2D FEM Analysis of Microstrip Circular Patch Array Antenna

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***Abstract*: In this paper the attempt has been made to design and analyze microstrip circular patch array antenna using finite element method. The aim is to compute all design parameters like capacitance, energy density, potential distribution etc. of MCPAA by using latest finite element tool. The simulation work has been carried out with the help of FEM based complete design Quick Field software. The Microstrip patch antenna is the main choice of antenna designers due to its easy fabrication, light weight and compact designs. To improve the design further, adaptive mesh refinement technique is applied to achieve more accurate two dimensional results.**

Keywords : Adaptive Mesh Refinement, Field Strength , Finite Element Method (FEM), Microstrip Circular Patch Array Antenna (MCPAA) .

I. INTRODUCTION

With the increased use of communication technology, many efforts were made for the advancement and miniaturization of the antennas. This paper is dedicated to one of the advanced antenna. The main aim of this paper is to compare the voltage distribution of the microstrip circular patch array antenna with and without dielectric [6]. A circular patch, made of copper material having very small thickness is placed in the isotropic and homogeneous medium. The thickness of the conductor has been taken very small just to radiate the signal with low distortion. In this work, we design two models of MCPAA i.e. with dielectric and without dielectric, using FEM with Quick Field simulation software. The capacitance value for the patch conductor is considered to be significant in designing advance integrated circuits in order to optimize the electrical properties of the integrated circuits [5]. Capacitance can also help to optimize the layout of circuit.

II. FE MODEL OF MCPAA

Finite Element Method is best suited method for the analysis of the microstrip circular patch array antenna [2]. This method is processed in three stages: Pre-processing, Processing and Post-processing. In Pre-processing the whole structure is divided into sub domains, which are called finite elements and the field equations are applied to each of them. In Processing the FEM are basically based on determination of the distribution of electric and magnetic fields in the structures. In Post-processing primary simulation results give the values for the electric potential and field gradient. And other parameters like field strength, energy density etc. can be calculated as secondary post-processing results. The models of microstrip circular patch array antenna are designed under electrostatics in Quick Field simulation software. Quick Field is an interactive environment for electromagnetic, thermal and stress analysis. It facilitates all steps in the designing of an electromagnetic model from defining geometry to visualizing results.

There are some parameters which are used in the modeling of microstrip circular patch array antenna.

The characteristic Impedance of lossless circular patch conductor is [1].

$$Z = 1\big/ v\sqrt{CC_0} \qquad \dots (1)$$

Z= Characteristic Impedance of the patch

C= Capacitance per unit area of the circular patch when substrate is replaced with air

C_0= Capacitance per unit area of the circular patch when dielectric substrate is in place

v= Speed of light in vacuum

Velocity of propagation can be defined in terms of inductance per unit area and capacitance per unit area.

$$V_p = 1/\sqrt{LC} \qquad \dots (2)$$

Now phase velocity for the air dielectric transmission conductor, where the velocity must be the speed of light.

$$v = 2.998 \times 10^8 \ m/\sec$$

By using this value of v in above equation, then equation becomes

$$v = 1/\sqrt{LC_0} \qquad \dots (3)$$

If all materials are non magnetic, then

$$L = 1/v^2 C_0 \qquad \dots (4)$$

We know,

$$Z_0 = \sqrt{L}/\sqrt{C} \qquad \dots (5)$$

Substituting the value of L in eqn. (5)

Then,

$$Z_0 = v\sqrt{CC_0} \qquad \dots (6)$$

2D cross-sectional electrostatic solver is used to compute the capacitance.

A. Analysis of Microstrip Circular Patch Array Antenna

The circular patch used in the antenna is made of copper material. In this model, dielectric medium is air, so the value of relative permittivity is 1.

Air:
Relative Permittivity (ε_r) = 1 F/m
Conductivity (s) = 0 S/m

Conductor Material:
Relative Permittivity (ε_r) = 1 F/m
Conductivity (s) = 5.8×10^7 S/m

These values have been taken for the circular patch elements of the array.

d = Diameter of the conducting circular patch=2mm
b = Width of the outer conductor (air) =10mm
a = Length of the outer conductor =10mm
Thickness of the patch conductor is negligible small.

