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Title: **DESIGN AND ANALYSIS OF 2×2 CIRCULAR MICRO-STRIP PATCH ANTENNA ARRAY FOR 2.4 GHZ WIRELESS COMMUNICATION APPLICATION**

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DESIGN AND ANALYSIS OF 2×2 CIRCULAR MICRO-STRIP PATCH ANTENNA ARRAY FOR 2.4 GHZ WIRELESS COMMUNICATION APPLICATION

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Abstract:

This paper presents, design and analysis of 2×2 circular micro-strip patch antenna array on FR-4 epoxy substrate material thickness of substrate is 1.6 mm. The design of proposed antenna array, we are using FR4 Epoxy dielectric substrate material. The name "FR" stand for Flame Retardant and type 4 indicates Woven Glass reinforced Epoxy resin. The design of proposed antenna array using probe feeding technique. The 2 by 2 CMSPA array is designed for 2.4 GHz operating or resonant frequency, this 2.4 GHz frequency is suitable for WLAN applications. In order to design a micro-strip 2 by 2 circular patch antenna to operate at 2.4 GHz frequency range, even though there are various simulation software available, such as FEKO, IE3D, CST, HFSS …etc. the design and simulation of 2 by 2 CMSPA using High Frequency Structure Simulator (HFSS) software. The resonant or operating frequency of this paper presents at 2.4 GHz for wireless communications that provides S parameters (return loss), VSWR value, bandwidth and radiation pattern of rETotal, Total Gain and Dir Total and 3D polar plot of rETotal, Total Gain and Dir Total.

Index Terms— Micro-strip Patch Antenna, FR-4 Substrate, HFSS, WLAN, FEKO, IE3D, CST, VSWR and probe feed technique.

I.CIRCULAR MICRO STRIP PATCH ANTENNA ARRAY

Micro strip patch antennas patches are in diversity of shapes, such as rectangular, square, triangular and circulator, etc.

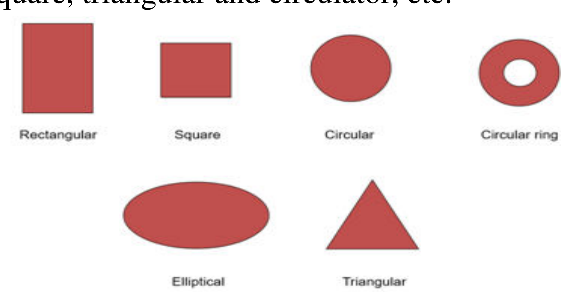

Fig 1: Common shapes of micro-strip patch elements

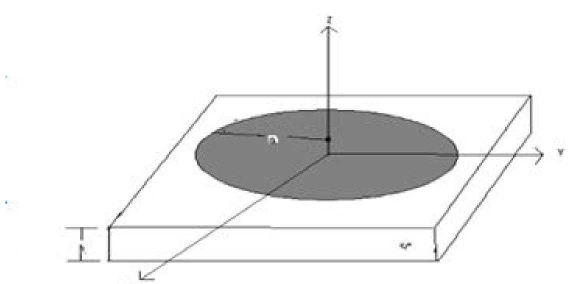

Fig 2: Circular patch antenna

The 2 by 2 configuration of the circular antenna is shown in figure 3. The antenna design consists substrate thickness 1.6 mm. the dielectric constant of the substrate is 4.4

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and antenna is fabricated on FR-4 material. In this paper, select the value of the substrate (FR-4) constraints relative dielectric constant (εr) to be 4.4 and the substrate thickness (h) to be 1.6 mm. Then, we determine the radius of the circular Patch antenna using the expression:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}}$$

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}$$

Hence, the operating frequency for the dominant TM_{110} is

$$(f_r)_{110} = \frac{1.8412 v_0}{2\pi a_e \sqrt{\varepsilon_r}}$$

Where v_0 = free space speed of light.

The 2 by 2circular micro-strip patch antenna design specifications are shown in below table.

PARAMETER	VALUE
Operating frequency	2.4 GHz
Substrate dielectric material	FR4 epoxy
Dielectric Constant	4.4
Substrate length	67.075 mm
Substrate width	240.7 mm
Width of 70.7 ohm Feed line	1.6 mm
Circular Patch Radius	17 mm
Feeding technique	Edge (line) feeding
Inter Element Spacing	62.5 mm
Width of 100 ohm Feed line	0.7 mm
Width of 50 ohm Feed line	3 mm

Table 1: 2 by 2 Circular Patch Antenna Array Specifications

II.2X2 CIRCULAR MICRO-STRIP PATCH ANTENNA ARRAY DESIGN STEPS

In this paper, we design a 2 by 2 circular micro strip patch antenna suitable methods are used. The design procedure of 2 by 2 circular micro-strip patch antenna array as shown below steps:

1.In HFSS design, select the rotate around model center and double click on Z-axis, which is nothing but XY plane.

