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A Novel Technique for Higher Bandwidth: Waveguide Coupled Microstrip Patch Antenna

Sahana K
PG Department of Physics
SDM College (Autonomous), Ujire
Karnataka, India

Nandkumar M Shetti
PG Department of Physics
SDM College (Autonomous), Ujire
Karnataka, India

***Abstract*— A new technique is developed to couple the advantages of both the microstrip patch antenna and rectangular waveguide. A rectangle is used as radiating patch. This patch is fabricated on one face of a single layer dielectric substrate with double sided copper clad coated with tin and on the other face a rectangular patch is fabricated which resembles as iris. Antenna parameters like return loss, gain and bandwidth are studied for circular patch. The results obtained are discussed in detail and explained. Matlab PDE toolbox is used to generate two dimensional meshes. These meshes are converted into three dimensional form using sub domain numbers. RWG basis functions are used for MoM to calculate impedances. Reflection coefficient and two dimensional current (2D current) are obtained using the complex impedances.**

Keywords*— waveguide coupled microstrip patch antenna, 2D current, iris type rectangular patch.

I. INTRODUCTION

The rapid advancement in the wireless communication led to the development of more efficient antenna. Microstrip patch antennas are increasing in popularity for use in wireless applications. However, the main disadvantage of microstrip antennas is the narrow bandwidth and low gain. Different feeding techniques are used to overcome the problem of narrow bandwidth. In this study, waveguide coupling technique is used for improving the bandwidth. Waveguide Coupled Microstrip Patch Antenna (WCMPA) [1] consists of two patches, one radiating patch which faces open air and the other faces the open end of the rectangular waveguide. WCMPA incorporates attractive features of microstrip antenna like low profile, light weight, compact and conformable in structure, easy to fabricate and it also possesses good features of waveguide, like high power handling capability, lower losses (resistive). In this technique microstrip antenna is directly mounted on the mouth of the waveguide. Because of this maximum energy is radiated. The patch on the mouth of the waveguide which is of rectangular ring shape acts as a matching load to absorb maximum energy.

II. WAVEGUIDE COUPLED MICROSTRIP PATCH ANTENNA

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. The literature reveals a rectangular slot which resembles an iris type radiator which was proposed by J. C. SLATTER [2], so for further study this pattern was retained and the systematic study is performed on this type of waveguide coupled microstrip patch antenna. In this paper circular shaped patch is used as a radiating element.

III. CONSTRUCTION

The outer dimension of the patch is 40.785mm x 40.73mm and the corresponding CAD corner points are (10, 10), (50.785, 10), (10, 50.73) and (50.78, 50.73). There are four mounting holes, the centers of these form a rectangle of dimension 30.90mm x 32.70 mm and the corresponding 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 of its corner 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 5.7mm and 4.14 mm and CAD points are (27.39, 28.29), (33.09, 28.29), (27.39, 32.43) and (33.09, 32.43). The circular disk antenna mounting co-ordinates are (27.39, 31.90). The radius of cicular disk is 4.575mm. The feed point co-ordinates are (27.39, 32.43). P. T. hole diameter is 0.8 mm. Photo etching method is use for preparing this antenna. Microstrip antenna is constructed for 10GHz. For this frequency duroid material was preferred, but we used double sided glass epoxy of dielectric constant of 4.2. CAD software was used for designing microstrip patch antenna. Thickness of the dielectric is 1.5mm and copper thickness is 35micron. Minimum line thickness possible is 0.25mm. Fabricated antenna photographs are shown in Fig.1.

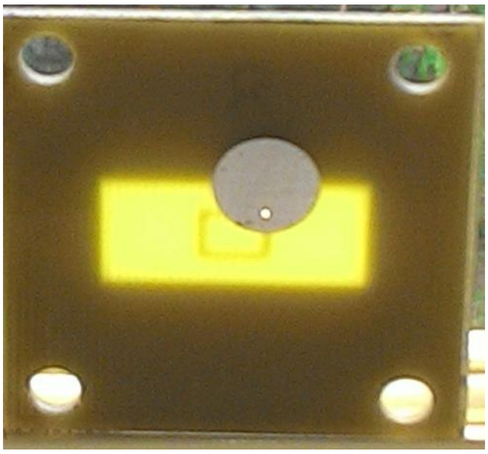

Fig.1. Radiating side of constructed waveguide coupled microstrip patch antenna.