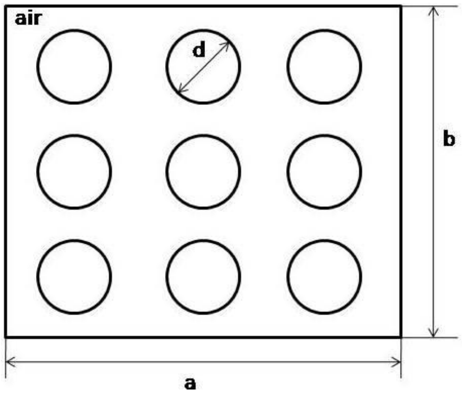

Figure 1. Cross Sectional Geometrical View of Microstrip Circular Patch Array Antenna

Geometry of the microstrip circular patch antenna shown in Fig. 1 is created by using the mentioned values.

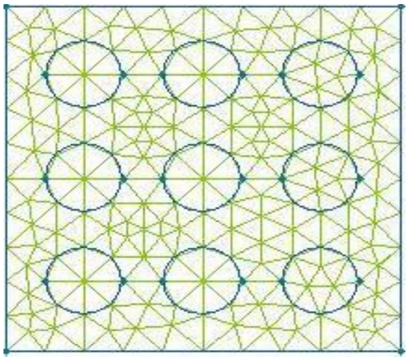

Figure 2. Meshing of Microstrip Circular Patch Array Antenna using 2D Mesh Elements

The 2D mesh has been generated by using triangular mesh elements as shown in Fig. 2. In the boundary settings, the outer conductor acts as a ground and circular patch as a port. Adaptive mesh refinement performs meshing after applying the boundary conditions.

B. Analysis of Microstrip Circular Patch Array Antenna with Dielctric Substrate

In this analysis of the antenna, a dielectric substrate of thickness 2mm is placed in outer conductor. The dielectric properties are:

Relative Permittivity (ε_r) = 8.8 F/m
Conductivity (s) = 0 S/m

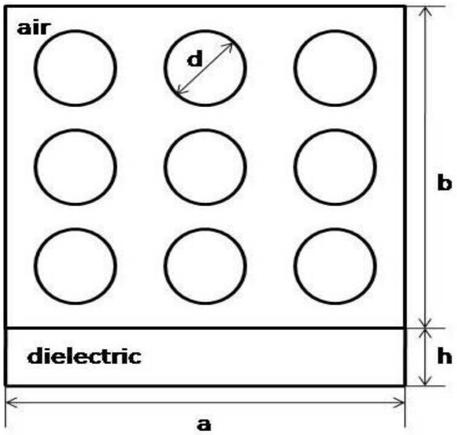

Figure 3. Cross Sectional Geometrical View of Microstrip Circular Patch Array Antenna with Dielectric

In Fig. 3, dielectric substrate of 2 mm thickness is placed under the circular patch conductor. Width of the dielectric substrate is equal to the outer conductor.

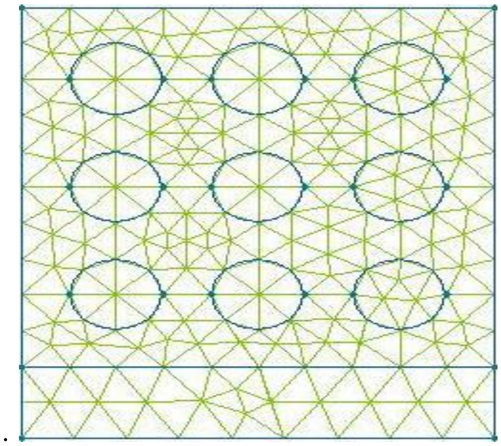

Figure 4. Meshing of Microstrip Circular Patch Array Antenna with Dielectric Substrate using 2D Mesh Elements

Fig. 4 shows the geometry of microstrip circular patch array with dielectric substrate . The geometry values for this are same as that of the microstrip circular patch array without dielectric substrate.

