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Design and Performance Analysis of Microstrip Patch Array Antennas with different configurations

A. De[1], C. K. Chosh[2] and A. K Bhattacherjee[1]

[1]Dept. of ECE, NIT, Durgapur, West Bengal, India
[2]Dr. B.C Roy Engineering College, Durgapur, W.B, India
arnabderocks@gmail.com

Abstract

This abstract demonstrates simple, low cost and high gain microstrip array antennas with suitable feeding technique and suitable dielectric substrate for applications in the GHz frequency range. The objective of this paper is to design, and fabricate a 16 element rectangular microstrip patch array antenna. Therefore, a novel particle swarm optimization method based on IE3D was used to design an inset feed linearly polarized rectangular microstrip patch antenna array with sixteen elements. .Initially we set our antenna as a single patch and after evaluating the outcomes of antenna features; operation frequency, radiation patterns, reflected loss, efficiency and antenna gain, we transformed it to a 2x1 array. Finally, we analyzed the 2×2 array, then 4×2 array and finally 4 × 4 array to increase directivity, gain, efficiency and have better radiation patterns. The simulation has been performed by Zeland software version 14.0 and the desired antenna provides a return loss of -42.154dB at 2.45 GHz by using RT Duroid dielectric substrate with ϵ_r*= 2.45 and height , h= 1.58mm. The gain of the antenna is found to be 19.455 dBi and the side lobe is maintained lower than the main lobe. Since the resonant frequency of these antenna is around 2- 4 GHz, so these are suitable for S – band applications and can be used in WLAN communication systems.*

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Keywords*: Microstrip patch , array antennas, WLAN, IE3D, S-band*

1. Introduction

In the recent years the development in communication systems requires the development of low cost, minimal weight and low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. Microstrip patch antenna is a single layer design which contains mainly these four parts - Patch, Ground plane, Substrate and Feeding part. It is very simple in construction using conventional microstrip line feed. Patch can be given any shape but rectangular and circular configurations are mostly used. Ground Plane can be finite or infinite according to model (Transmission line - model, cavity model, full wave Model or method of moments) used for analysis of dimensions [1-4]. Relative Permittivity (ϵ_r) and height (h) are two important characteristics for substrate, Feeding Part can be implemented in these ways - Microstrip line, coaxial probe, Aperture coupled and Proximity coupled Feed [5-7]. Single microstrip patch antenna has some advantages (low cost, light weight, conformal & low profile), but it has little disadvantages too like low gain, low efficiency, low directivity and narrow bandwidth. These disadvantages can be overcome by implementation of many patch antennas in array configuration. As we increase number of patch elements to form an array, improvement in performance is observed. For a rectangular patch, the length L of the patch is usually $0.3333\lambda o<L<0.5\lambda o$, where λo is the free-space wavelength. The height h of the dielectric substrate is usually $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate (ϵ_r) is typically in the range $2.2 \leq \epsilon_r \leq 12$. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance [8-11].

2. Design of a Rectangular Single Element Antenna

The three essential parameters for the design of a rectangular Microstrip Patch Antenna are:

- Frequency of operation (f_o) = 2.45 GHz
- Dielectric constant of the substrate (ϵ_r)=2.45
- Height of dielectric substrate (h)=1.58 mm
- The width of the Microstrip patch antenna is given as:

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}}$$

Therefore, W = 46.62 mm

- The effective dielectric constant is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Where ε_{reff} = Effective dielectric constant
ε_r = Dielectric constant of substrate
h = Height of dielectric substrate
W = Width of the patch

Therefore, ϵ_{reff} = 2.3362

- The effective length is:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}}$$

L_{eff} = 40.056mm

- The length extension is:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

ΔL = 0.812mm

- The actual length is given as:

L = L_{eff} – 2 ΔL
Therefore, L = 38.432 mm

- Inset fed depth y_0 = 11.2 mm.

- Feed width = 5.5 mm.

After optimization we get,

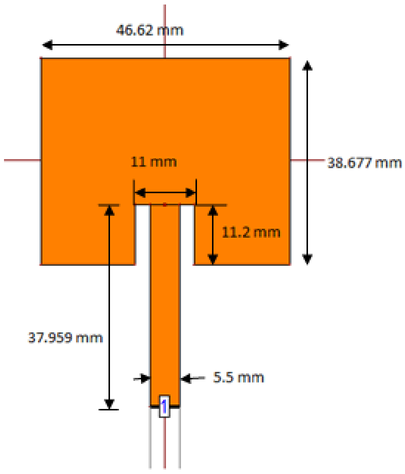

Figure 1. Design of a Single Element Antenna

After optimizing and simulation of the antenna the return loss is found to be -37.1654 dB at 2.45 GHz and the gain is found to be 6.758 dBi at that resonant frequency with a bandwidth of about 33 MHz. The RL plot and the radiation pattern plot is shown below.

