

Trapezoidal Microstrip Patch Antenna Array for Low Frequency Medical Applications

Suganthi Santhanam (✉ tvssugi@gmail.com)

K Ramakrishnan College of Technology <https://orcid.org/0000-0001-5663-1088>

Thiruvallar Selvan Palavesam

SRM TRP Engineering College

Research Article

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Trapezoidal Microstrip patch antenna array for low frequency medical applications

Suganthi Santhanam¹, Thiruvallar Selvan Palavesam²
^{1&2}Professor

^{1&2}Department of Electronics and Communication Engineering,

¹K.Ramakrishnan College of Technology, Tamilnadu, India

²SRM TRP Engineering College, Tamilnadu, India

ABSTRACT

This paper presents the design of flexible trapezoidal radiating patch antenna array with FR4 substrate for onbody low frequency medical applications. Initial single element trapezoidal patch antenna having size of 30 x 70 mm has been modified with 2 x 2 array with same size for reduction in dimension. The array resonates at 1.891 GHz with impedance bandwidth of 80 MHz and low return loss of -26.19 dB. The VSWR of 1.103 validate the activeness of the proposed antenna array having maximum surface current 133.1 (A/m) and directivity of 4.48 dBi. The antenna array exhibit the H-Field strength of 160.52 (A/m) and E-Field of 36093.4 (V/m) prove the radiation capability at low frequency on body application. The antenna has been simulated in low frequency S band form 2 GHz to 4 GHz and compared with other works in literature. These properties demonstrate the suitability of proposed array antenna for on body medical wireless applications.

Keywords: Microstrip feed, trapezoidal patch, return loss, VSWR, radiation pattern, low frequency medical applications,

1. INTRODUCTION

Microwave antenna is one of the key elements in low cost [1] microwave portable diagnostics tools. In microwave head imaging, designing portable and desired radiation properties antenna present great challenge in terms of band of operation [2]. The low frequency microwave band within 1 GHz to 4 GHz provides a acceptable compromise between the resolution of resulting image and penetration of signal into human head. Different types of antenna have been proposed in the above frequency band for size reduction [3], antenna structure with matching need elimination [4]. The wideband, compact size antenna requirements in medical imaging have spurred out several research and innovation in microwave systems [5]. Monopole omni - directional antennas are widely used in ensuring better images due to its low profile [6] and simple fabrication. Though the directional antenna is complex in nature, they are preferred in medical imaging for less environment interface sensitivity [7]. The directional antennas exhibits smoother gain pattern due to less fluctuation [6] in current distribution. Antenna size, mutual coupling between array elements in limited area [8] and constrain in frequency band are major challenges in antenna research for medical applications. Several types of conventional substrate antenna arrays have been proposed [9] using FR4, Rogers, Duroid etc. In tomography microwave imaging, to map the entire electrical profile [10] of the breast and in confocal imaging [11] for mapping the location of significant scatterers [12], the antenna array made up of wideband elements has been utilized to send and receive the test signals.

Flat, compact and mechanically convenient radiating structure antennas using microstrip transmission line are now a day preferred for coupling electromagnetic energy into biological systems due to simple to design and fabricate. For the microstrip antenna to penetrate at best in human body, the antenna tends to be physically too large and produce radiation leakage at narrow band. The main difference in design of microstrip antenna for medical and other applications is the medical antenna must be designed to radiate in lossy medium and the other applications antenna is often radiate in to free space. Microstrip antenna with bandwidth enhancement can be implemented by several approaches like increasing the substrate thickness [13], impedance matching optimization, reduction in substrate permittivity and inclusion of multiple resonances.

Microstrip antenna array are mostly used for high gain wireless power transfer medical implants applications. Many array antennas are realized like 1 x2 antenna array for RF power transfer in pacemaker [14], UWB antenna for human body changes measurement in footwear applications [15], square patch antenna array with complimentary split ring resonators [16], CP implanted patch antenna [17] for

impedance matching, rectangular patch antenna with a rectangular slot [18] for ISM band applications, square shape CSRR [19] to reduce the power observed inside the body, omnidirectional pattern radiation characteristics analysis in close proximity with human body [20], hexagonal shape patch antenna [21] for ISM application, metamaterial antenna with 2×2 array of H-shape unit cell [22] for WBAN applications, Flexible Parasitic Element Patch (FPEP) antenna with defects on ground plane at ISM band for biomedical application [23], etc. One of the challenges in antenna array large scale production for medical applications is the use of non conventional flexible substrate like fabric and plastic [24]. The cost efficient, high gain and flexible characteristics antenna array is highly desirable for biotelemetry and health monitoring applications [25]. In this paper, a flexible trapezoidal radiating patch microstrip antenna array has been designed for on body application to operate at low frequency. The radiating trapezoidal shape is coated on copper ground plane which radiate on free space with FR4 as substrate. All ideal characteristics support for parametric analysis of designed antenna has been simulated using Finite Integration Techniques (FIT) analyzer.