Now,
Capacitance per unit area is,
$C = Q/V_0$ F
Where Q is charge on one conductor in columbs per meter^2.
V_0 is the potential difference in volts.
Characteristic Impedancce is,

$$Z = 1/v\sqrt{CC_0} \qquad \text{.... (7)}$$

Transmission mediun is homogenenous. So, relative permittivity can be written as,

$$\varepsilon_r = C/C_0 \qquad \text{.... (8)}$$

$$C = \sqrt{\varepsilon_r}\,/\,cZ_0 \qquad \text{.... (9)}$$

Where C is the Capacitance per unit area of the microstrip circular patch conductor.

The Meshing Statistics recorded for both the models sre shown in Table 1.

Table I. Adaptive Meshing Refinement Statistics of Microstrip Circular Patch Array Antenna

Items	**Adaptive mesh refinement of Microstrip circular patch array antenna**	**Adaptive mesh refinement of Microstrip circular patch array antenna with dielectric**
Mesh Nodes	215	232
No. of Blocks	10	11
Vertices	22	26
Edges	22	25

III. SIMULATION RESULTS

A. *Surafce Voltage Distribution*

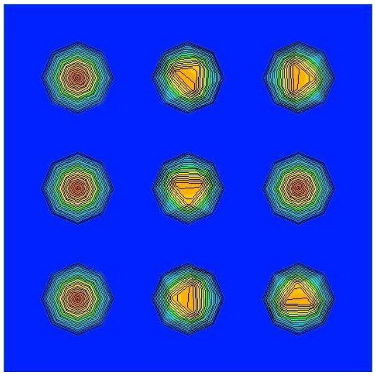
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Figure 5. 2D Surface Voltage Distribution of Microstrip Circular Patch Array Antenna

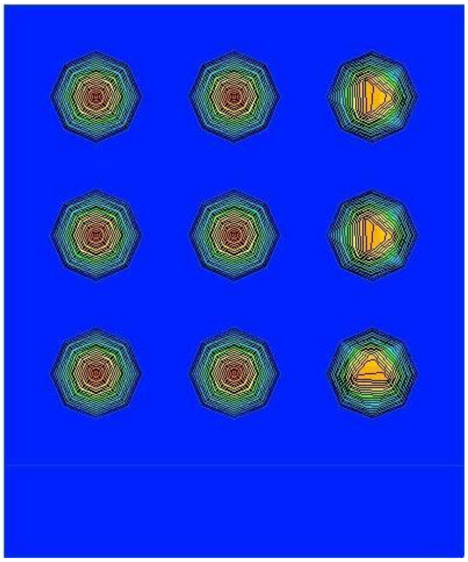

Figure 6. 2D Surface Voltage Distribution of Microstrip Circular Patch Array Antenna with Dielectric

The value of capacitance per unit area varies with dielectric substrate and with the Adaptive mesh refinement.

The Capacitance for both the models have been computed with coarse and fine mesh refinement is shown in Table 2.

Table II. Capacitance values with and without dielectric

Capacitance values	**With Dielectric**	**Without Dielectric**
With Mesh Refinement	0.71 pF	0.81 pF
Without Mesh Refinement	0.25 pF	0.127 pF

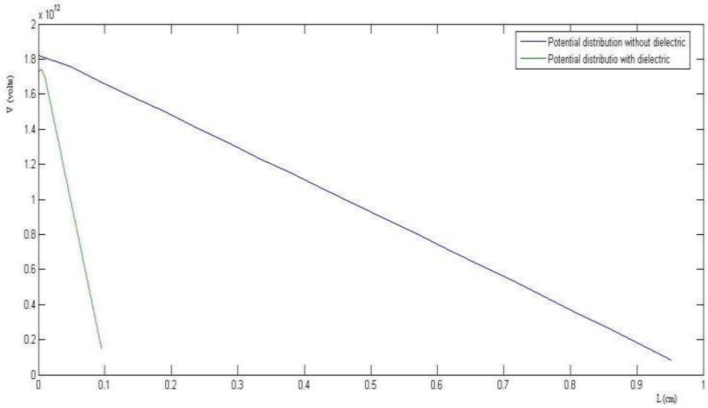

Figure 7. Surface Voltage Distribution of Microstrip Circular Patch Array Antenna without Adaptive Mesh Refinement

