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Comparison of N-by-1 Rectangular Patch Antenna Design at 2.4 GHz and 5 GHz

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Abstract: ***In the present era, advancement in communication systems requires the development of minimal weight, low profile antennas and low cost which can maintain high performance over a wide spectrum of frequencies. Microstrip patch antenna has provided the needs of the modern era with various designs. The objective of this paper is to design and simulate a 2x1, 4x1 and 8x1 Rectangular patch array antenna at 2.4 GHz and 5 GHz then compare the performance analysis using Antenna Magus software. This is being tested for better gain and high directivity for applications such as wireless systems and satellite communications.***

Keywords: Patch antenna, Array, Antenna Magus, Gain, Communication

1. Introduction

An Antenna can be considered as the most essential part of the modern wireless communication system. The Microstrip patch antenna is simple to design and has attractive features such as low cost and weight, ease of fabrication and affordable manufacturing for real-time applications. An antenna array is used for transmitting and receiving radio waves in a way that individual currents are in phase relationship and specified amplitude. The antenna array is formed by interconnecting all the elements with high-end transmission line and feeding the power at first element. Cooperate feed is versatile which is used to scan the beam of an antenna system and is mostly used feeding technique to fabricate the antenna array in which incident power is equally distributed to the individual antenna elements which are connected by using quarter wavelength impedance transformers. These antenna arrays are widely used in Wireless Local Area Network (WLAN). The frequency of operation (f_0) is the essential parameter for designing a rectangular Microstrip patch antenna.

Antenna Magus

Antenna Magus is an antenna synthesis tool with over 350 antennas and feed structures in its database which can be explored for designing to meet the system criteria and integrate with design workflow. The database is continuously updated with various antenna models and designs so that a user can explore. It is the most fast, flexible design tool which provides better designs and to evaluate in a short period of time. This software has been designed to represent data in a manner that enables the user to consider different options with minimal effort and time. The Array synthesis tool can synthesize excitation distributions and array layouts for objectives like bandwidth, beam width and gain which can be exported in other formats for further simulation. The antenna magus toolbox has a collection of a consistent and reliable set of design tools and utilities for designers to simplify antenna design tasks.

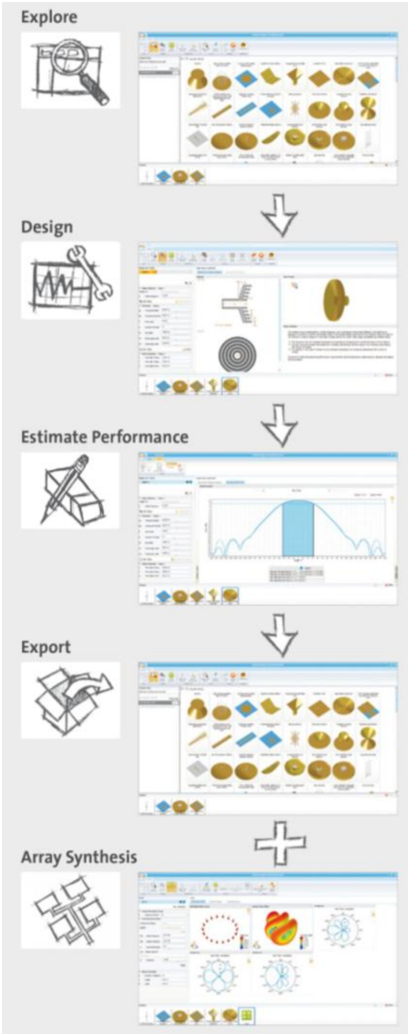

Figure 1: Steps for Design

These tools are grouped according to Approximation tools, Antenna properties, Data Conversion tools, and system calculators.

2. Literature Review

I. Ayn Qurratul, et al. [1] In this paper, 2x1 Circular patch antenna array is designed with FR4 Epoxy Glass substrate using probe feeding technique and 2x1, 4x1 arrays are

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designed using edge feeding technique is simulated by HFSS Software. From the simulated design, the maximum achieved gain for 4x1 array is 8.2572 dB and for a 2x1 array is 5.7414 dB.

