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Miniaturized Highly Directive Patch Antenna Array Using CSRR Metamaterial

Dr. Monish Gupta
Astt. Professor, University Institute of Engineering & Technology, Kurukshetra University, Kurukshetra,

Abstract: Antenna plays a key role in designing wireless systems. It is always desirable to have compact and highly directive antenna. In this paper a compact, conformal and highly directive patch antenna array is proposed. Compactness is achieved using complementary split ring resonator. It acts as a filter and thereby reduces electromagnetic interference among patch antenna elements. By reducing electromagnetic interference patch antenna elements can be fabricated in small area which leads to miniaturization. Miniaturization of 4.34% is achieved by using this method without affecting the performance parameters of array. Simulation results are obtained by using High Frequency Structure Simulator.

Index Terms: Patch Antenna, Complementary Split Ring Resonator(CSRR), Wilkinson power divider.

I. Introduction

Microstrip patch antenna meets the requirements of planar and conformal structure so it is widely used in wireless systems. Microstrip line patch antenna design using is as shown in Fig.1

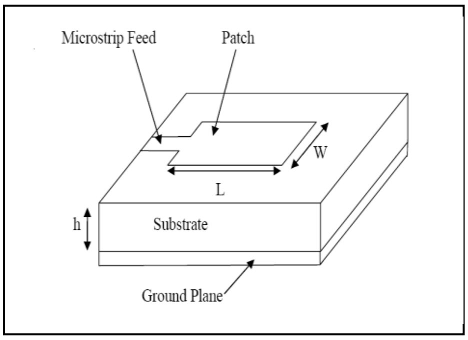

Fig.1(PatchAntenna using Microstrip line)

Bahl and Bhartia [1], Balanis[2], Kumar, G. et al [3], Hammerstad,[4] proposed the method of analyses of patch antenna. It can be concluded that operative frequency of patch antenna depends on permittivity of substrate, Length and width of Patch.

The required width of patch antenna is given by the expression

$$w = \frac{C}{2f\sqrt{\frac{\varepsilon_{eff}+1}{2}}}$$

Here C is the velocity of light and is the effective permittivity of the substrate which is given by expression

$$\varepsilon_{eff} = \frac{\varepsilon+1}{2} + \frac{\varepsilon-1}{2}\sqrt{1+12\frac{h}{w}}$$

Here is the dielectric constant of substrate and his the thickness of the substrate.

The required length of Patch is given by the expression

$$L = \frac{C}{2f\sqrt{\varepsilon_{eff}}} - 2\,\Delta l$$

 is the small increment in the length of patch due to existence of electric and magnetic field.

For operative frequency of 2.4 GHz with Duriod as the material of substrate required Length and width of Patch of patch antenna are calculated as

Table.1(Patch antenna dimensions)

Length of Patch	41.7 mm
Width of Patch	47.93 mm
Thickness of patch	.05 mm
Material of Patch	Perfect Electric Conductor

Desired Radiation characteristics which cannot be achieved by using single antenna are obtained by using arrays of antenna. Arrays can be obtained by connecting patch antenna elements either in series or in parallel. Series patch antenna is simple to design but it incorporates high electromagnetic interference and low gain. So it is always preferable to obtain patch antenna array by connecting patch elements in parallel. Appropriate power division device need to be used for dividing equal power among antenna elements. In this paper wilkinson power divider is used to divide input power among antenna elements. It has the capability to divide input power equally among the output ports with advantages of achieving high value of isolation among the output ports. High value of isolation among output ports means that power from one output port is not coupled with other output port. Wilkinson power divider (WPD) structure is represented in Fig. 2

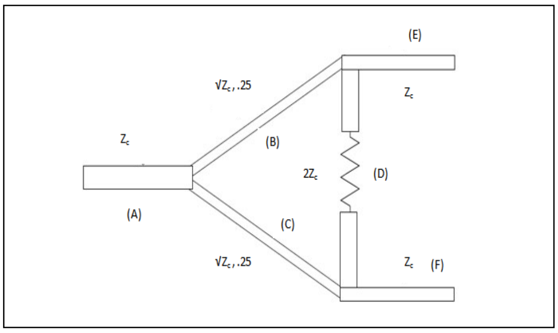

Fig. 2 (Wilkinson Power Divider)

The microstrip patch antenna array designed using WPD is represented in Fig.3. For 2.4 GHz operative frequency, the calculated width and length of various parts of WPD by using Duroid substrate having height of .79 mm is given as given in Table3.