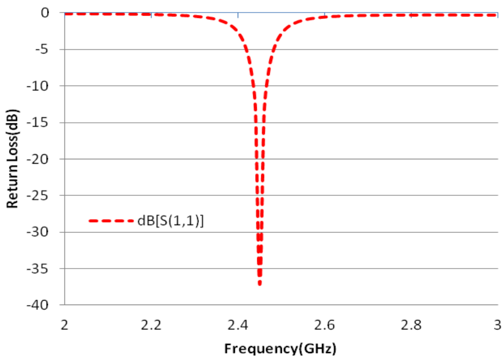

Figure 1(A). Return Loss

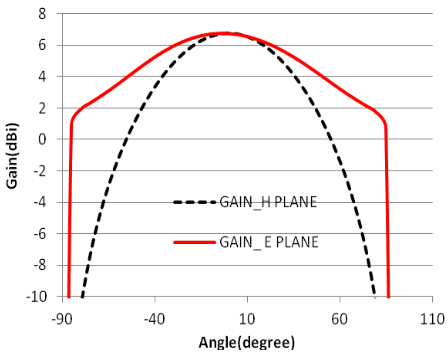

Figure 1(B). Radiation Pattern

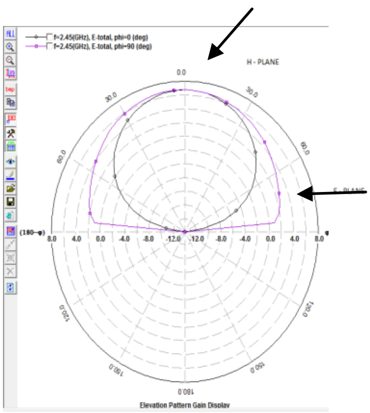

Figure 1(C). 2d Radiation Pattern Plot

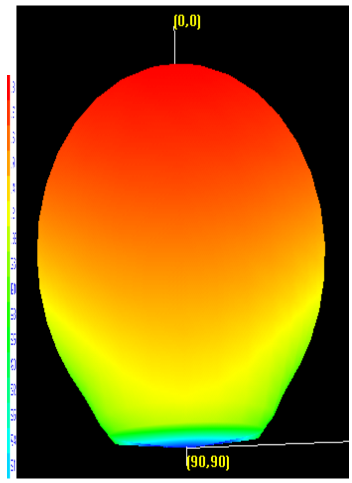

Figure 1(D). 3d Radiation Pattern Polar at 2.45 Ghz

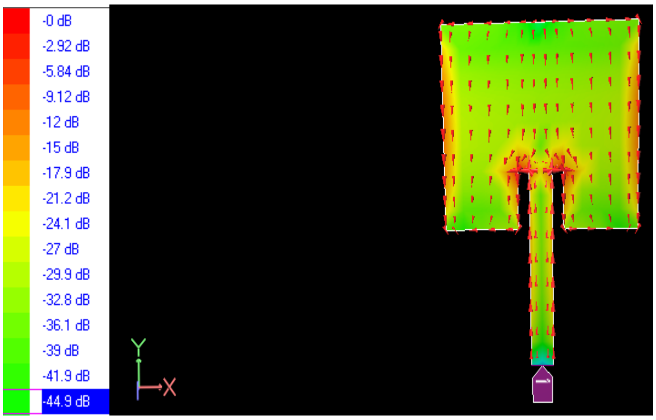

Figure 1(E). Current Distribution Pattern at 2.45 Ghz

2. Patch Array Analysis

a) Design and analysis of a 2×1 array

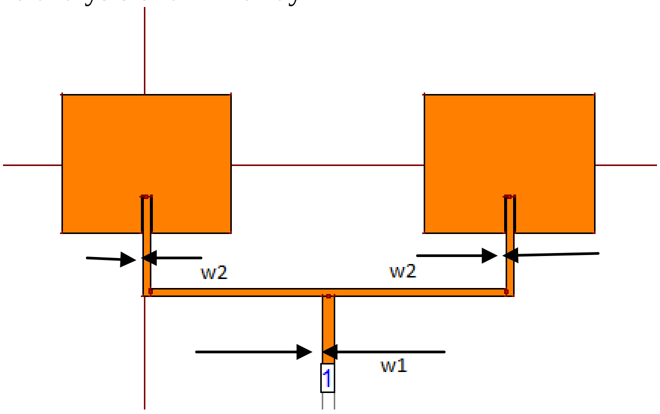

Figure 2. A 2× 1 Array

Here a 2×1 array is designed with the above said dimensions. Formation of an array requires feeding arrangement with proper impedance matched network (as shown in fig.2).Inset Fed has been used here, dimensions for feeding line are: width (w1) of 50 ohm impedance line is 3mm and of 100 ohm (w2) is 2.2 mm.