II. Errifi, et al. [2] In this paper, design and simulation of rectangular patch array antenna using HFSS Software is designed and simulated with 2 elements, 4 elements and 8 elements with that of a single patch for the same operating frequency of 10 GHz using RT-Duroid Substrate. The array antenna would be possible to design operating at WLAN, WIMAX or other wireless systems by changing the dimension of the patch.

III. Ratheesh, et al. [3] In this paper, comparing the performance of two-element and four-element antenna array with an FR4 substrate and 2.4 GHz operating frequency using HFSS Software. From the analysis, 4 element array with cooperate feeding is more efficient and gives good return loss at the desired frequency and higher gain.

3. Design of N-by-1 Antenna Rectangular Patch Array

The design of a N by 1 patch array combines the design of the individual patch element with the design of the microstrip feed network. The dimensions of a single resonant patch are constrained by the substrate parameters, while the characteristic impedance of the feed lines is dictated by realization considerations. For microstrip arrays with coplanar feed networks, the choice of substrate relative permittivity is a compromise between the often-conflicting requirements of patch bandwidth and tightly bound, non-radiating quasi-TEM.

- The overall input impedance may be controlled sufficiently by adjusting the width of the input matching section of the corporate feed network.
- To increase bandwidth, substrate height should be increased and/or decreasing the substrate permittivity which will affect the impedance matching and resonant frequency.
- The length of the patches may be changed to shift the resonances or center frequencies of the individual elements.

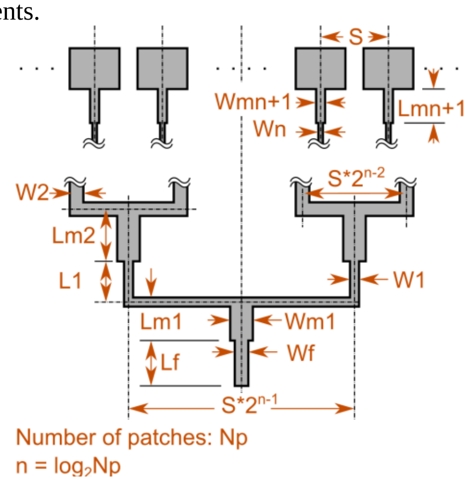


Figure 2: Top View of Array

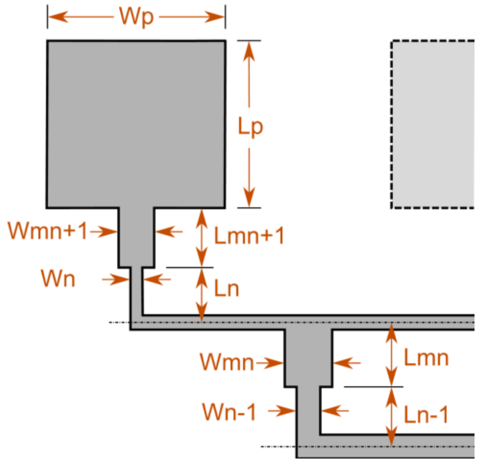


Figure 3: Detailed Patch View of Array

Figure 4: Side View of Array

3.1 Method of Design and Simulation

Specification of antenna for simulation and design:

- Centre frequency (f_0) = 2.4 GHz & 5 GHz
- Number of patches (Np) = 2, 4 & 8 patches
- Input resistance (Rin) = 50 Ω
- Substrate
  The thickness of the substrate = 1.65 mm
  The relative permittivity of the substrate = 2.2
- Loss tangent(tanδ) = 0

3.2 Antenna Design

A N-element patch antenna is designed and compared with single patch antenna. Appropriate values are selected by using design parameter equations.

1) A practical width for a good radiation of frequency is

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

2) Effective Dielectric Constant

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^\wedge - \frac{1}{2} \quad (2)$$

3) Extension of Length

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

4) Actual Length of the Patch

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \quad (4)$$

3.3 Design Analysis at f_0 = 2.45 GHz for 2x1, 4x1, 8x1 Antenna Array

The following figures show design of N-by-1 rectangular patch antenna at 2.45 GHz frequency of device dimensions with N=2, 4, 8.