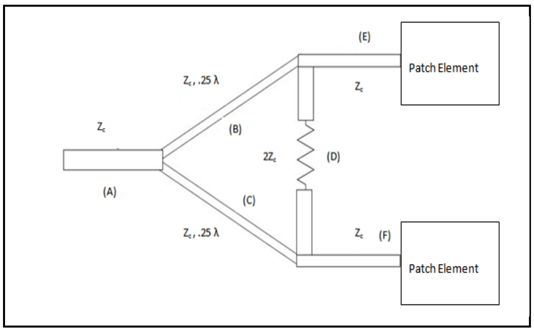

Fig. 3(Patch array using Wilkinson power divider)

For 2.4 GHz operative frequency, the calculated width and length of various parts of WPD by using Duroid substrate having height of .79 mm is given as

Table2.WPD Dimensions

Part A, Part D, Part E	
Length of line	2.43 mm
Width of line	13.35
Part B, Part C	
Length of line	1.38
Width of line	23.33

Due to common substrate shared by various elements like Patch element, WPD and microstrip line, surface waves propagate and electromagnetic interference exist between various elements in array. This electromagnetic interference restricts the miniaturization and performance of antenna array. One of the methods to overcome the effect of surface wave is by increasing distance between the elements. The disadvantage of increasing the distance between elements is increased size of antenna array. Several methods [5-16]are proposed to overcome electromagnetic interference between elements. In this work electromagnetic interference between elements is reduced by embedding the resonant element complementary split ring resonator metamaetrial in the ground plane of antenna array. Metamaterials [17-18] are the engineered materials whose characteristics are different from their constituent material. They can possess values of permittivity and permeability ranging from positive, zero to negative value. As per the law of optics a material possessing either negative value of permittivity or negative value of permeability do not allow electromagnetic waves to pass through it and hence acts like a filter. Metamaterials can be realized using fine mesh of wires or by using complementary split ring resonator. In this work due to planar structure of CSRR we are designing filter using CSRR. Structure of CSRR is represented Fig (4).

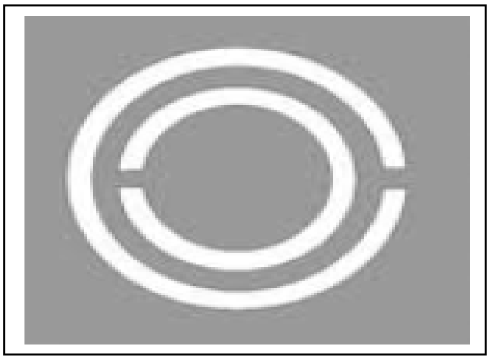

Fig. 4(CSRR)

The frequency at which CSRR offers high attenuation is dependent on the CSRR dimensions which outer radius of CSRR, distance between outer and inner ring of CSRR and its internal radius. External radius of CSRR is usually kept one tenth of operative frequency.The optimized dimensions of CSRR for filtering frequency of 2.4 GHz by using substrate of Relative permittivity 2.2 and height.794 mm areas provided in Table 3.