Here an improved gain of 9.64118dBi is obtained but consists of side lobes which was not present in the simple single patch. After simulation we get a return loss of -40.1492dB at 2.45 GHz.

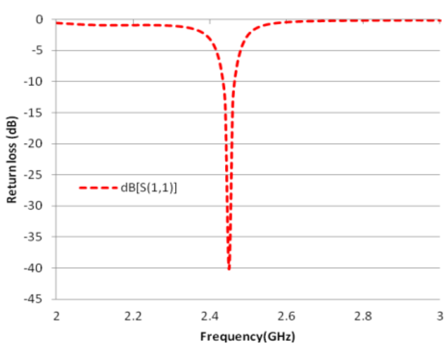

Figure 2(A). S-Parameters Plot

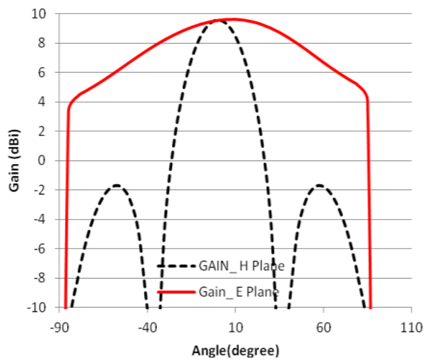

Figure 2(B). Radiation Pattern

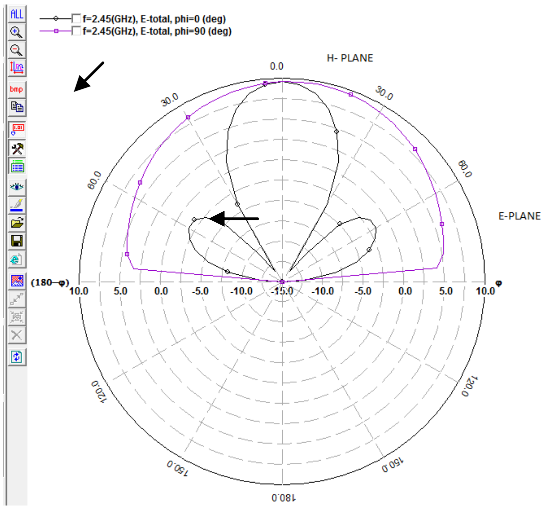

Figure 2(C). 2D Radiation Pattern Polar Plot

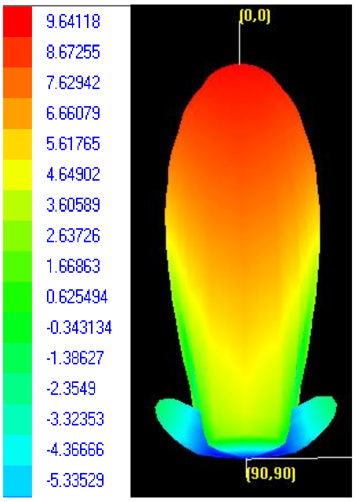

Figure 2(D). 3D Radiation Pattern Plot

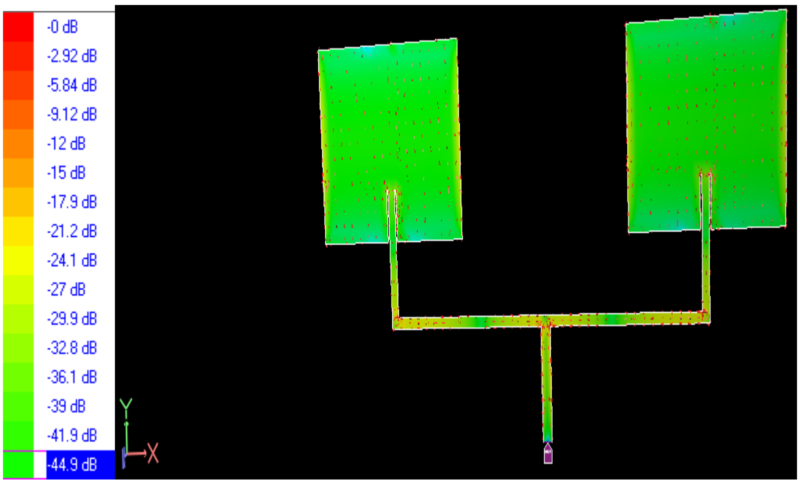

Figure 2(E). Current Distribution Pattern at 2.45 Ghz

b) Design and Analysis of a 2×2 Array

From the previous array we designed an array with 4 elements and the element spacing of 53.88mm.