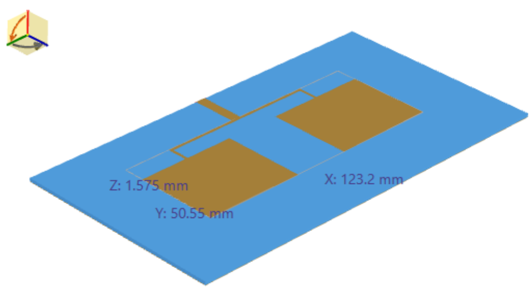


Figure 5: 2x1 Patch Antenna design at f_0 = 2.45 GHz

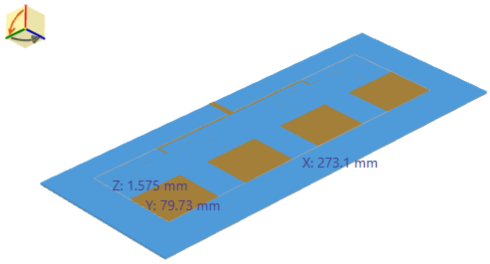


Figure 6: 4x1 Patch Antenna design at f_0 = 2.45 GHz

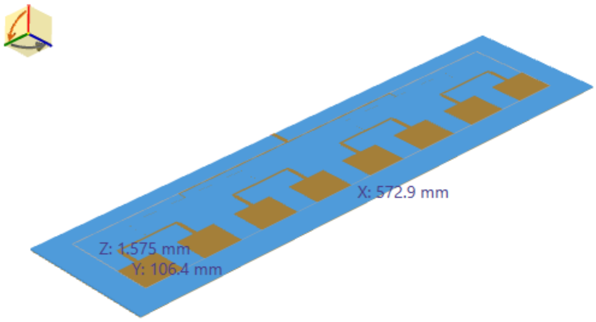


Figure 7: 8x1 Patch Antenna design at f_0 = 2.45 GHz

3.4 Design Analysis at f_0 = 5 GHz for 2x1, 4x1, 8x1 Antenna Array

The following figures show design of N-by-1 rectangular patch antenna at 5 GHz frequency of device dimensions with N=2, 4, 8.