Table 3. CSRR Dimensions

Sr. No.	CSRR Part	Value
1	Outer radius	6.23mm
2	Distance between rings	1.2 mm
3	Inner radius	4.5 mm

In this work a microstrip patch antenna for 2.4GHz frequency is designed using HFSS. Wilkinson power divider is used to design corporate fed patch antenna array. CSRR designed for filtering frequency of 2.4 GHz is embedded into ground plane of antenna array. Patch antenna array directive gain is compared with miniaturized patch array using CSRR to illustrate that miniaturized patch array can be obtained using CSRR

II. Results & Discussion

Microstrip patch antenna having material and dimensions as provided in Table 1 is designed using HFSS. Height of substrate used is .787 mm. The reflection scattering coefficient (S_{11}) of patch antenna is as plotted in Fig (5).

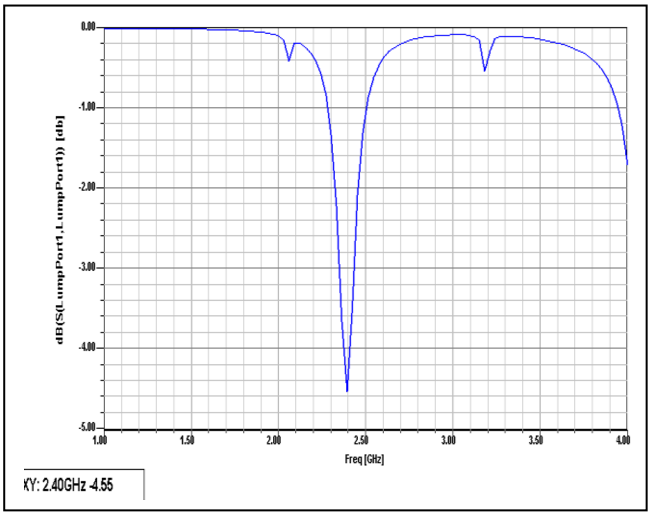

Fig5
(Reflection Scattering coefficient (S_{11})Vs. Frequency)

The value of obtained reflection coefficient is – 4.55 dB at 2.4 GHz. The maximum directive gain of 6.08 dB is obtained at 2.4 GHz. Obtained directive gain is plotted in Fig.6. Antenna array is designed using WPD and two patch elements. The structure of WPD obtained using HFSS is shown in Fig 7. The transmission parameters of WPD between input and output port are shown in Fig 8 and transmission parameters between two output ports are shown in Fig 9. From transmission parameters it is evident that input power is equally divided between output ports and output ports are isolated from one other. The patch antenna array designed using HFSS is shown in Fig 10. The inter element spacing between patch elements is kept at 25 mm. The achieved directive gain of this antenna array is 9.04 dB. The directive gain is plotted in Fig. 11. From the value of directive gain it can be concluded that by using two patch elements directive gain had improved. It can further be illustrated that by using more number of patch elements directive gain will increase further. The directive gain for patch array with inter element spacing of 20 mm. is as shown in Fig.12.

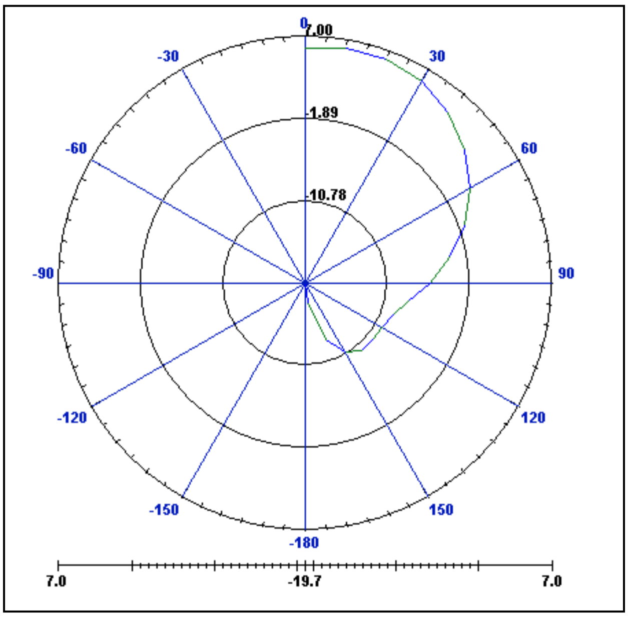

Fig.6(Directive gain of antenna)