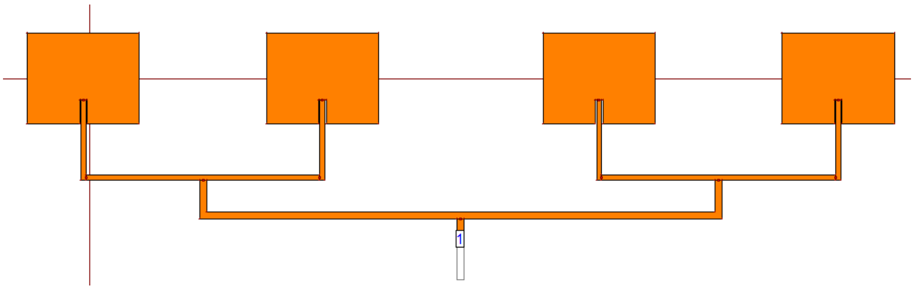

Figure 3. Array with 4 Elements

After simulation we get a Return loss of -40.1154dB at 2.45 GHz with an increased gain of about 12.4062dBi and improved radiation parameters.

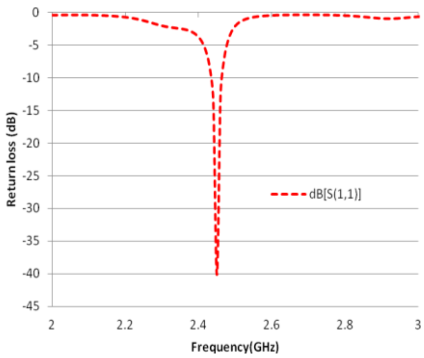

Figure 3(A). S-Parameters Plot

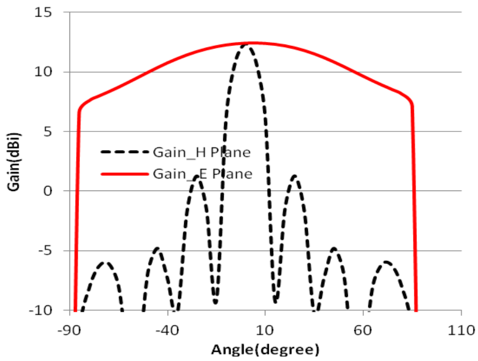

Figure 3(B). 2D Radiation Pattern

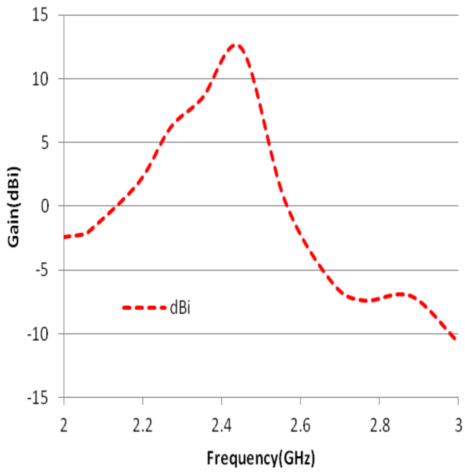

Figure 3(C). Gain vs. Frequency Plot

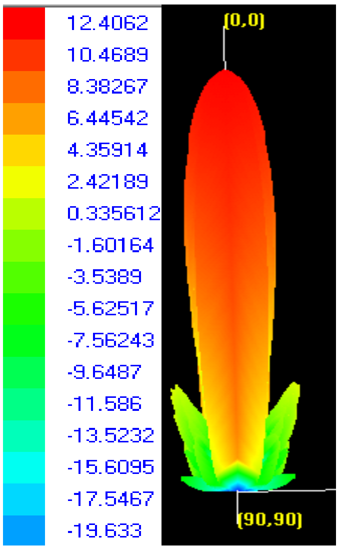