2. ANTENNA DESIGN

Flexible and economical microstrip trapezoidal antenna array for onbody health monitoring applications is realized on 2.4 mm thickness FR4 substrate with relative permittivity of 4.3 and loss tangent of 0.025. The radiation patterns are drawn on conductive copper foils for the prototype antenna array having $30 \times 70 \text{ mm}^2$ size. Generally the conducting patch of any shape and simple half wavelength trapezoidal shape is chosen for simple analysis and performance prediction. The dimensions of the structure are calculated by using the basic microstrip antenna design and transmission line theory and are optimized carefully to operate the antenna in required specifications. The proposed 2×2 linear array microstrip fed antenna comprise of copper foil on single copper layer on one side and FR4 substrate on other side.

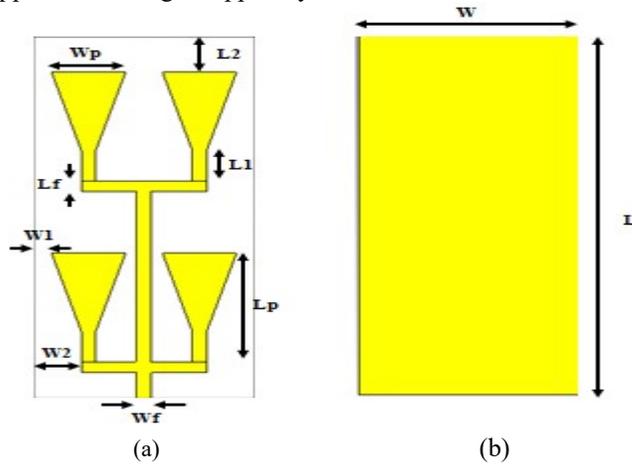


Figure 1. Proposed Trapezoidal patch antenna array (a) Front view (b) Back view

Table 1. Dimension of proposed antenna array in (mm)

Parameter	W	Wf	Wp	W1	W2
Value	30	2	10	2.5	6.5
Parameter	L	Lf	Lp	L1	L2
Value	70	20	21	6	7

Single layer metallization supports desire radiation pattern and high gain which may degrade when the antenna comes in close proximity with human body. Hence the design procedure used in this proposal involves the design of single radiating element and replication of same trapezoidal element as 2×2 array fed by microstrip configuration. L_1 and W_1 are chosen as the length and width of the substrate material with a thickness of 2.4 mm as shown in figure 1 (a) and (b) for front and back view of proposal with dimension given in table.1. Based on transmission line model [26], the width of radiating patch is desired first, length is calculated with fringing field consideration [27] and the trapezoidal shape is arranged to produce circular polarization.

3. RESULTS AND DISCUSSION

The antenna array proposed is designed and analyzed using FIT CST software and the simulated parameters are explained here. For desired radiation pattern, abrupt change in geometry which create discontinuity for electric and magnetic field has been introduced by line width at the feed line and radiating patch junction.

3.1. Return Loss

The return loss characteristic of the simulation is shown in figure 2 (a) which relate the maximum power transfer ability and impedance matching of the array. The array resonates at 1.891 GHz with -26.18 dB reflection coefficient and impedance bandwidth of 80 MHz (1.85 GHz- 1.93 GHz). The antenna bandwidth is the frequency range at which the return loss magnitude is below -10 dB and the reflected wave is less compared to incident wave. This represents the good impedance matching between the antenna and its feed line. This low and negative reflection coefficient prove that the antenna array is active and effective to deliver the power from source.

3.2. VSWR

Next parameters called voltage standing wave ration (VSWR) which related the efficiency of the antenna is shown in figure. 2 (b). The operating bandwidth (VSWR < 1.5) has been shifted to 60 MHz (1.92 GHz-1.86 GHz). The simulated VSWR of the proposed array antenna meets the practical requirements of (VSWR \leq 2) at the resonant frequency, where the VSWR is a measure for how the line is matching with the load.