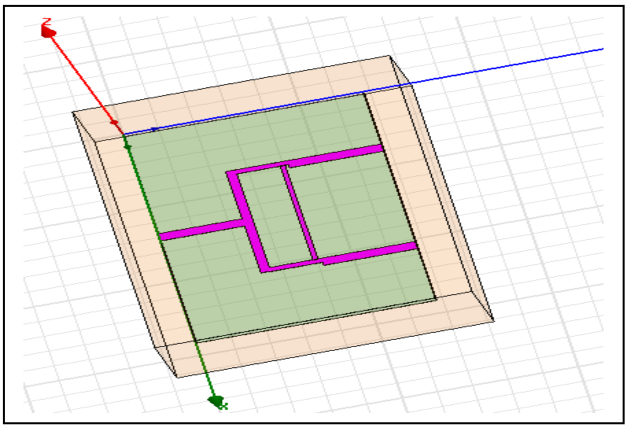

Fig.7 (Wilkinson power divider)

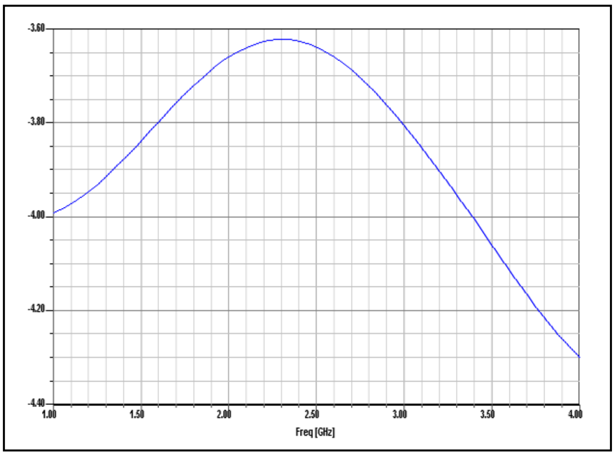

Fig.8 (Transmission parameters between input/output port)

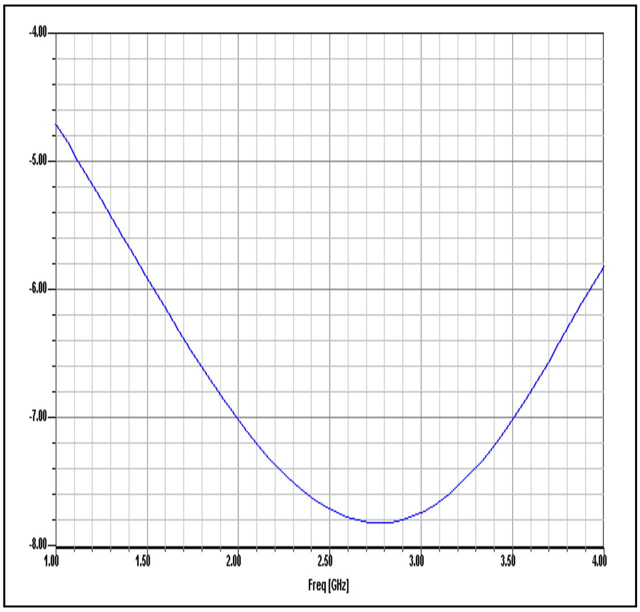

Fig.9(Transmission parameters between output ports)