Figure 3(D). 3D Radiation Pattern

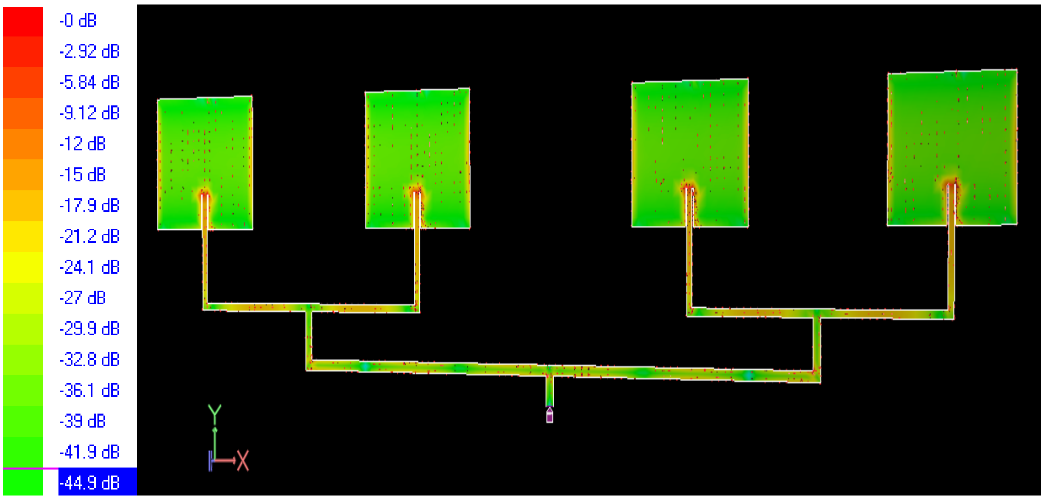

Figure 3(E). Current Distribution Pattern at 2.45 Ghz

c)Design and Analysis of A 4×2 Array

Now we have designed an array with 8 elements

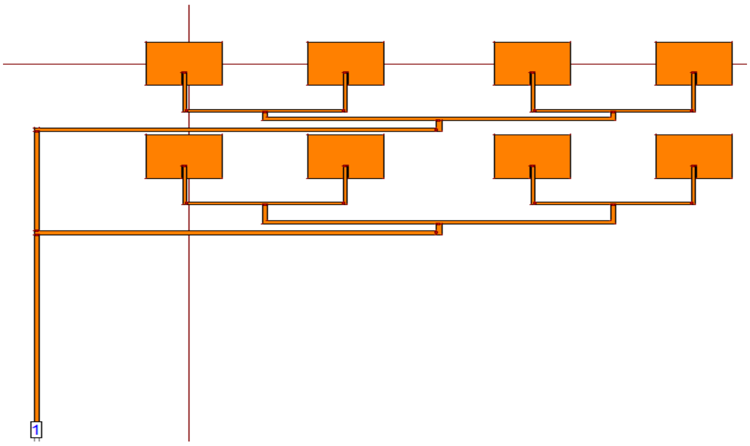

Figure 4. A 4×2 Array

After simulation at 2.45GHz we get a gain of about 16.2112dBi with an increased Directivity of about 17.216dBi with a Return loss of -38.045dB with a bandwidth of 23 MHz.