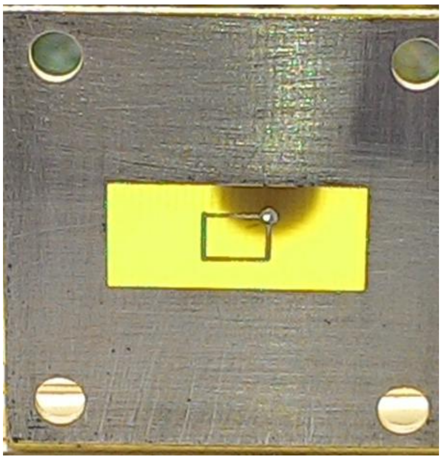

Fig.2. Waveguide side of constructed waveguide coupled microstrip patch antenna.

IV. EXPERIMENT

Experimental setup is shown in the following figures. Fig. 3 shows a horn antenna used for radiation pattern measurement. Here (Fig. 4) reflectometer is used to find out return loss [3]. The experiment is carried out using Voltage Controlled Oscillator (VCO) source for 8-12GHz.

Fig.3. Experimental setup for Radiation Pattern measurement.

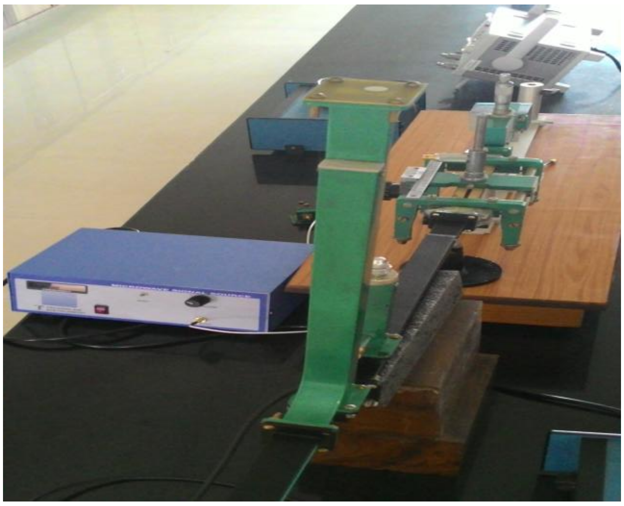

Fig.4. Experimental setup for Return loss measurement using Reflectometer technique.

V. ANALYSIS

For analyzing this kind of antenna we assume that microwave travels in the waveguide in zig-zag passion at the centre of the waveguide. This microwave falls on the IRIS shaped rectangular patch. This IRIS acts as a filter and absorbs microwave energy and feed to the feed point. Method of moments is used for the analysis of this waveguide coupled microstrip antenna.The total electric field on the waveguide coupled microstrip patch antenna is given by the following expression.

$$E = E^a + E^s \tag{1}$$

Where E is the total electric field, E^a is the applied electric field and E^s is the scattered field. Because of infinite conductivity the tangential component of electric field is zero.

$$E_{tan} = 0 = E^a + E^s \tag{2}$$

Here E^s is due to the vector and scalar potentials. The vector potential is due to the current density on the patch antenna and the scalar potential is due to the charges. The scattered electric field is given by the equation

$$\vec{E}^s = -j\omega\vec{A}_M(\vec{r}) - \nabla\emptyset_M(\vec{r}) \tag{3}$$

Where $(\vec{r})$ on S, magnetic flux density is given by,

$$\vec{B} = \nabla \times \vec{A} \tag{4}$$

The scalar potential due to charges and vector potential due to current density are given by the following equations.

$$\emptyset(\rho) = \int_S G_V(\rho) q_S(\rho) ds \tag{5}$$

$$\vec{A}(\vec{\rho}) = \int_S G_A(\rho) \vec{J}_S(\vec{\rho}) ds \tag{6}$$

Now the applied electric field is given by

$$E^a = (j\omega\vec{A}_M + \nabla\emptyset_M)_{tan} \tag{7}$$

where $(\vec{r})$ on S.

The general formula for method of moments [4] is given by

$$L(J) = V \tag{8}$$

Here L is a linear operator representing the integrodifferential operator, J is the unknown current distribution and V is the voltage excitation.