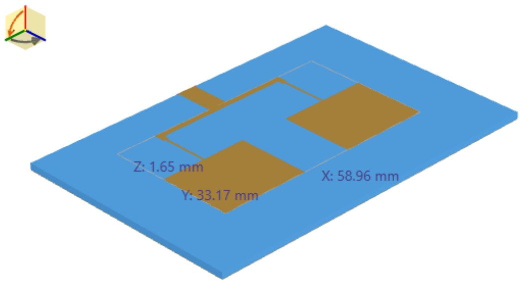


Figure 8: 2x1 Patch Antenna design at f_0 = 5 GHz

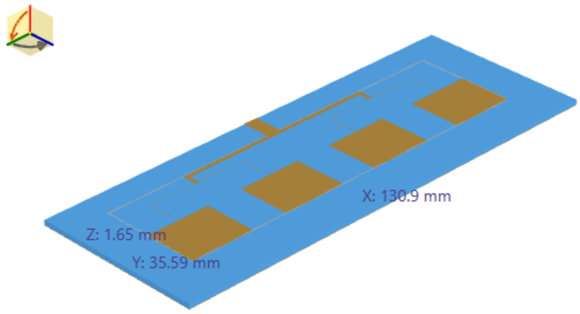


Figure 9: 4x1 Patch Antenna design at f_0 = 5 GHz

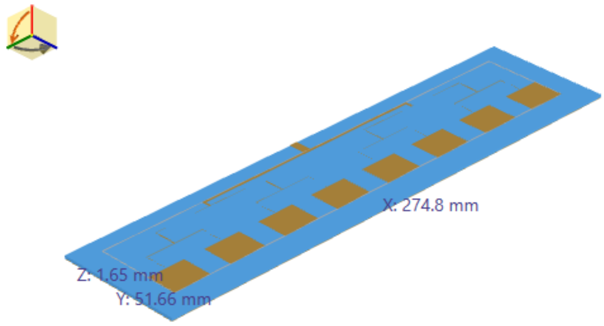
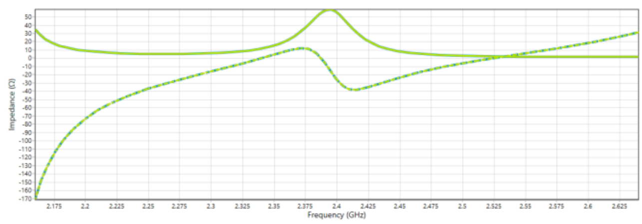


Figure 10: 8x1 Patch Antenna design at f_0 = 5 GHz

4. Simulation Results

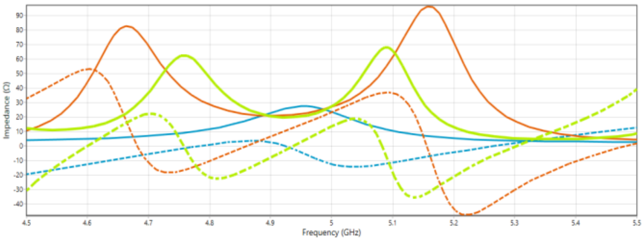
a) Impedance

Antenna Impedance is the measure of resistance to an electrical signal in an antenna. It is the ratio of voltage to current and is expressed in Ohms(Ω). Antenna Impedance can be affected by environmental factors. The real part of antenna impedance represents radiated or absorbed power within the antenna whereas the imaginary part represents power which is stored in the field of antenna i.e. non-radiated power.



	2x1 Array		4x1 Array		8x1 Array	
	Port 1 Real	Port 1 Imaginary	Port 1 Real	Port 1 Imaginary	Port 1 Real	Port 1 Imaginary
Minimum impedance value	1.390 Ω	-170.8 Ω	1.390 Ω	-170.8 Ω	1.390 Ω	-170.8 Ω
Frequency value at minimum impedance value	2.603 GHz	2.16 GHz	2.603 GHz	2.16 GHz	2.603 GHz	2.16 GHz
Maximum impedance value	58.99 Ω	31.26 Ω	58.99 Ω	31.26 Ω	58.99 Ω	31.26 Ω
Frequency value at maximum impedance value	2.394 GHz	2.64 GHz	2.394 GHz	2.64 GHz	2.394 GHz	2.64 GHz
The average impedance value of the data	11.15 Ω	-19.43 Ω	11.15 Ω	-19.43 Ω	11.15 Ω	-19.43 Ω

Figure 11: Impedance (Ω) vs Frequency (GHz) at 2.45 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array

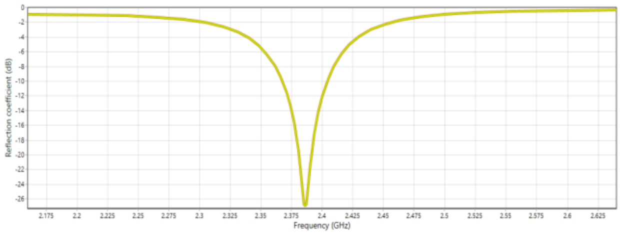


	2x1 Array Port 1 Real	2x1 Array Port 1 Imaginary	4x1 Array Port 1 Real	4x1 Array Port 1 Imaginary	8x1 Array Port 1 Real	8x1 Array Port 1 Imaginary
Minimum impedance value	2.611 Ω	-19.51 Ω	4.145 Ω	-47.83 Ω	4.517 Ω	-35.77 Ω
Frequency value at minimum impedance value	5.5 GHz	4.5 GHz	5.5 GHz	5.22 GHz	5.363 GHz	5.137 GHz
Maximum impedance value	27.23 Ω	12.71 Ω	96.40 Ω	52.93 Ω	67.88 Ω	39.02 Ω
Frequency value at maximum impedance value	4.953 GHz	5.5 GHz	5.16 GHz	4.603 GHz	5.09 GHz	5.5 GHz
The average impedance value of the data	9.325 Ω	-3.849 Ω	35.85 Ω	3.535 Ω	23.76 Ω	-937.1e-3 Ω