2.First draw a circle and radius of circular position origin (0, 0, 0), radius of the circle is 17 mm in Z-axis (XY-plane) and name of the circle is patch, define the patch color (brown color) and set the transparency is 0.3.

3.Copy and paste the above circular patch, which is called second circular patch. The patches are separated by 62.5 mm along Y-axis, the second circular patch position is 0, 62.5, 0.

4.Copy and paste the step2 circular patch, which is called third circular patch. The patches are separated by 62.5 mm along X-axis, this circular patch position is 62.5, 0, 0.

5.Copy and paste the circular patch2, which is called fourth circular patch. The antenna patches are divided by 62.5 mm along X-axis and Y-axis, this circular patch position is 62.5, 62.5, 0.

6.All the patches are connected to 100 ohm lines each and the width of 100 ohm feed line is 0.7 mm.

7.Select and draw the rectangle box at first circular patch, this called first rectangle (rectangle1), the rectangle1 dimensions are XSize: -0.7, YSize: -20 and Axis: Z and the position of this rectangle1 is 0.35, 0, 0 (half of 100 ohm feed line width).

8.Copy and paste the rectangle1, which is called second rectangle (rectangle2). The inter element spacing of patches are 62.5 mm, because of that, the rectangle1 Y-position is 62.5 mm. The rectangle2 X, Y and Z sizes are same sizes of rectangle1.

9.Copy and paste the rectangle1, which is called third rectangle (rectangle3). The inter element spacing of patches are 62.5 mm and rectangle1 X-position is 0.35 mm, now add the 62.5+0.35=62.85, this value is the X-position of rectangle3. The rectangle3 X, Y and Z sizes are same sizes of rectangle1.

10.Copy and paste the rectangle2, which is called fourth rectangle (rectangle4), already the rectangle2 X-position is 0.35, which can be added to the inter element spacing of patches, now the X-position value is 0.35+62.5=62.85.

11.Select the rectangle and draw the one end of the first rectangle (rectangle1) to another end of third rectangle (rectangle3), which is the fifth rectangle (rectangle5) and change the value of YSize (=-0.7).

12.Copy and paste the rectangle5, which is the sixth rectangle (recrangle6), the existing y-position value is -20 and the new y-position value is 62.5-20=42.5.

13.The equivalent at the junction of each pair is 50 ohm. As shown in the design a quarter wave transformer is placed between a 50 ohm equivalent point and 100 ohm line whose resultant impedance is calculated as Z = √ZinZout = √50*100 = 70.7 ohm.

14.Select the rectangle and draw the one end of the fifth rectangle (rectangle5) to another end of sixth rectangle (rectangle6), which is the seventh rectangle (rectangle7). The value of YSize is 62.5/4 = 15.625+0.7 = 16.325 (i.e., -16.325), the value of XSize is 1.6 and the value of X-Position is calculated as {[(XSize-1.6)/2]+xposition=XPosition}, here, [(63.2-1.6)/2] - 0.35 = 30.45, this is the value of X-Position.

15.Copy and paste the rectangle7, which is called eighth rectangle (rectangle8), the new Y-Position value is calculated as inter element spacing plus old y-position value plus 0.7 (here, 62.5-20.7=41.8+0.7=42.5) and change the sign conversion of YSize value.

16.Select the rectangle and draw the one end of the seventh rectangle (rectangle7) to another end of eighth rectangle (rectangle8), which is the ninth rectangle (rectangle9). The value of new X-position value is calculated as [(XSize-0.7)/2] plus old x-position value, [here (1.6-0.7)/2=0.45+30.45=30.9] and new XSize value is 0.7.

17.Finally two pair of 100 ohm lines from each side resultant in an equivalent of 50 ohm where the coaxial feeding is given and the 50 ohm feed line width is 3 mm.