The current distribution in an antenna is the sum of a set of N different current distributions or basis functions is given by

$$J = \sum_{n=1}^{N} I_n f_n(r) \tag{9}$$

Where N is the total number of basis functions $f_n(r)$ and I_n the unknown weighting coefficient for the n^{th} basis function. Hence the excitation voltage is given by

$$\sum_{n=1}^{N} I_n L(f_n(r)) = V \tag{10}$$

The inner product is defined as

$$\langle f_m(r), f_n(r)\rangle = \int_S f_m(r) f_n(r)\, ds \tag{11}$$

Where $f_m(r)$ is the test function.

Applying the inner product we get

$$\sum_{n=1}^{N} I_n \langle f_m(r), L(f_n(r))\rangle = \langle f_m(r), V\rangle \tag{12}$$

This equation can be written as

$$ZI = V \tag{13}$$

Where

$$I = \sum_{n=1}^{N} I_n \tag{14}$$

$$V = \langle f_m(r), V \rangle \tag{15}$$

and

$$Z = \sum_{n=1}^{N} \langle f_m(r), L(f_n(r)) \rangle \tag{16}$$

The testing function when applied to our patch we get the equation

$$\vec{f}^M_{m.} \vec{E}^a \, ds = j\omega \int_S \vec{f}^M_m . \vec{A}_M \, ds - \int_S (\nabla . \vec{f}^M_m) \emptyset_M \, ds. \tag{17}$$

According to Stokes theorem,

$$\int_S \nabla \emptyset_M . \vec{f}^M_m ds = -\int_S \emptyset_M (\nabla . \vec{f}^M_m) ds. \tag{18}$$

The vector potential is given by

$$\vec{A}_M(\vec{r}) = \frac{\mu_0}{4\pi} \int_S \vec{J}_M g ds' \tag{19}$$

Where μ_0 is the permeability in vacuum and $g = e^{\left(-\frac{jkR}{R}\right)}$, $R = |\vec{r} - \vec{r}'|$, is the free space Green's function,

$$\vec{J}_M = \sum_{n=1}^{N_M} I_n \vec{f}^M_n . \tag{20}$$

By substituting the value of $\vec{J}_M$ in $\vec{A}_M$ we get,

$$\vec{A}_M(\vec{r}) = \sum_{n=1}^{N_M} \left\{ \frac{\mu_0}{4\pi} \int_S \vec{f}^M_n (\vec{r}') g ds' \right\} I_n . \tag{21}$$

Similarly scalar or electric potential is given by

$$\emptyset_M(\vec{r}) = \frac{1}{4\pi\epsilon_0} \int_S \sigma_M g ds' \tag{22}$$

$$j\omega\sigma_M = -\nabla_S . \vec{J}_M \tag{23}$$

Where σ_M can be expressed as current density and hence electric potential becomes

$$\emptyset_M(\vec{r}) = \sum_{n=1}^{N_M} \left\{ \frac{1}{4\pi\epsilon_0} \frac{j}{\omega} \int_S \nabla . \vec{f}^M_m (\vec{r}') ds' \right\} I_n \tag{24}$$

According to moments method current distribution can be find out from the matrix equation.

$$\sum_{n=1}^{N_M} Z^{MM}_{mn} I_n = v^M_m \tag{25}$$

Where $m = 1, \ldots, N_M$

$$v^M_m = \int_S \vec{f}^M_m . \vec{E}^a ds \tag{26}$$

In our present work we used Matlab PDE toolbox for 2-D generation of triangular mesh. Then using Delaunay function this mesh is converted into 3-D form and triangulation is obtained by the function trimesh. The total number of triangles obtained here is 1850. The area, center and edges of all the triangles are calculated [5]. For RWG basis function calculations, we made 2702 plus and minus triangles [6]. Edge lengths of common edges plus and minus triangles are ranges from 0.0010 to 5.164. Using barycentric subdivision the plus and the minus triangles are divided into 9 subtriangles. Using the edge length (subtriangle), centers of all 9 triangles are calculated. Then free vertexes of all plus and corresponding minus triangles are calculated by comparing all the three vertices of plus triangle with minus triangle. $\vec{\rho}^{\,+}$ and $\vec{\rho}^{\,-}$ are obtained by taking the difference between free vertex and center of all plus and minus triangles. The Green's function is calculated by using the distance between free vertex and center of 9 subtriangles. To find Z inner product expansion for both plus and minus triangles is given by the following expression:

$$\iint_S \vec{f}^M_m \vec{f}^M_n g ds' ds$$

$$= + \frac{l_m l_n}{4A^+_m A^+_n} \int_{t^+_m} \int_{t^+_n} \left(\vec{\rho}^{\,+}_m . \vec{\rho}^{\,\prime +}_n\right) g ds' ds + \frac{l_m l_n}{4A^+_m A^-_n} \int_{t^+_m} \int_{t^-_n} \left(\vec{\rho}^{\,+}_m . \vec{\rho}^{\,\prime -}_n\right) g ds' ds$$
$$+ \frac{l_m l_n}{4A^-_m A^+_n} \int_{t^-_m} \int_{t^+_n} \left(\vec{\rho}^{\,-}_m . \vec{\rho}^{\,\prime +}_n\right) g ds' ds + \frac{l_m l_n}{4A^-_m A^-_n} \int_{t^-_m} \int_{t^-_n} \left(\vec{\rho}^{\,-}_m . \vec{\rho}^{\,\prime -}_n\right) g ds' ds \tag{26}$$

and

$$\iint_S (\nabla . \vec{f}^M_m)(\nabla . \vec{f}^M_n) g ds' ds$$

$$= + \frac{l_m l_n}{4A^+_m A^+_n} \int_{t^+_m} \int_{t^+_n} g ds' ds + \frac{l_m l_n}{4A^+_m A^-_n} \int_{t^+_m} \int_{t^-_n} g ds' ds + \frac{l_m l_n}{4A^-_m A^+_n} \int_{t^-_m} \int_{t^+_n} g ds' ds$$
$$+ \frac{l_m l_n}{4A^-_m A^-_n} \int_{t^-_m} \int_{t^-_n} g ds' ds \tag{27}$$

In this equation the double integration is performed by summing the required values of all the triangles. Current is calculated by matrix inversion method. Now the impedance for different frequencies is calculated and return loss graph is plotted. Radiation pattern is obtained by summing the currents of each triangle in different angles.

VI. RESULT AND DISCUSSION

Return loss obtained using Matlab for our waveguide coupled microstrip patch antenna is -40dB for a resonant frequency of 10.5GHz. The experimentally observed result is -41dB for a resonant frequency of 10.5GHz. The radiation peak observed at 80degree and experimental result is at 90degree.

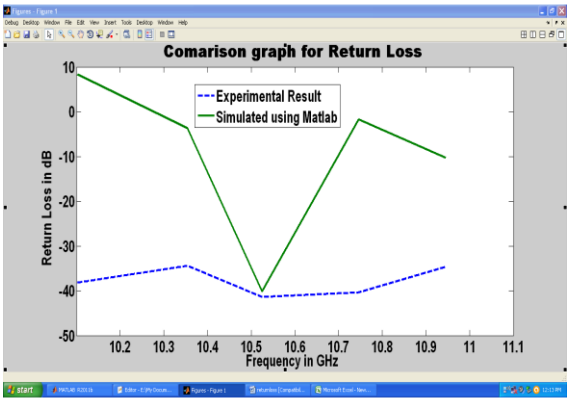

Fig.5. Experimentally observed and Matlab simulated Comparison graph of Returnloss.

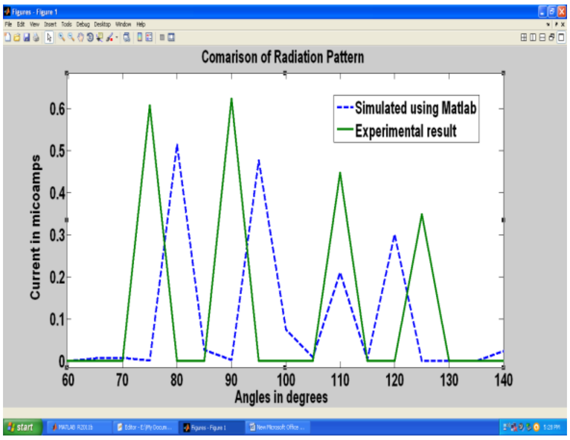

Fig.6. Experimentally observed and Matlab simulated Comparison graph of Radiation Pattern.

Fig.7. Mounting of Waveguide Coupled Microstrip Patch Antenna to waveguide to coaxial adopter.

VII. CONCLUSION

Simulated result from Matlab is in agreement with the experimentally observed result. However there is a small discrepancy in the simulated result because of our assumption. In further work this problem will be solved using Sommerfeld integral and Floquet series.

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