Figure 12: Impedance (Ω) vs Frequency (GHz) at 5 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array

b) Reflection coefficient

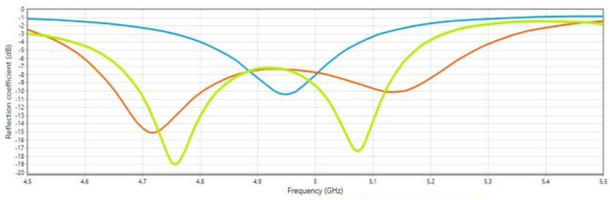
Reflection Coefficient is a parameter which describes the amount of reflected electromagnetic wave by a discontinuity in transmission medium. It is defined as the ratio of amplitude of the reflected wave to the incident wave.



	2x1 Array	4x1 Array	8x1 Array
Reference impedance @ port 1	(50+0j) Ω	(50+0j) Ω	(50+0j) Ω

	Port 1	Port 1	Port 1
Minimum S-parameter value	-26.91 dB	-26.91 dB	-26.91 dB
Frequency value at minimum S-parameter value	2.386 GHz	2.386 GHz	2.386 GHz
The average S-parameter value of the data	-3.060 dB	-3.060 dB	-3.060 dB
Bandwidth (below the -10.0 dB level)	36.77 MHz	36.77 MHz	36.77 MHz
Bandwidth (%)	1.541 %	1.541 %	1.541 %

Figure 13: Reflection coefficient (dB) vs Frequency (GHz) at 2.45 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array



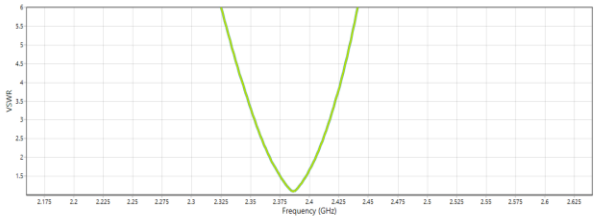
	2x1 Array	4x1 Array	8x1 Array
Reference impedance @ port 1	(50+0j) Ω	(50+0j) Ω	(50+0j) Ω

	Port 1	Port 1	Port 1
Minimum S-parameter value	-10.44 dB	-15.15 dB	-19.06 dB
Frequency value at minimum S-parameter value	4.947 GHz	4.717 GHz	4.757 GHz
The average S-parameter value of the data	-3.339 dB	-7.291 dB	-7.036 dB
Bandwidth (below the -10.0 dB level)	38.91 MHz	154.0 MHz	137.4 MHz
Bandwidth (%)	786.3e-3 %	3.257 %	2.884 %
Bandwidth (below the -10.0 dB level)	-	42.49 MHz	112.7 MHz
Bandwidth (%)	-	827.4e-3 %	2.224 %

Figure 14: Reflection coefficient (dB) vs Frequency (GHz) at 5 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array

c) VSWR

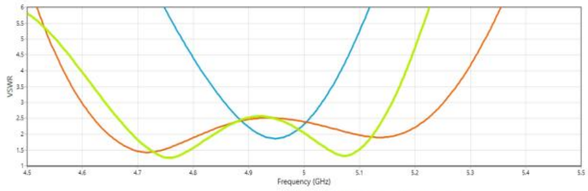
In a standing wave pattern, it is defined as the maximum voltage to the minimum voltage along the length of the transmission line structure.