18.Select the rectangle and draw the one end of the seventh rectangle (rectangle7) to another end of eighth rectangle (rectangle8), which is the tenth rectangle (rectangle10). The new X-Position value is old x-position value minus 0.7 (i.e., 30.45-0.7=29.75) and the new Y-Position value is calculated as (Ysize-3)/2 plus old y-position value [here, (30.55-3)/2 = 13.775-4.375=9.4] and new XSize & YSize value are 3.

19. The rectangle10 is called as feed.

20.Select patch 1 to patch 4, rectangle1 to rectangle9 and feed line are in "Unite" condition.

21.Ground Plane: Select and draw the rectangle and change the rectangle name, which is called "Ground Plane", change the color and set the transparency (0.7).

XPosition: 62.5 + radius of circle + 6*height of substrate [62.5+17+9.6=89.1].

YPosition: 62.5 + radius of circle + 6*height of substrate [62.5+17+9.6=89.1].

ZPosition: -1.6.

XSize: XPosition value+17+9.6 = 89.1+17+9.6 = 115.7 (i.e., -115.7).

YSize: YPosition value + 20.7 + 9.6 = 89.1+20.7+9.6 = 119.4 (i.e., -119.4) and axis is Z.

22.Create Substrate: first set the 3 dimensional view and select and draw the box at one end of the ground plane to another end of ground plane, name of the box is substrate, select the FR4_epoxy material, and set the pink color and 0.7 transparency. The value of the substrate is same as the values of ground plane except ZSize, here ZSize is 1.6.

23.First set the 3 dimensional view and then select and draw the circle, which is called ground_cut_out. The ground_cut_out positions are 31.25, 10.9, -1.6 and the radius is 1.6. Finally set the 3 dimensional view.

24.Subtract the ground_cut_out from the ground.

25.Select and draw the cylinder, name of the cylinder is probe, material is pec and set the color. The probe positions are 31.25, 10.9, 0, height -6.6 and the radius is 0.35.

26.Select and draw the cylinder, name of the cylinder is pin, material is pec and set the color. The pin positions are 31.25, 10.9, -1.6, height -5 and the radius is 0.7.

27.Select and draw the cylinder, name of the cylinder is coax, material is Teflon, transparency is 0.7 and set the color. The coax positions are 31.25, 10.9, -1.6, height -5 and the radius is 1.6.

28.Select and draw the circle, name of the circle is source and set the color. The source positions are 31.25, 10.9, -6.6 and the radius is 1.6.

29.Create Radiation Box: select the box and draw one end of the substrate to another end of substrate extended, name of the box is Radiation Box, material is vacuum, set the color and 0.9 transparency.

ZSize: 31.25+1.6 = 32.85. Remaining dimensions are same.

30.Select all the faces of radiation box and assign radiation boundary.

31.Right click on patch and assign perfect E1 boundary, right click on ground and assign perfect E2 boundary, right click on source and assign wave port excitation and then select the use port object name and click on OK button.

32.Select Add solution setup ----> solution frequency is 2.4 GHz and type the maximum number of passes 12. Next select the add frequency sweep, select the fast sweep type, select the frequency type is linear count, start frequency 1 GHz, stop frequency 5 GHz and count is 91.

33.Save the HFSS design, check the validate and analyze all.

34.The simulation results as shown below.

III. DESIGN OF 2X2 CIRCULAR MICRO STRIP PATCH ANTENNA ARRAY IN HFSS

The configuration of 2x2 circular patch antenna array design, perfect E1(Patch)-plane design, perfect E2 (Ground)-plane design and enclosed inside radiation box design as shown in above figure (3), (4), (5) and (5).

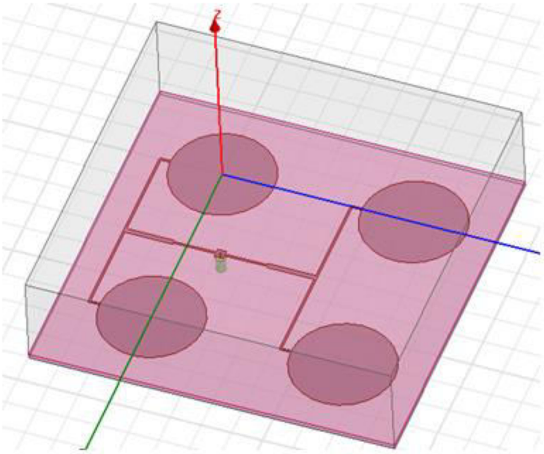

Fig 3: 2x2 circular patch antenna array Design.