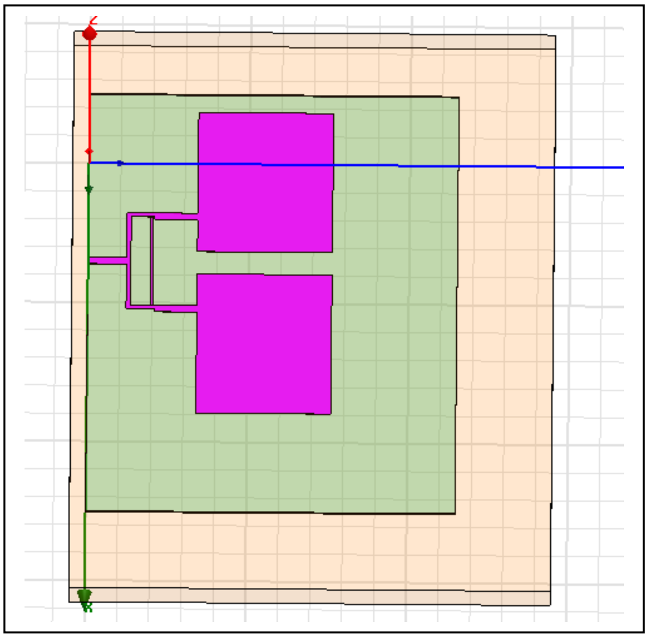

Fig.10 (Corporate eed Patch array)

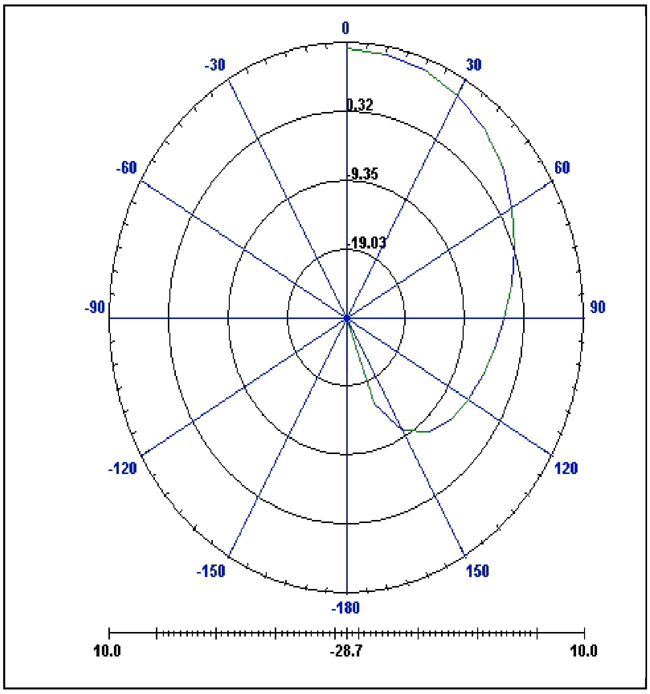

Fig.11(Antenna array directive gain)

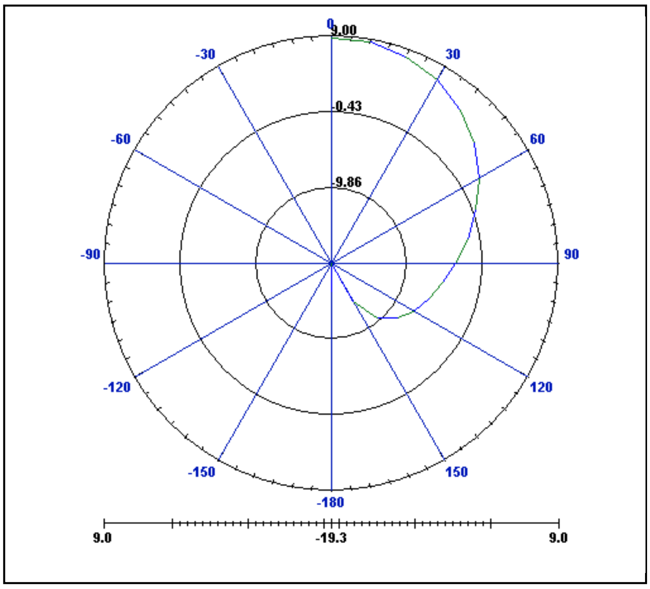

Fig (12)

(Directive gain of array with reduced interelementspacing)

The maximum value of achieved directive gain is 8.71 dB. Directive gain by using less distance between patch elements is decreased. It is interpreted as that due to reduction in inter element distance electromagnetic interference between elements had increased due to which directive gain is decreased**.** We are reducing the effect of electromagnetic interference between elements by inserting a CSRR into ground plane of patch antenna array.