	2x1 Array	4x1 Array	8x1 Array
Reference impedance @ port 1	(50+0j) Ω	(50+0j) Ω	(50+0j) Ω

	Port 1	Port 1	Port 1
Minimum VSWR value	1.095	1.095	1.095
Frequency value at minimum VSWR value	2.386 GHz	2.386 GHz	2.386 GHz
The average VSWR value of the data	16.92	16.92	16.92
Bandwidth (below the 2.0 level)	38.99 MHz	38.99 MHz	38.99 MHz
Bandwidth (%)	1.634 %	1.634 %	1.634 %

Figure 15: VSWR vs Frequency (GHz) at 2.45 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array



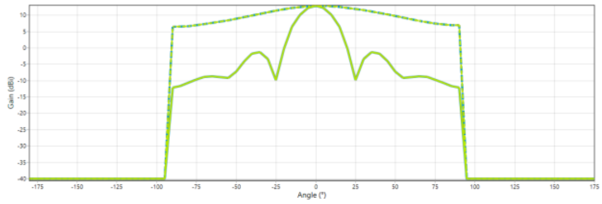
	2x1 Array	4x1 Array	8x1 Array
Reference impedance @ port 1	(50+0j) Ω	(50+0j) Ω	(50+0j) Ω

	Port 1	Port 1	Port 1
Minimum VSWR value	1.860	1.424	1.251
Frequency value at minimum VSWR value	4.947 GHz	4.717 GHz	4.757 GHz
The average VSWR value of the data	9.298	3.590	4.698
Bandwidth (below the 2.0 level)	57.65 MHz	168.9 MHz	148.2 MHz
Bandwidth (%)	1.165 %	3.571 %	3.111 %
Bandwidth (below the 2.0 level)	-	82.61 MHz	122.1 MHz
Bandwidth (%)	-	1.609 %	2.412 %

Figure 16: VSWR vs Frequency (GHz) at 5 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array

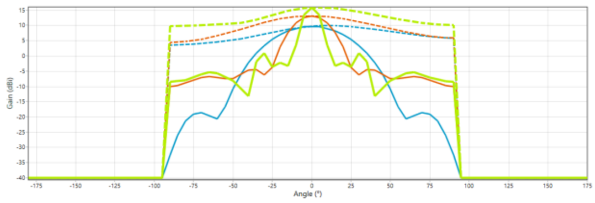
d) Antenna Gain

It is the antenna ability to radiate more or less in any direction compared to theoretical antenna. Directional antennas can be configured with gains upto more than 20 dB.



	2x1 Array Φ = 0°	2x1 Array Φ = 90°	4x1 Array Φ = 0°	4x1 Array Φ = 90°	8x1 Array Φ = 0°	8x1 Array Φ = 90°
Minimum gain value	-40 dBi	-40 dBi	-40 dBi	-40 dBi	-40 dBi	-40 dBi
Angle value at minimum gain value	-180 °	-180 °	-180 °	-180 °	-180 °	-180 °
Maximum gain value	12.77 dBi	12.77 dBi	12.77 dBi	12.77 dBi	12.77 dBi	12.77 dBi
Angle value at maximum gain value	0 °	5 °	0 °	5 °	0 °	5 °
The average gain value of the data	-21.48 dBi	-14.46 dBi	-21.48 dBi	-14.46 dBi	-21.48 dBi	-14.46 dBi
Beamwidth (above 3.0 dB below the peak level)	20.91 °	91.26 °	20.91 °	91.26 °	20.91 °	91.26 °

Figure 17: Gain (dBi) vs Angle (^{0}) at 2.45 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array



	2x1 Array Φ = 0°	2x1 Array Φ = 90°	4x1 Array Φ = 0°	4x1 Array Φ = 90°	8x1 Array Φ = 0°	8x1 Array Φ = 90°
Minimum gain value	-40 dBi	-40 dBi	-40 dBi	-40 dBi	-40 dBi	-40 dBi
Angle value at minimum gain value	-180 °	-180 °	-180 °	-180 °	-180 °	-180 °
Maximum gain value	9.701 dBi	9.898 dBi	13.09 dBi	13.09 dBi	15.87 dBi	15.91 dBi
Angle value at maximum gain value	0 °	10 °	0 °	0 °	0 °	5 °
The average gain value of the data	-23.49 dBi	-15.83 dBi	-21.03 dBi	-14.81 dBi	-21.49 dBi	-13.11 dBi
Beamwidth (above 3.0 dB below the peak level)	41.53 °	97.40 °	22.31 °	76.34 °	10.54 °	72.38 °

Figure 18: Gain (dBi) vs Angle (^{0}) at 5 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array

e) Fairfield

Farfield is a region in a Electromagnetic field around a transmitting antenna. Farfield or Radiation field is the field which is far from antenna as radiation is high in this region. Antenna directivity, Radiation pattern and many other antenna parameters are considered in this region.