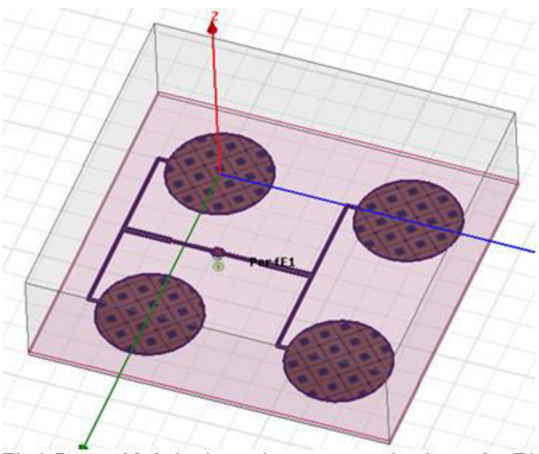

Fig 4: Proposed 2x2 circular patch antenna array showing perfect E1 (Patch)-plane.

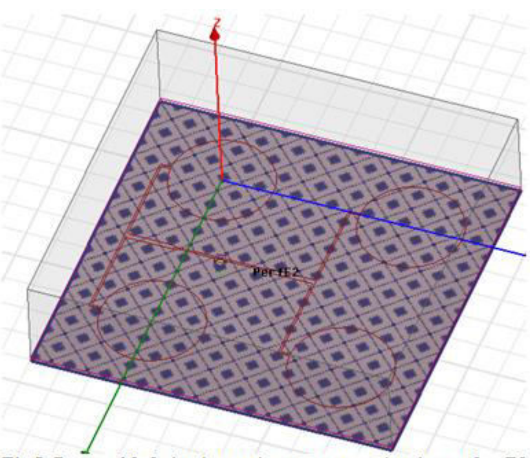

Fig 5: Proposed 2x2 circular patch antenna array showing perfect E2 (Ground)-plane.

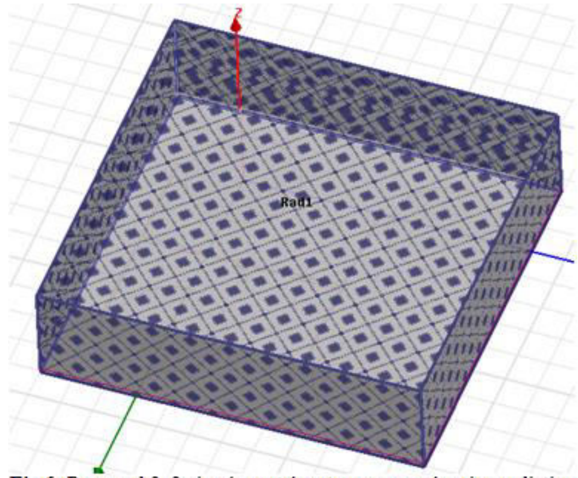

Fig 6: Proposed 2x2 circular patch antenna array showing radiation box.

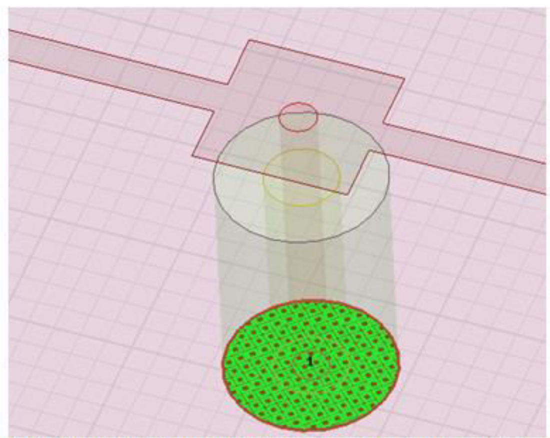

Fig 7: Proposed 2x2 circular patch antenna array showing excitation lumped port.

IV. SIMULATION RESULTS OF 2 BY 2 CIRCULAR MICRO STRIP PATCH ANTENNA ARRAY

5.1(a) Simulation Results of Return Loss (S Parameters):

Operating frequency: 2.4 GHz

Primary Sweep: Freq

Solution Setup1: Sweep

Domain: Sweep

Value of return loss (in db): -15.1945 dB

Highest point of operating frequency: 2.4001 GHz.

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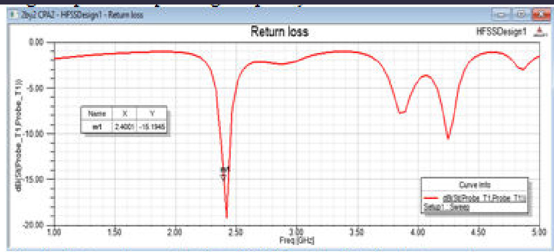

Fig 8: Return Loss plot for 2x2 Circular Patch Antenna Array.