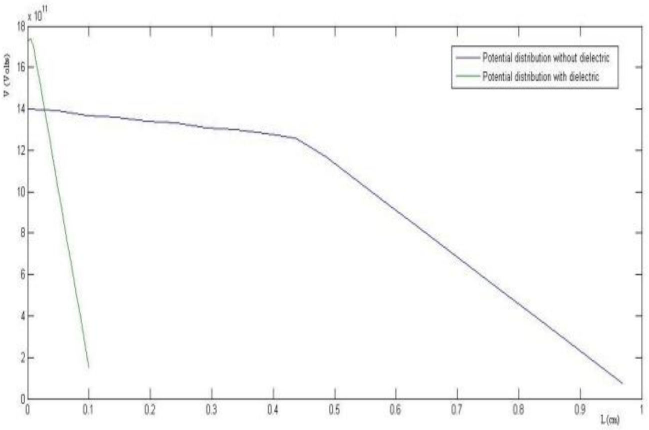

Figure 8. Surface Voltage Distribution of Microstrip Circular Patch Antenna with Adaptive Mesh Refinement

Fig. 5-8 shows the voltage distribution of the antenna. From these figures it has been noticed that surface voltage distribution of microstrip circular patch array antenna decreases linearly without adaptive mesh refinement. And for with adaptive mesh refinement, surface potential first decreases exponentially and then linearly. Table 3 shows the results of surface voltage distribution for both the models for with coarse and fine mesh refinement technique respectively.

Table III. Surface Voltage Distribution of Antenna

Surface Voltage distribution	**With Dielectric**	**Without Dielectric**
Without Mesh Refinement	1.41×10^{12} V	1.39×10^{12} V
With Mesh Refinement	1.82×10^{12} V	1.80×10^{12} V

B. Field Gradient of Antenna

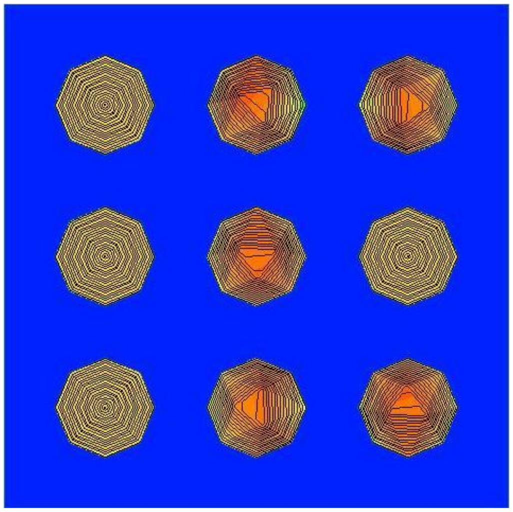

Figure 9. Field Gradient Color Map of Microstrip Circular Patch Array Antenna without Dielectric

Table IV. Field Gradient of Antenna

Field Gradient	**With Dielectric**	**Without Dielectric**
With Mesh Refinement	1.99×10^{18} V/m^2	1.97×10^{18} V/m^2
Without Mesh Refinement	1.34×10^{18} V/m^2	1.34×10^{18} V/m^2

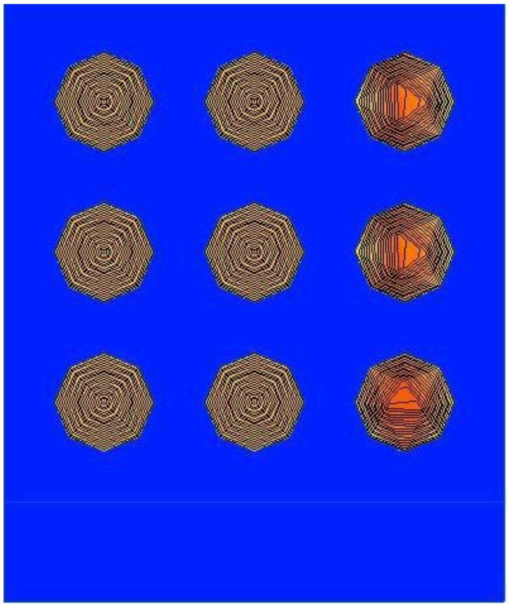

Figure 10. Field Gradient Color Map of Microstrip Circular Patch Array Antenna with Dielectric