Filtering characteristics of CSRR is demonstrated using microstrip line. Transmission parameters of microstrip line are compared with transmission parameters of microstrip line inserted with CSRR to demonstrate the filtering action of CSRR.

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The transmission parameters of microstrip line are plotted inFig 13. Transmission parameters of microstrip line indicate that there is zero dB of attenuation when signal travels from one port to second port.

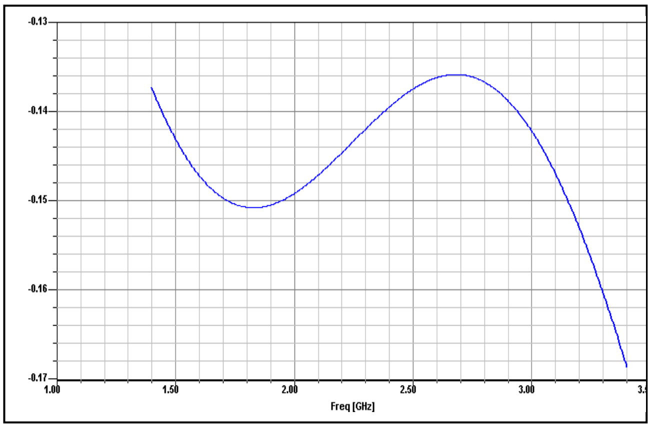

Fig 13 (Transmission parameters of microstrip line)

Microstrip line inserted with CSRR into its ground plane designed using HFSS is shown in Fig14.

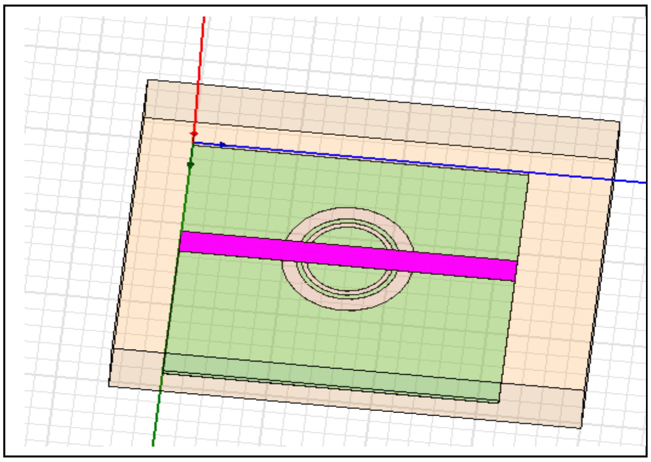

Fig 14 (Microstrip line inserted with CSRR)

The transmission parameters of microstrip line with CSRR are plotted in Fig 15. An attenuation of -19.9 dB is observed at 2.40 GHz. It indicates that microstrip line inserted with CSRR do not allow signal of frequency 2.4GHz to pass through it. Hence designed CSRR is acting as filter for 2.4 GHz.

The designed CSRR is inserted into ground plane of patch antenna array having inter element spacing to be 20mm. and designed structure using HFSS is plotted in Fig 16.