From the fig 8, It is evident that the proposed Circular 2x2 Patch Antenna Array. Considering -10 dB to be the base value, the obtained Return Loss value is -15.1945 dB at 2.4001 GHz.

5.1(b) Simulation Results of VSWR Plot:

Operating frequency: 2.4 GHz
Primary Sweep: Freq
Solution Setup1: Sweep
Domain: Sweep
Value of VSWR: 1.4885
Highest point of operating frequency: 2.4014 GHz

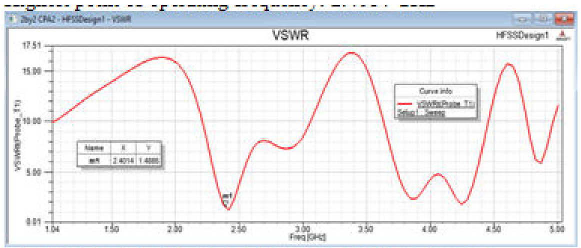

Fig 9: VSWR plot for 2x2 Circular Patch Antenna Array.

The exact theoretical value of VSWR is 1 dB and practically it should not be cross 2.6 dB. From the fig 9, it is evident that the planned Antenna, the obtained VSWR value is 1.4885 at 2.4014 GHz.

5.1(c) Simulation Results of Band Width:

Operating frequency: 2.4 GHz
Primary Sweep: Freq
Solution Setup1: Sweep
Domain: Sweep
Value of Lower Frequency at -10.0029 dB: 2.3691 GHz
Value of Higher Frequency at -10.0029 dB: 2.4567 GHz
Value of Center Frequency: 2.4 GHz
Value of Band Width:
Value of return loss (in db): -15.1945 db
Highest point of operating frequency: 3.65%.

The bandwidth of frequency and the percentage bandwidth for a circular Micro-strip patch antenna are determined using following formulas:

Frequency Bandwidth = fH-fL

Percentage Bandwidth is given by

$$\frac{f_H - f_L}{f_C} \times 100\%$$

Where fH and fL are two frequency points on the return loss curve obtained on the -10 dB line and fC is the center frequency at which the resonant peak is observed.

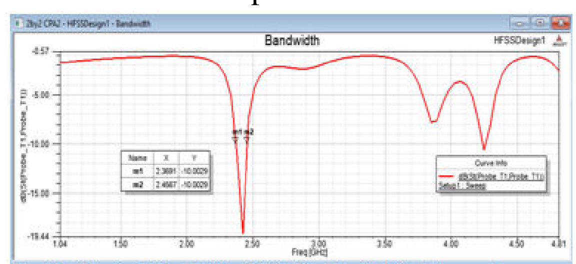

Fig 10: Band width plot for 2x2 Circular Patch Antenna Array.

Fig. 10 shows the return loss (S11) parameter is improved than -10 dB within the frequency range of (2.4567 - 2.3691)/2.4 GHz, which means 3.65 % band-width.

5.1(d) Simulation Results of 2D Radiation pattern:

The radiation pattern is selected as infinite sphere, by setting the EH Plane, the far field radiation sphere setup values of Phi start from 0 and stop 360 degrees, with step size

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of 10. Similarly, the values of Theta start from -180 deg. And stop at 180 deg. With a step size of 10. The 2D plot of the radiation pattern of the 2 by 2 circular patch antenna as shown in fig 11.

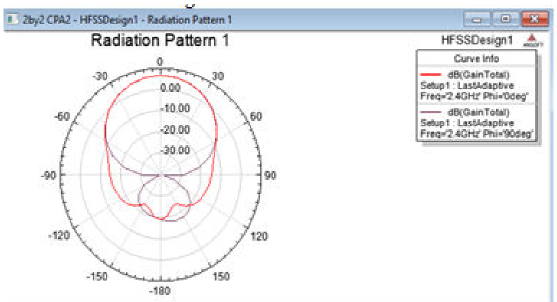

Fig 11: 2D Radiation (Gain Total) plot for 2x2 Circular Patch Antenna Array with Phi = 0^0 and 90^0 phase shift.