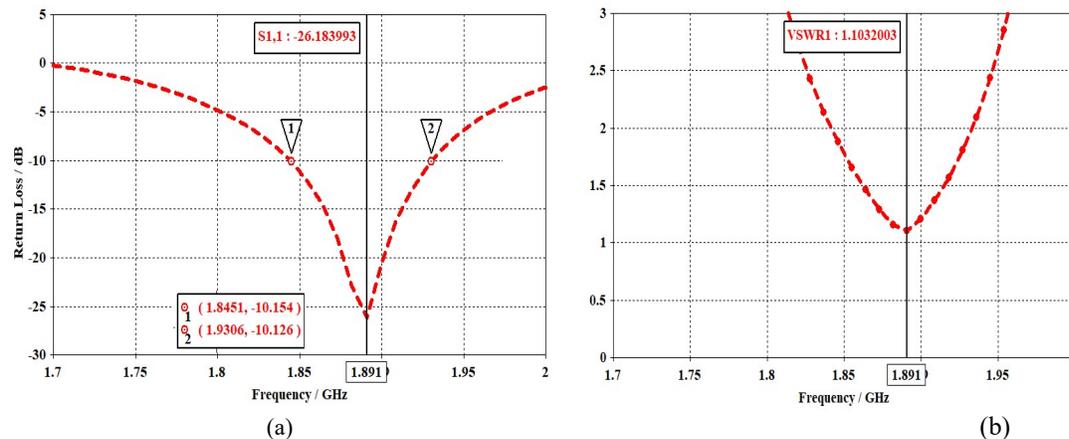


Figure 2. Characteristics of Microstrip Trapezoidal patch antenna array (a) return Loss (b) VSWR

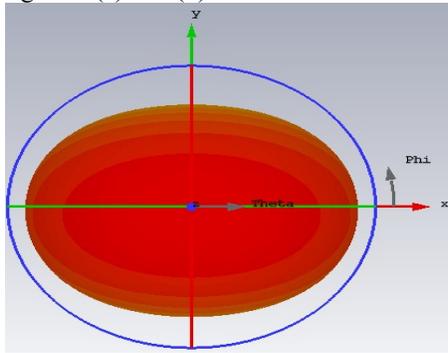
3.3. Far field patterns

Far field where the radiation effect is high, antenna parameters along with the antenna directivity and the radiation pattern of the antenna are considered in this region only. It is also defined as the region where the outgoing wave front is planar and the antenna radiation pattern has a polar variation and is independent of the distance from the antenna. Figure 3 represents the 2D and 3D radiation pattern behavior of array carried out at 1.89 GHz. It is observed that the proposed array antenna array exhibit directional pattern in electric and magnetic planes with gain of 4.98 dBi in 4 degree main lobe direction, 83.4 degree and 3 dB angular width. It radiates in side also with back lobe width -8.8 dB as shown in figure 3 (b).

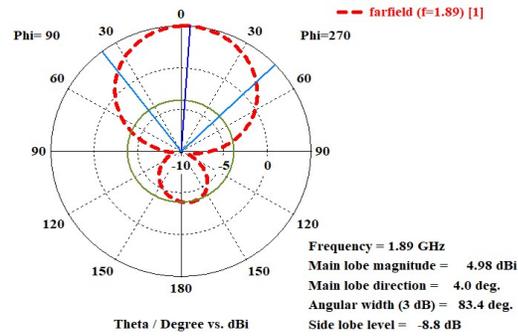
3.4. Surface current distribution

For further analysis of antenna performance the simulated surface current distribution is shown in figure 4 (a). It shows that the distribution of current has maximum value of 133.102 (A/m) which concentrated at feed line and adjacent to radiating patch beside the feed line. From the 3D radiation pattern, the far filed directivity can be calculated by evaluating the ratio between the radiation intensity and the average value of the radiation intensity. Since the radiation intensity is a function of power, the square of the far-field has to be used in the directivity expression in the radiation pattern settings window for the antenna directivity calculation. From figure 3 (b) it shows that the proposed antenna array exhibits 4.98 dBi directivity and the variation of directivity with respect to angle in z (conical cut) and x axis (planar cut) directions are shown in

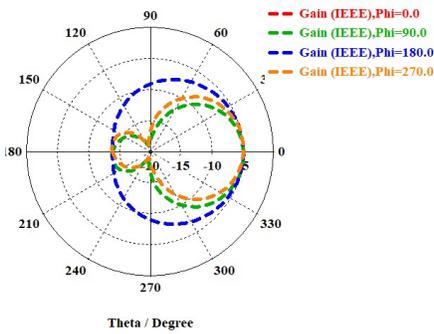
figure 4 (c) and (d) .