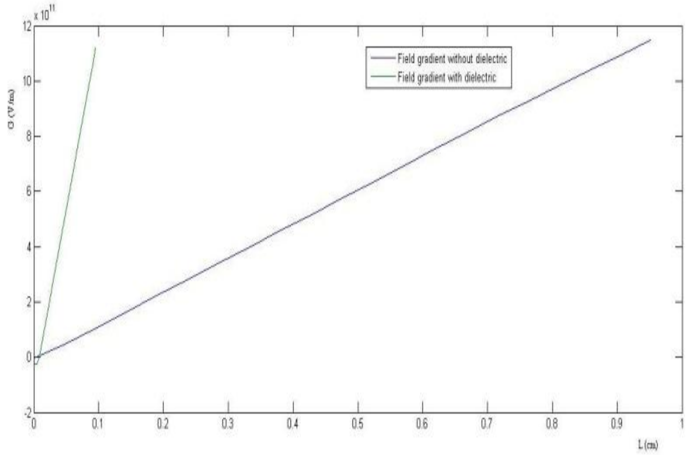

Figure 11. Field Gradient of Microstrip Circular Patch Array Antenna without Adaptive Mesh Refinement

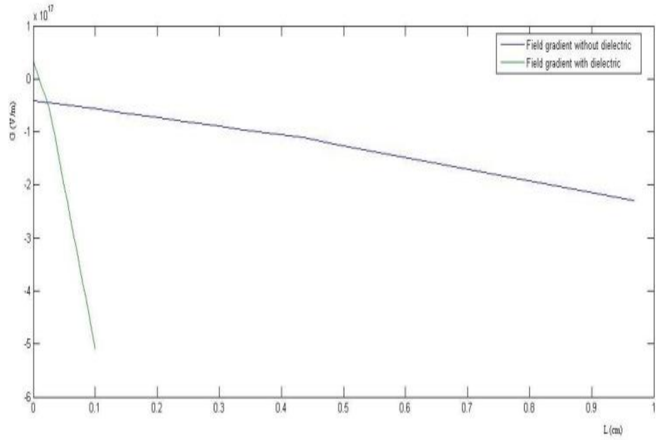

Figure 12. Field Gradient of Microstrip Circular Patch Array Antenna with Mesh Refinement

Fig. 9-12 shows the field gradient of microstrip circular patch array antenna with arc length. From these graphs we can conclude that field gradient remains constant without mesh refinement. It decreases when we apply the adaptive mesh refinement method. Table 4 shows the computed values for the field gradient for both the models of MCPAA.

C. *Energy Density of Antenna*

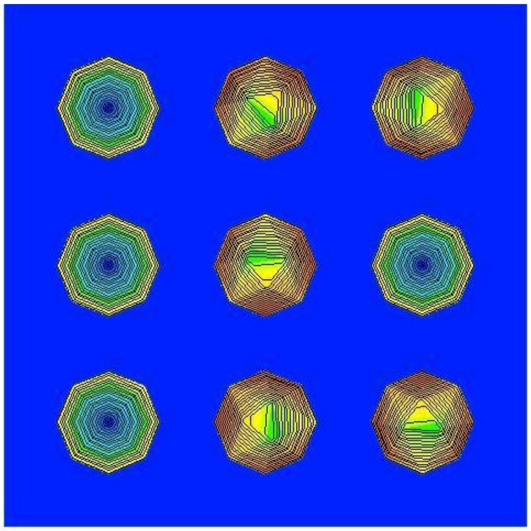

Figure 13. Energy Density Color Map of Microstrip Circular Patch Array Antenna without Dielectric

