_T} = \frac{1}{Q_R} + \frac{1}{Q_D} + \frac{1}{Q_C}$$

$$G_E = \frac{\pi \times 2.39}{4 \times h^2 \times \sqrt{\sigma (\pi \times f \times \mu_0)^{3/2}}} \qquad G_R = \frac{2.32}{4 \times \mu_0 \times h \times f \times Q_R} \qquad G_D = \frac{2.39 \times \tan\delta}{4 \times \mu_0 \times f \times h}$$

$$G_T = G_R + G_D + G_E$$

Where

Y = the admittance of the circular disk antenna, R = the input resistance, Q_T = the Quality factor, f=frequency , f_r= Resonant frequency, Q_R=Resistive Quality factor, Q_D=Dielectric Quality factor, Q_c=Conductance Quality factor , α_{11}=1.84118, ε_r=Dielectric constant 4.2, h= 1.6mm thickness of the substrate, tan δ=Dissipation, factor=0.001, σ =conductivity, μ_0=free space permeability, ρ=feed point distance(distance between the centre of the disk to feed point), $J_1(K\rho)$=Bessel function of the first order with argument(Kρ), $K=\omega\sqrt{\mu\varepsilon}$ propagation constant, G_T= Total conductance, G_R=Radiation, conductance, G_D=dielectric conductance, G_E=conductance due to copper loss

$F(x)=F(\alpha_{11}/ \sqrt{\varepsilon_r})$

$=2.666667378-1.066662519x^2 +0.209534311x^4-0.019411347x^6+0.001044121x^8-0.000049747x^{10},$

Effective Fringing Area Modelling

In this modeling admittance of circular patch is not calculated, instead nearest rectangle formed by the circular disc on the ground plane is considered for calculation. As full circular patch was not overlapping on ground plane fringing takes place only on those area of circular disk which is backed by ground plane. So fringing takes place by small area, and this fringing is responsible for radiation. Fringing takes place between the lower area of the circular patch and the ground plane. The calculation performed as in [11]. Fig. 9 indicates rectangle formed by considering the effective fringing area.

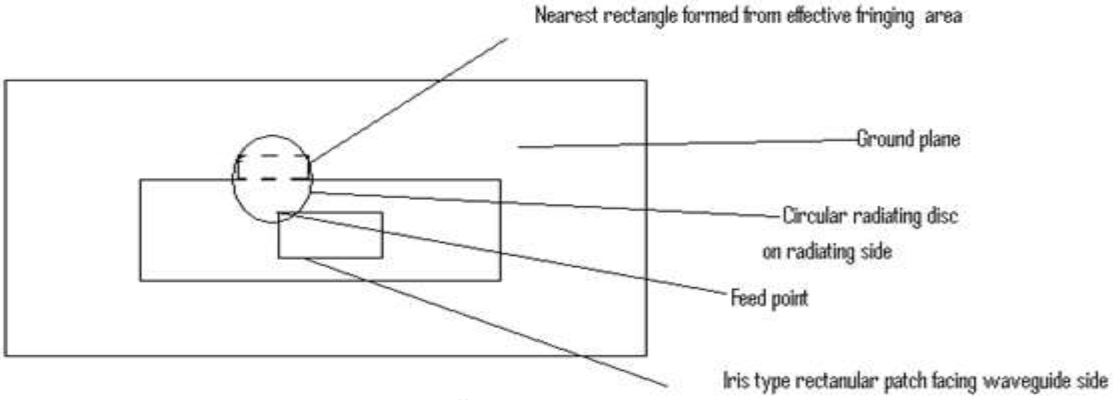

Fig. 9 Effective Fringing area method

Wall admittance [11]

$$Y_{WY} = Y_W = G_W = jB_W \qquad G_W = 0.00836\, W/\lambda_0 \qquad B_W = 0.01668 \frac{\Delta l}{h}\frac{W}{\lambda_0}\varepsilon_e$$

$$\varepsilon_e = \left(\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12 \times h}{W}\right)^{-\frac{1}{2}}\right) \qquad \frac{\Delta l}{h} = 0.412\left(\frac{\varepsilon_e + 0.3\left(\frac{W}{h} + 0.264\right)}{\varepsilon_e - 0.250\left(\frac{W}{h} + 0.8\right)}\right)$$

These formulas were used to calculate the return loss graph for all the 12 discrete frequencies and graph is plotted. In patch no 19 it matches exactly with the observed data. The observed return loss is -55.04db. The calculated return loss is -29.34 db. The outline of waveguide coupled Microstrip antenna is shown below along with the comparison graph of return loss.

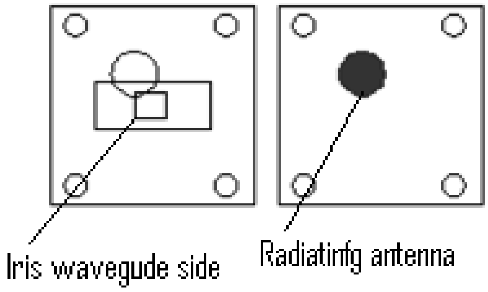

Fig. 10 Waveguide Coupled microstrip patch

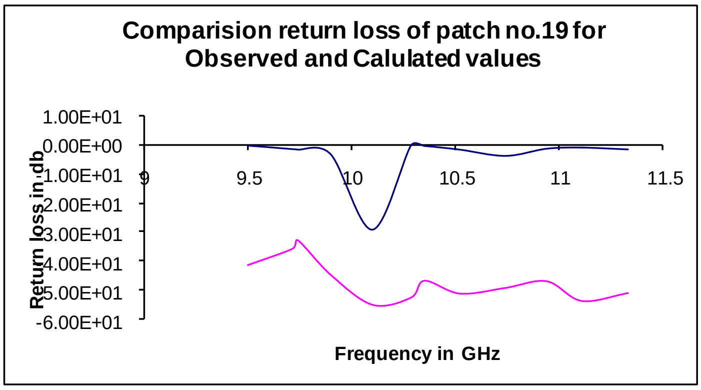

Fig. 11 Return loss graph for observed and calculated values

CONCLUSION

Successfully tested the new kind antenna called waveguide coupled microstrip patch antenna Study revealed that by changing the geometry we can change the important parameters like radiation loss , polarization, bandwidth and alter the main beam position. This opens new area of research using the available microwave bench. Now we can proceed to part 2 for detail mathematical analyzing. Effective fringing area method yields very good results .In patch no 19 both results were 10.102GHz whereas for other three it is in 10% variation .So this method can be used for analyzing of waveguide coupled microstrip patch antenna. For more accuracy moment's method tried using Prof. K. A. Michalsky formula.

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