5.1(e) Simulation Results of 3D Polar Plot:

The 3D gain plot determines the antenna efficiency. The planned micro-strip patch antenna achieved moderate 3D polar gain total of 6.7442 dB and directivity gain of 10.232 dBi, which is considered excellent in terms of a compact antenna design. Fig 12 to 13 presents the 3D polar plot for planned micro-strip patch antenna.

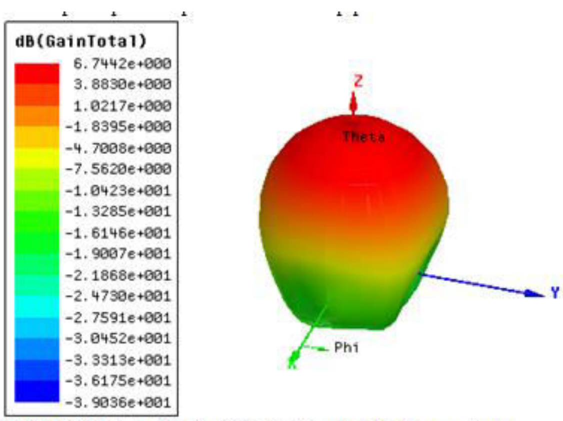

Fig 12: 3-D Gain plot for 2x2 Circular Patch Antenna Array.

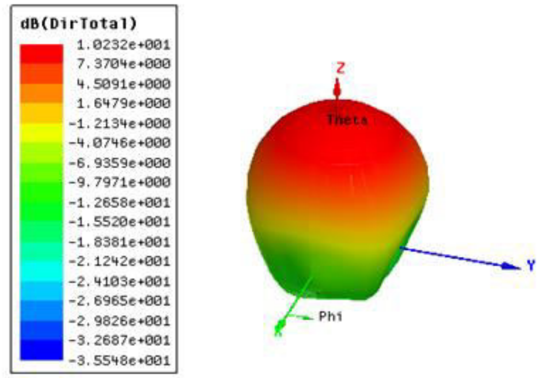

Fig 13: 3-D Directivity plot for 2x2 Circular Patch Antenna Array

Antenna Parameters

Inputs

Setup Name:	Infinite Sphere1
Solution:	Sweep
Array Setup:	None
Intrinsic Variation:	Freq='2.4GHz'
Design Variation:	

OK | Export | Export Fields

Antenna Parameters:

Quantity	Value	Units
Max U	0.0034383	W/sr
Peak Directivity	10.544	
Peak Gain	4.3569	
Peak Realized Gain	4.3208	
Radiated Power	0.0040979	W
Accepted Power	0.0099172	W
Incident Power	0.01	W
Radiation Efficiency	0.41321	
Front to Back Ratio	230.69	
Decay Factor	0	

Maximum Field Data:

rE Field	Value	Units	At Phi	At Theta
Total	1.6101	V	170deg	0deg
X	0.19879	V	140deg	40deg
Y	1.6101	V	170deg	0deg
Z	0.53264	V	90deg	30deg
Phi	1.6101	V	180deg	0deg
Theta	1.6101	V	270deg	0deg
LHCP	1.1436	V	200deg	0deg
RHCP	1.1334	V	170deg	0deg
Ludwig3/X dominant	0.16136	V	350deg	-40deg
Ludwig3/Y dominant	1.6101	V	170deg	0deg

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5.1(f) Simulation Results of Field Overlays:

The electric field variations of 2 by 2 circular patch antenna as shown in fig 14.

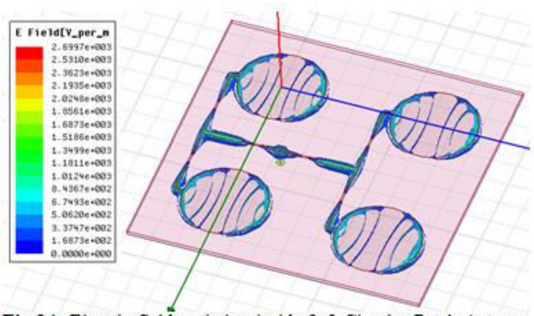

Fig 14: Electric field variation inside 2x2 Circular Patch Antenna Array

The various antenna parameters of designed circular patch antenna as shown below.

V.CONCLUSION

In this paper the 2x2 Circular Patch Antenna Array is designed for Wireless applications. The antenna resonates at frequencies of 2.4 GHz with a Return Loss value is -15.1945 dB, VSWR value is 1.4885, and band width is 3.65% and 3D polar plot gain total of 6.7442 dB and directivity gain of 10.232 dBi respectively.

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