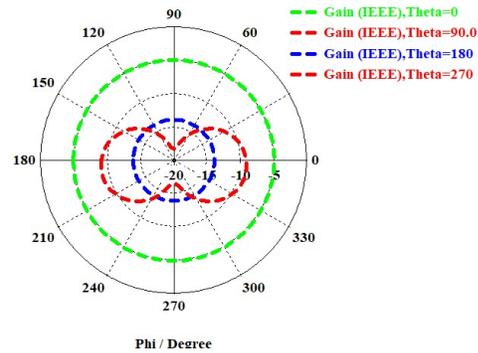
(a)



(b)



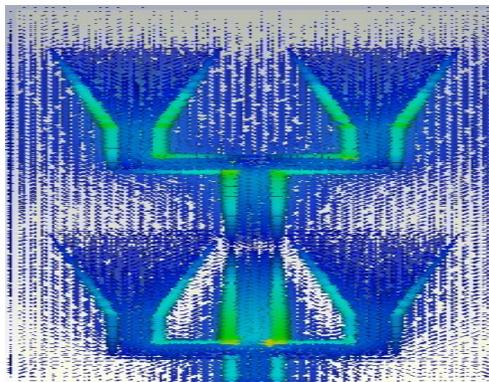
(c)



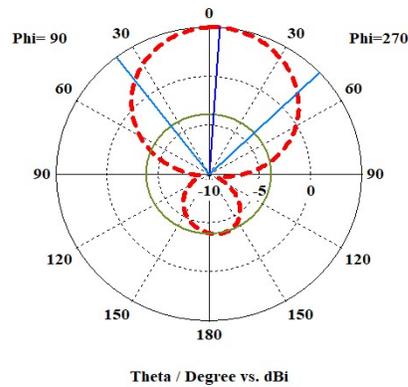
(d)

Figure 3. Farfield radiation pattern of antenna array (a) 3D (b) 2D view (c) Gain variation for different values of Phi (ϕ) produces a view that is parallel to the circuit layout plane (d) Gain variation for different values of Theta (θ)

Generally there are two ways or cuts to represent the directivity of an antenna. First one is the conical cut or theta cut where angle, Theta (θ) is kept constant and the angle, Phi (ϕ), related to x axis is swept from 0 to 360 degrees. The other is the phi cut or planar cut where phi is fixed and theta is swept. This produces the radiation pattern which gives the detail of directivity variation in parallel to the circuit layout plane as shown in figure 4 (c). The electric and magnetic field variation with respect to x direction angle of 0 and 90 degree are shown in figure 4(e) and (f) respectively. It shows that the electric and magnetic field have the maximum magnitude of 36093.4 (A/m) and 160.522 (A/m) respectively.



(a)



(b)