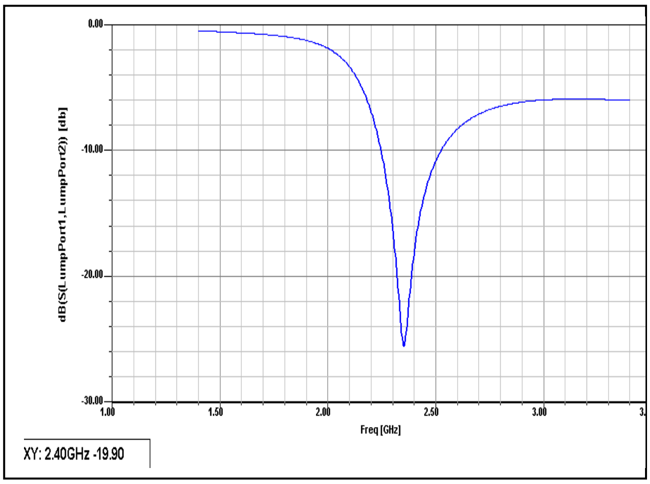

Fig (15)
(Transmission parameters of microstrip line with CSRR)

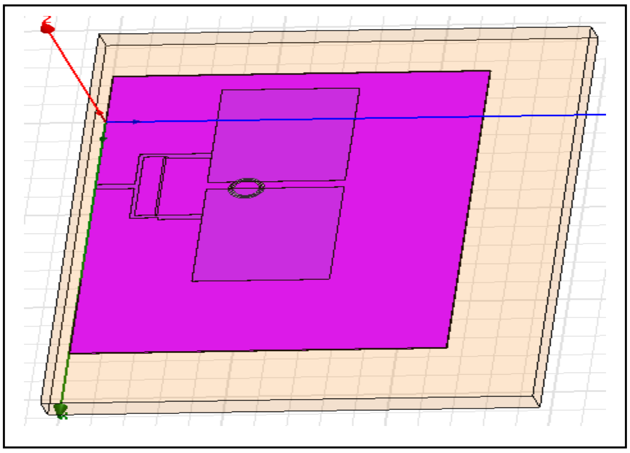

Fig 16
(Patch antenna array with CSRR in ground plane)

The maximum directive gain for this structure is 9.07 dB and is plotted in Fig.17. It is concluded that the power gain of miniaturized patch antenna array with inter element spacing 20 mm is comparable with Patch antenna array without CSRR having inter element spacing of 25mm. Area required to fabricate patch array with inter element spacing of 25 mm was 17250 mm^2. However same characteristics can be achieved by inserting CSRR in the ground plane of patch array having inter element spacing to be 20 mm. The required area for this design is 16500 mm^2. This indicated that a miniaturization of 4.34% has been achieved using this design.

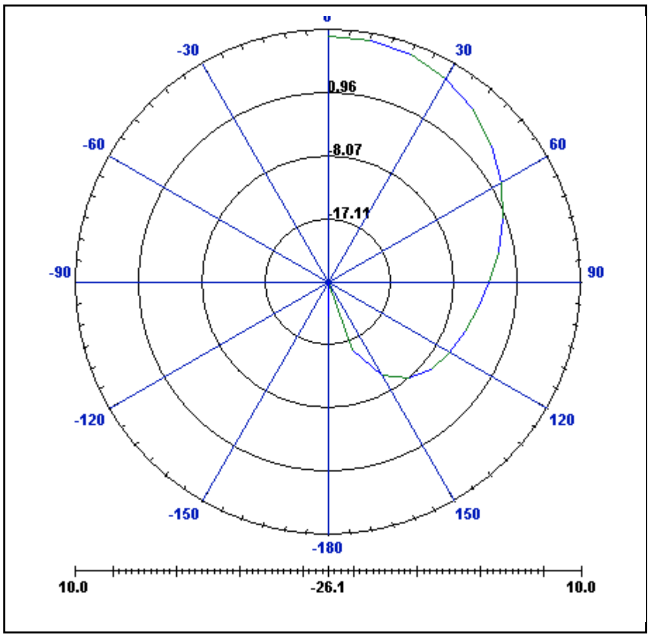

Fig (17) (Directive gain of array using CSRR)

III. Conclusion

A miniaturized patch antenna array for applications in wireless system is designed using CSRR. A miniaturization of 4.34% is achieved for two element Patch array by this method. The advantage of using CSRR to obtain miniaturization is that it provides a planner and conformal structure.

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