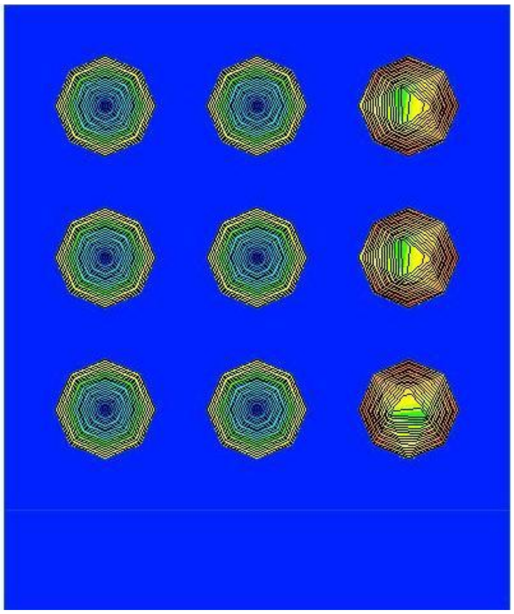

Figure 14. Energy Density Color Map of Microstrip Circular Patch Array Antenna with Dielectric

Table V. Energy density of the antenna

Energy Density	**With dielectric**	**Without Dielectric**
With Mesh Refinement	8.7×10^{18} V/m^3	1.16×10^{19} V/m^3
Without Mesh Refinement	6.31×10^{18} V/m^3	7.08×10^{18} V/m^3

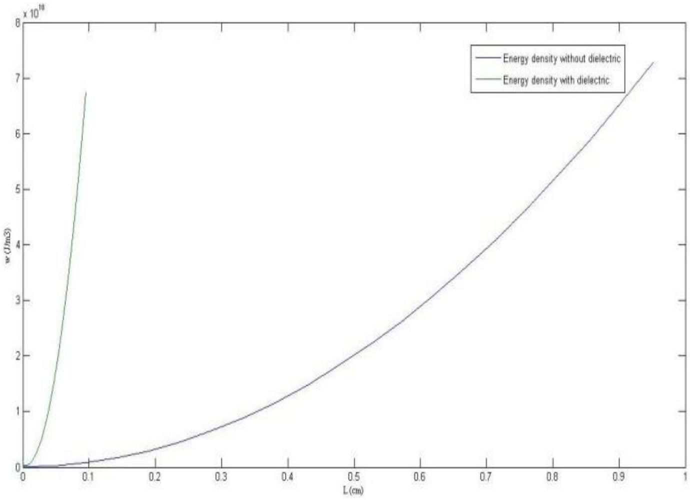

Figure 15. Energy Density of Microstrip Circular Patch Array Antenna without Adaptive Mesh Refinement

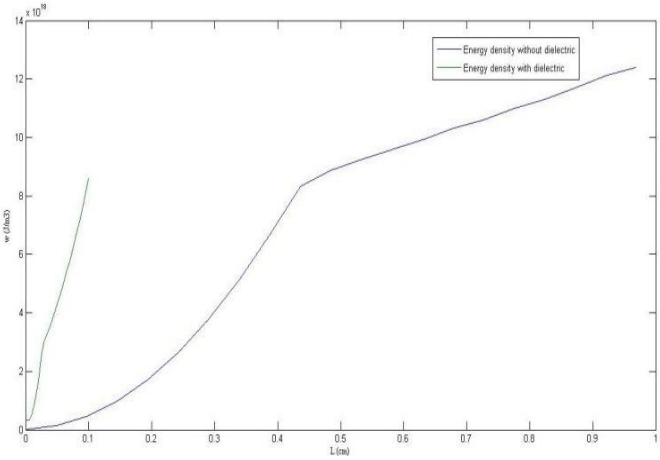

Figure 16. Energy Density of Microstrip Circular Patch Array Antenna with Adaptive Mesh Refinement

Fig.13-16 shows the energy density curve of microstrip circular patch array antenna. From these curves, we can conclude that energy density increases with the adaptive mesh refinement method. And energy density is more in non dielectric model. These statistics are shown in Table 5.

IV. CONCLUSION

In this work, two dimensional Quasi-static adaptive finite element analysis of MCPAA has been carried out. All the performance parameters like field gradient, energy density and capacitance computed as well as compared for both the models with and without dielectric respectively. The simulation results show the comparative analysis to design optimal model of MCPAA. It is found here that the surface voltage and field gradient are increased by 22.5% and 48.5 % respectively. The results are further improved by applying the adaptive mesh refinement technique on the models. The same analysis can be further applied to investigate the design parameters for different patch arrays. And the results can also be validated with real time working antennas to bring out more efficient design for better results.

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