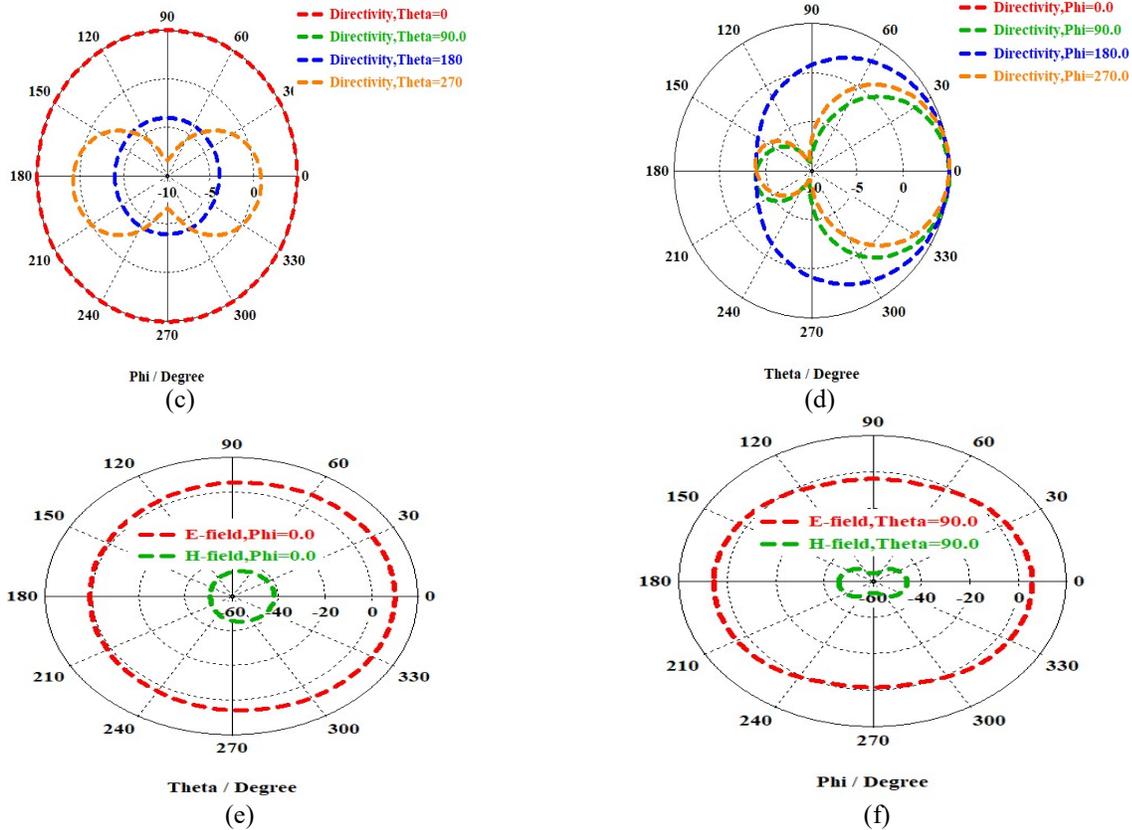


Figure 4. Far filed behavior of proposed array antenna (a) Current distribution (b) Directivity (c) and (d) Directivity variation in conical and planar cut (e) E and H filed distribution for Phi = 0 degree and (f) for Phi = 90 degree

The comparison of technical parameters which prove the efficiency of the proposed antenna array with the previous antenna models is tabulated in Table 4.

Ref.No	Antenna size	material	Operating bandwidth	Application
[17]	10 x 10 x 1.27 mm ³	Rogers	2.4 to 2.48 GHz	ISM
[18]	24 x 22 x 0.07 mm ³	Polymide	2.01 to 2.82 GHz	ISM
[19]	15 x 30 mm ²	-	Multiband < 2.45 GHz	MedRadio & ISM
[20]	25 x 35 mm ²	FR4	Ultra wide	Onbody
[21]	43 x 28 x 1.6 mm ³	FR4	2.27 to 2.57 GHz	Onbody & ISM
[22]	42 x 62 mm ²	RT Duroid	3.2 to 3.5 GHz 3.9 to 4.3 GHz	Onbody WBAN
[23]	25 x 20 x 0.07 mm ³	Polymide	2.45 to 2.48 GHz	ISM
This paper	30 x 70 mm ²	FR4	1.84 to 1.93 GHz	Onbody

4. CONCLUSION

In this paper microstrip trapezoidal four element antenna array using FR4 flexible substrate material has been proposed for onbody medical applications. The designed bandwidth of 80 MHz and 4.98 dBi gain with desired radiation characteristics of the proposed antenna array made them highly desirable for low frequency medical applications. The medical application antennas must take diverse shape on human body movements and the interaction with human body characteristics has to be investigated in future with fabricated model and validated.

DECLARATION

- ✓ **Funding:** The authors did not receive any funding from any organization for the submitted work
- ✓ **Conflict of interest/ Competing interest:** The authors have no Conflict of interest to declare that are relevant to the content of this article.
- ✓ **Availability of data and material:** Appropriate data are given in proposal & others maintained with author for further process.
- ✓ **Code availability** Not given in paper & available with authors for follow up & continuation of work.
- ✓ **Authors Contribution:**
- ❖ **Author 1:** Preparation of literature survey, problem identification & simulation work & validation
- ❖ **Author 2:** Simulation work, Paper editing and finalization as per the requirements.
- ✓ **Ethics approval:** Given instruction has been followed & accepted all terms.
- ✓ **Consent to participate:** Authors have consent to participate in the publication as per terms.
- ✓ **Consent for publication:** Authors have consent to publish the proposed paper as per terms.