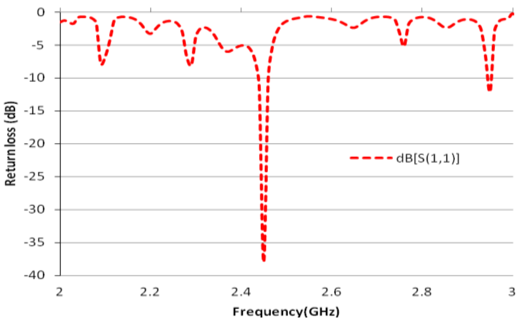

Figure 4(A). S –Parameters Plot

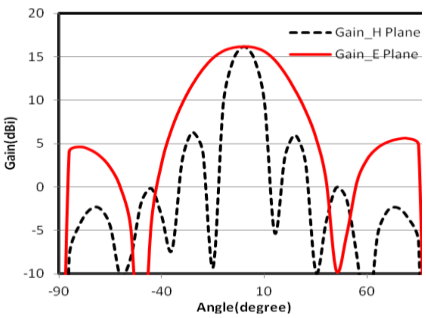

Figure 4(B). 2D Radiation Pattern

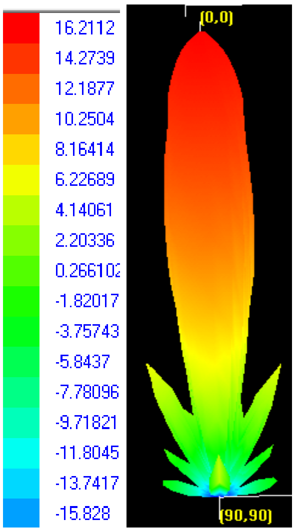

Figure 4(C). 3D Radiation Pattern

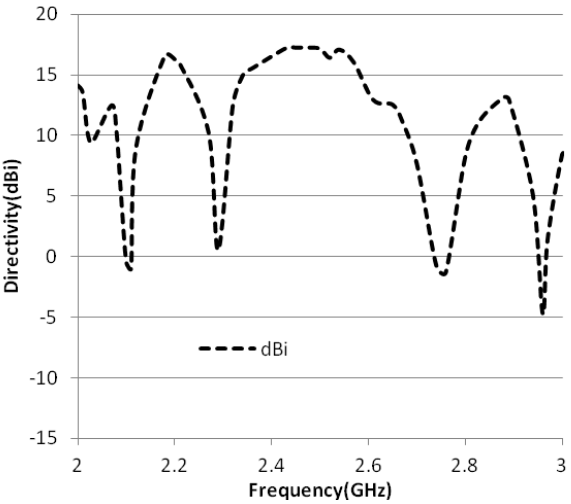

Figure 4(D). Directivity Vs. Frequency Plot

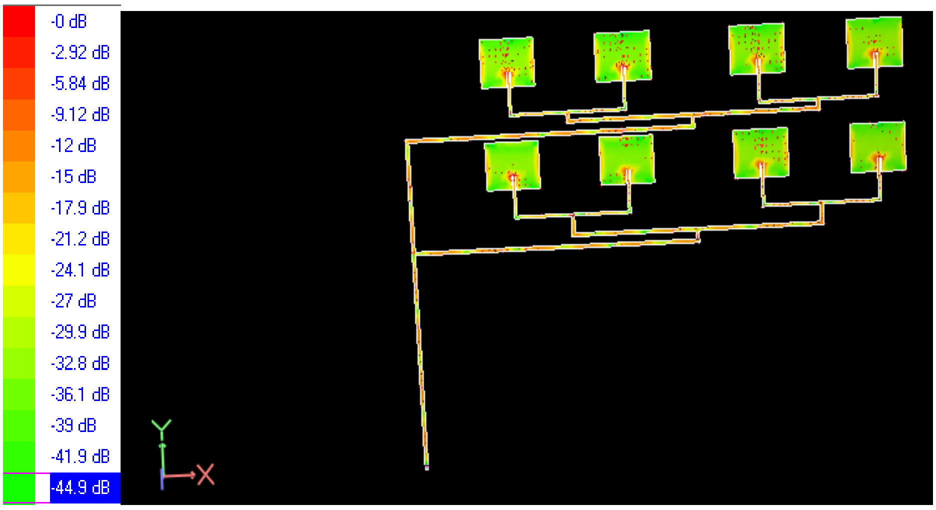

Figure 4(E). Current Distribution Pattern At 2.45 Ghz

d) Design and Analysis of a 4×4 Array

Finally 16 element (4×4) array is designed with corporate type of feed network with feed-width of 3 mm and feed-length of 17mm.

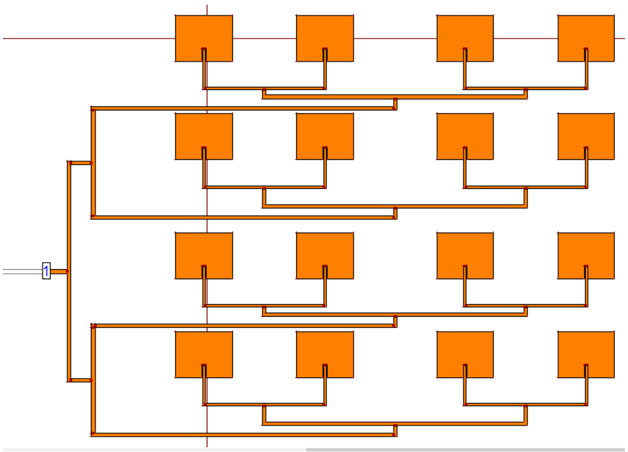

Figure 5A. 16 Element Array

After a no. of simulations we get a Return Loss of about -42.1538dB at 2.45GHz and an increased gain of about 19.455dBi and directivity of 20.1971dBi. The antenna and radiation efficiency is found to be 84.3035% and 84.3086%.