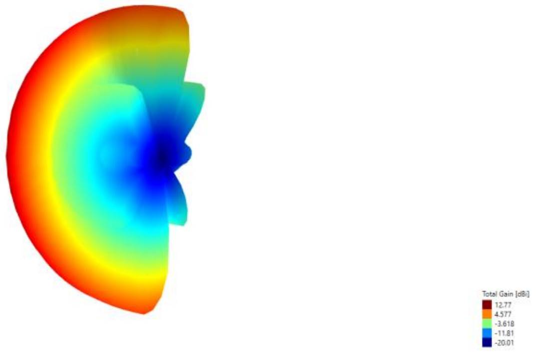


Figure 19: 3D Farfield at 2.45 GHz for 2x1, 4x1, 8x1 Rectangular Patch Array

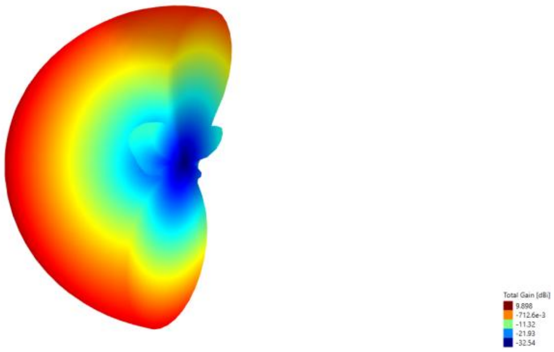


Figure 20: 3D Farfield at 5 GHz for 2x1 Rectangular Patch Array

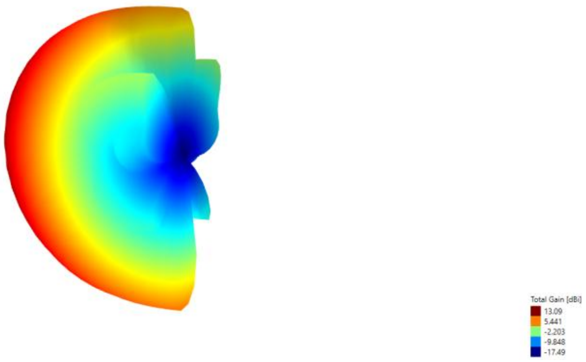


Figure 21: 3D Farfield at 5 GHz for 4x1 Rectangular Patch Array

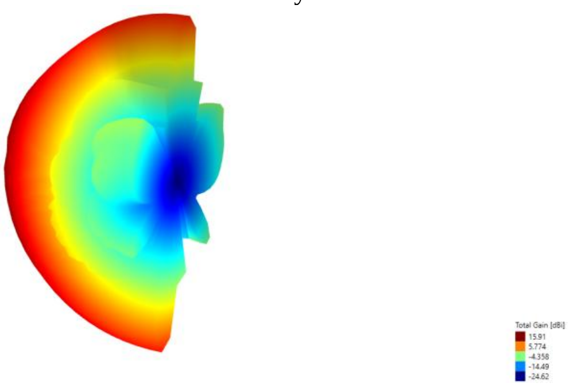


Figure 22: 3D Farfield at 5 GHz for 8x1 Rectangular Patch Array

5. Conclusion

The design and study of two-element and four-element array patch antenna has been performed. Changing the dielectric constant will change the dimensions and properties of the antenna. In this antenna, a Corporate feed network is used which can be fabricated along with antenna elements. The array design provides constant directivity over bandwidth and shows dual-band characteristics to avoid the use of individual antennas. The proposed antenna can be used at multiple frequencies by adjusting the design parameters. The proposed antenna can be used for modern wireless applications and Satellite communications.

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Author Profile

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