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Figures

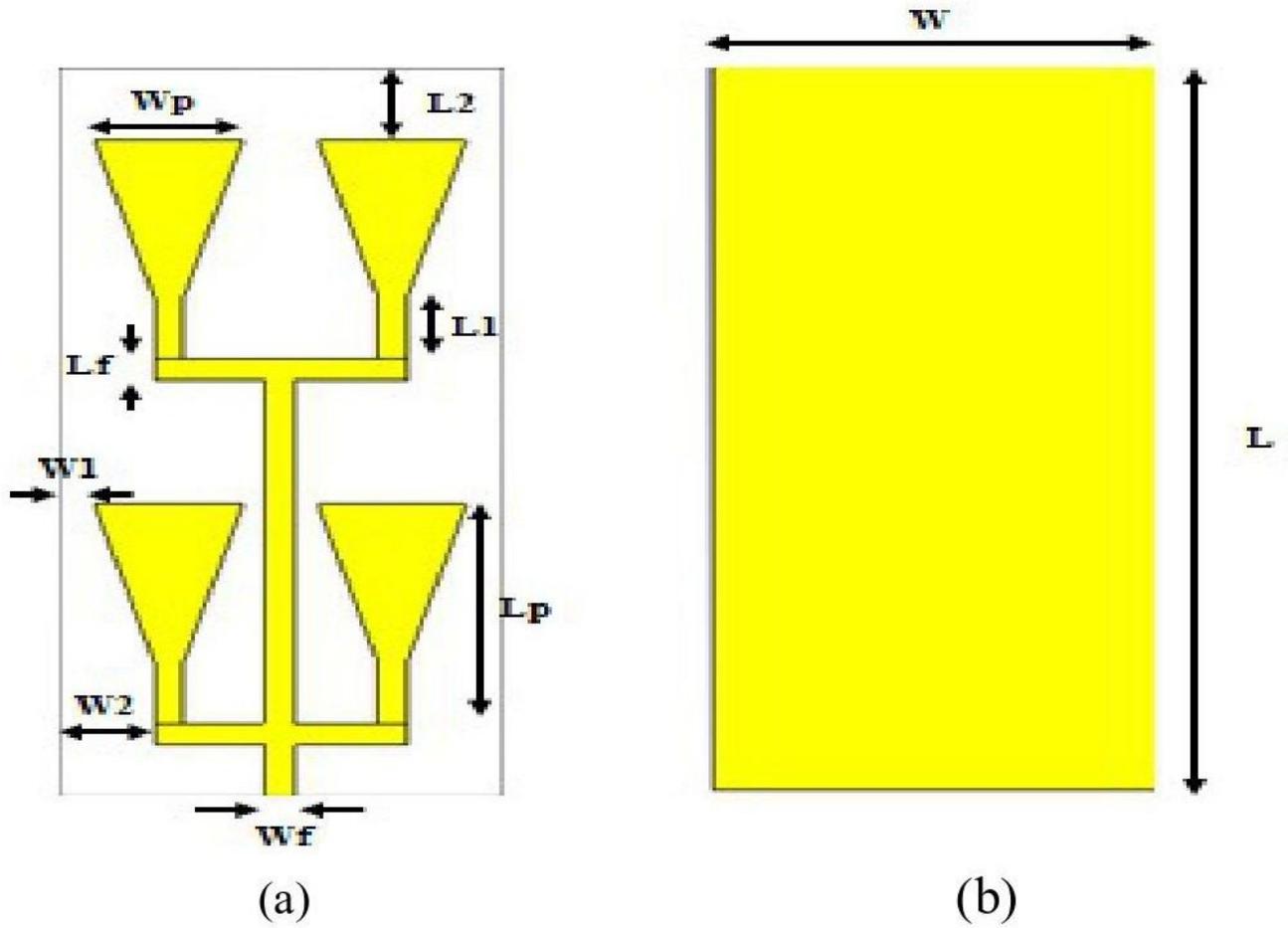


Figure 1

Proposed Trapezoidal patch antenna array (a) Front view (b) Back view

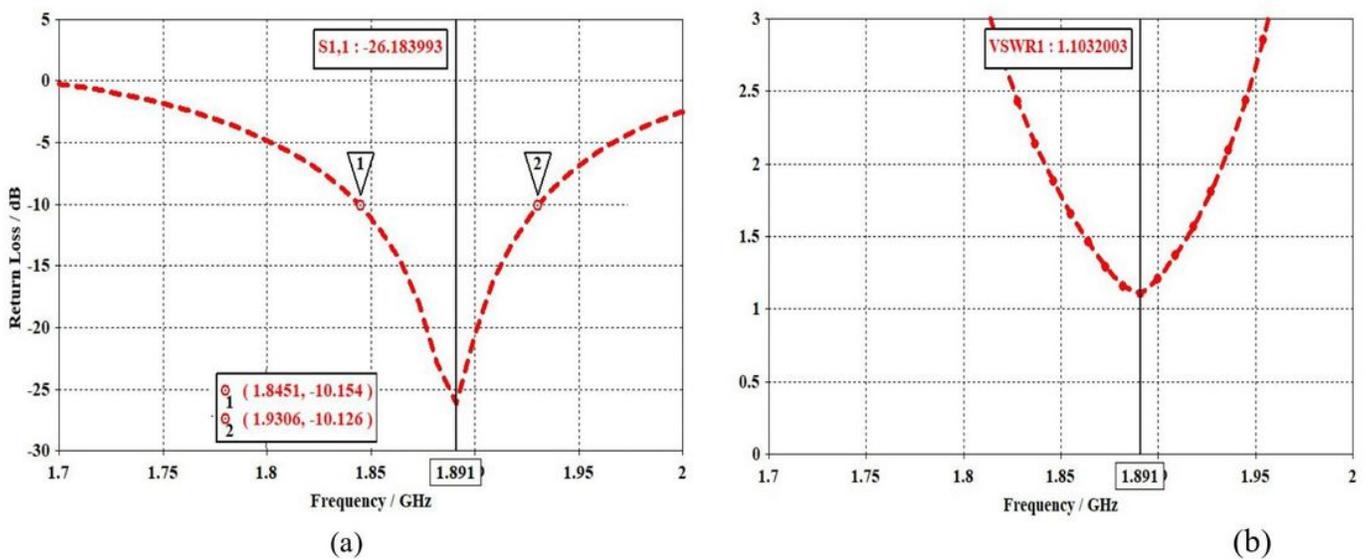
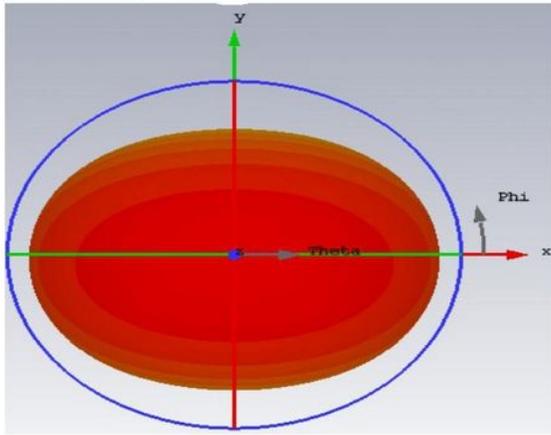
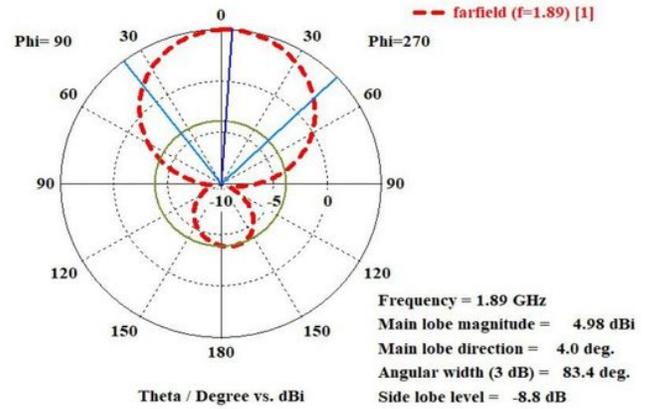