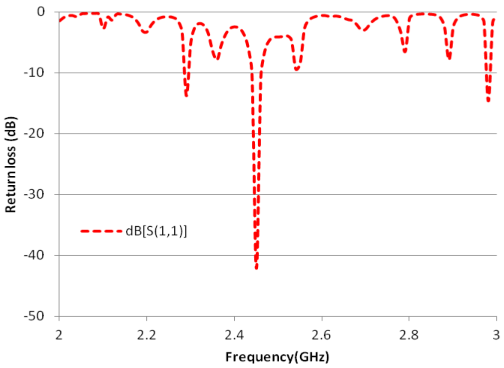

Figure 5(A). S-Parameters Plot

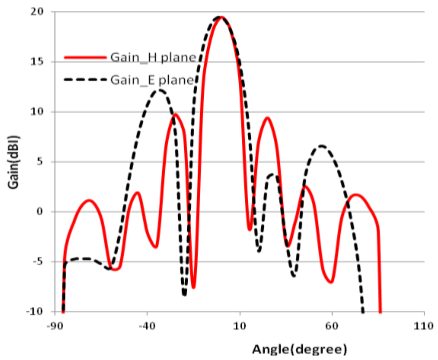

Figure 5(B). 2D Radiation Pattern

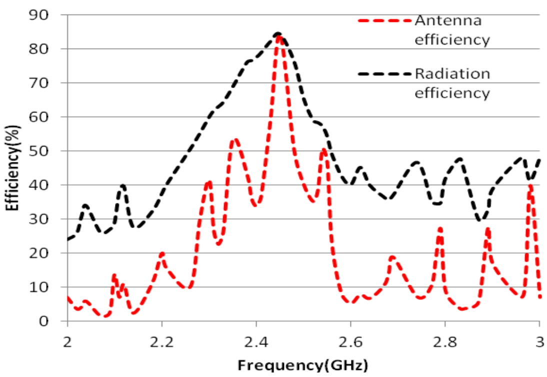

Figure 5(C). Efficiency Vs. Frequency Plot

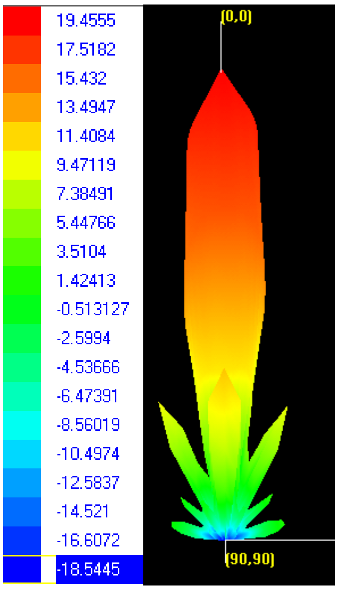

Figure 5(D). 3D Radiation Pattern

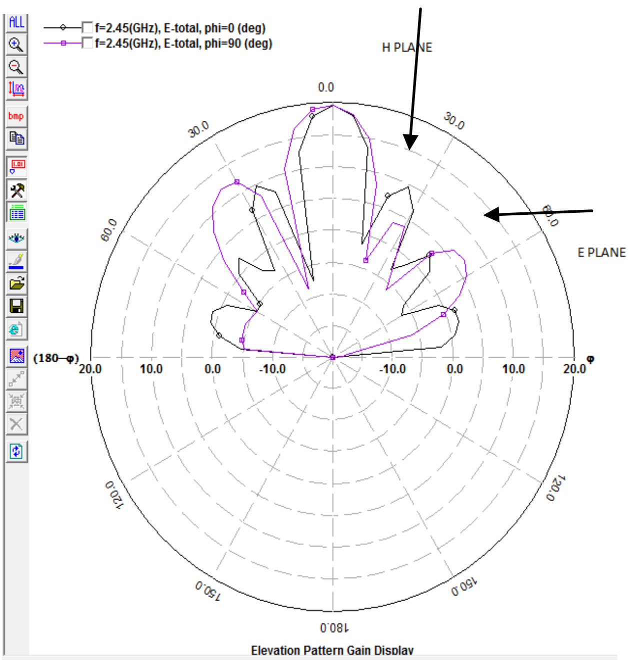

Figure 5(E). 2D Pattern Polar Plot

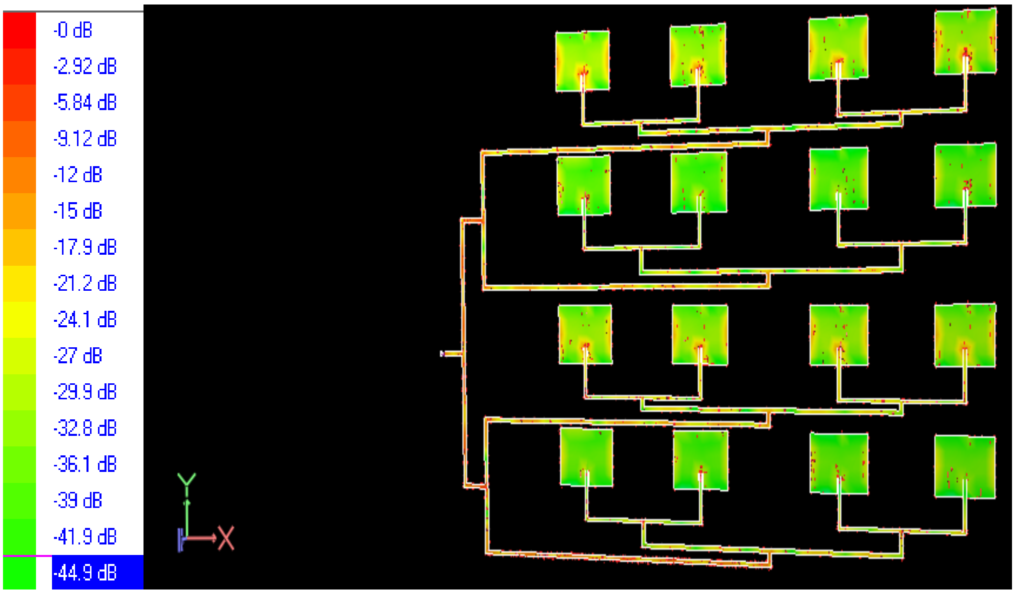

Figure 5(F). Current Distribution Pattern at 2.45ghz

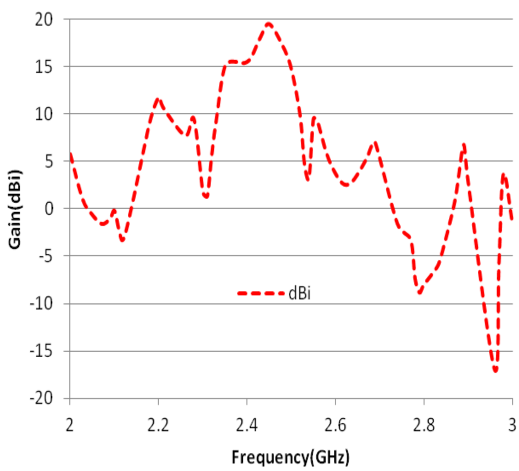

Figure 5(G). Gain Vs. Frequency Plot

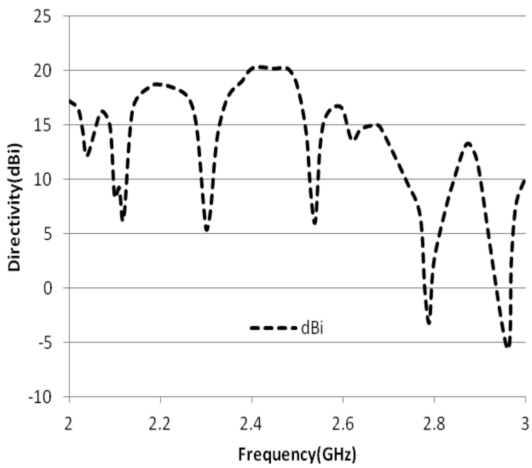

Figure 5(H). Directivity Vs. Frequency Plot

3. Comparative Study of All the Designs

ELEMENTS	RETURN LOSS(dB)	GAIN(dBi)	DIRECTIVITY(dBi)
Single	-37.1654	6.758	7.296
Two	-40.1492	9.64118	10.3166
Four	-40.1154	12.4062	13.2624
Eight	-38.045	16.2112	17.216
Sixteen	-42.1538	19.4555	20.1971

4. Conclusion

From above it is clear that with the increase of the no. of elements, there is an improvement of the antenna radiation parameters like gain, directivity etc. As a future work, we will make comparison between our proposed design for rectangular patch antenna with different design of triangular patch antennas or other shapes and make the array with more elements to provide better radiation efficiency and reduction of mutual coupling by using resonator and reductions in the size. The investigation has been limited mostly to theoretical study due to lack of distributive computing platform. Detailed experimental studies can be taken up at a later stage to find out a design procedure for balanced amplifying antennas. These designed antennas are very simple, cost effective and high efficiency for the applications in GHz frequency ranges. The optimum design parameters (i.e. dielectric material, height of the substrate, operating frequency) are used to achieve the compact dimensions and high radiation efficiency. The operating frequency of all our designed antennas is about 2.45GHz which is suitable for S-band applications.

It would also be possible to design an antenna operating in any other frequency bands by changing the design parameters. In future, we will investigate the spiral arrays with different feeding techniques which seem to be having more improved performances for both series feed and corporate feed networks.

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Authors

Arnab De, He received his M.Tech and B.Tech in Electronics and Communication Engingineering from West Bengal University of Technology in the year of 2012 and 2014 respectively. Now He is working his PhD degree at National Institute of Technology, Durgapur, India. His Current research includes the Array Antenna and Microwave Devices.

Chandan Kumar Gosh, He receiverd the B.Sc (Hons) degree in Physics and B.Tech degree in Radio physics and Electronics from University of Calcutta in the year 1987 and 1990 respectively. He did M. Tech. degree in microwave Engineering in the year 2003, from Burdwan University, India. From 1991 to 1995, he worked as Development Engineer in Sonodyne Electronics Co. Pvt. Ltd. and from 1996 to 1999 he worked as Assistant Manager (R&D) in Sur Iron & Steel Co. Pvt. Ltd. From 2000 to 2009 he was associated with the department of Electronics & communication Engineering of Murshidabad College of Engineering & Technology and from August 10 he is in Dr. B. C. Roy Engineering College, Durgapur, India and presently holds the post of Assistant Professor. He published more than 10 contributory papers in reffered journals and the international conferenve proceedings. His current research interests include the Array Antenna, MIMO antenna, DGS and EBG.

Anup Kumar Bhattacharjee, He received his BE in Electronics and Telecommunication Engineering from BE College Shibpur, Howrah in 1983. He received his ME and Ph.D. from Jadavpur University, Kolkata in 1985 and 1989 respectively. Presently he is attached with Electronics and Communication Engineering Department, in National Institute of Technology, Durgapur, and West Bengal, India as a Professor. His area of research is in Microstrip Antenna, Embedded System, and Mobile Communications. Fourteen number of PhD successfully awarded under his guidance.