Figure 2

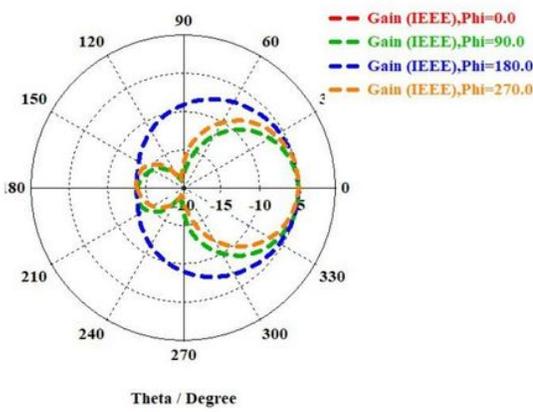
Characteristics of Microstrip Trapezoidal patch antenna array (a) return Loss (b) VSWR



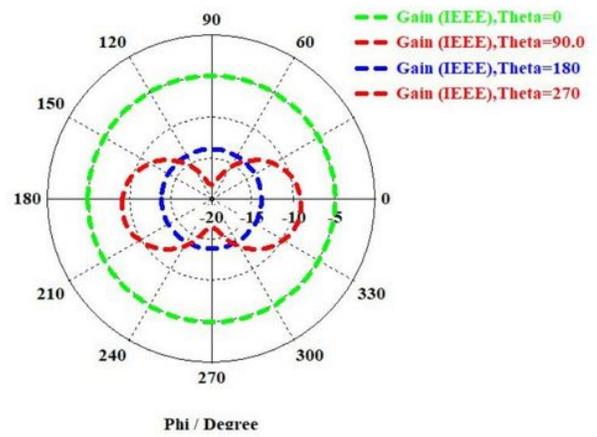
(a)



(b)



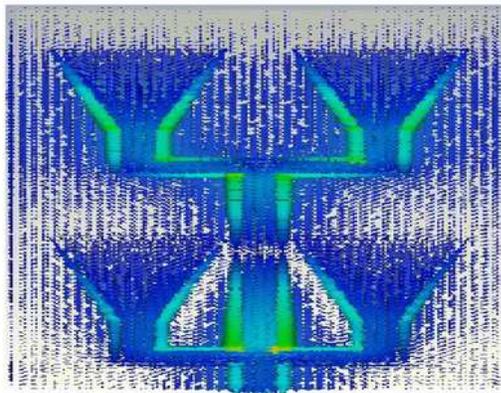
(c)



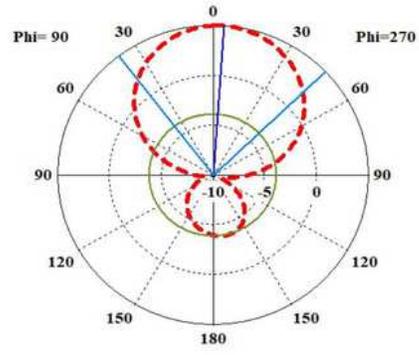
(d)

Figure 3

Farfield radiation pattern of antenna array (a) 3D (b) 2D view (c) Gain variation for different values of Phi (Φ) produces a view that is parallel to the circuit layout plane (d) Gain variation for different values of Theta (θ)

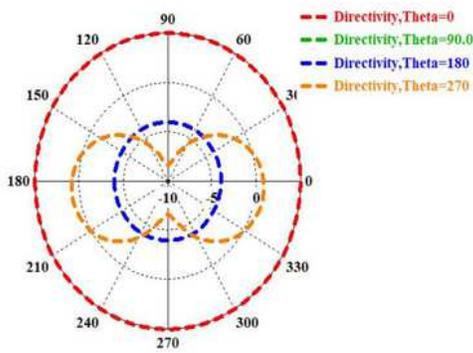


(a)



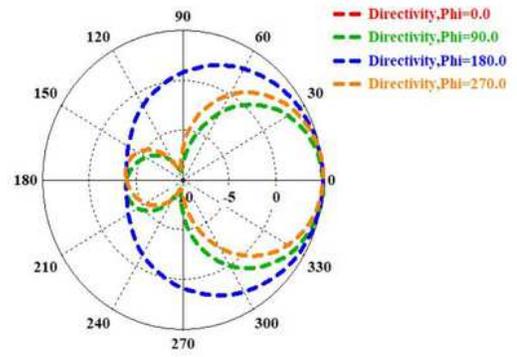
Theta / Degree vs. dBi

(b)



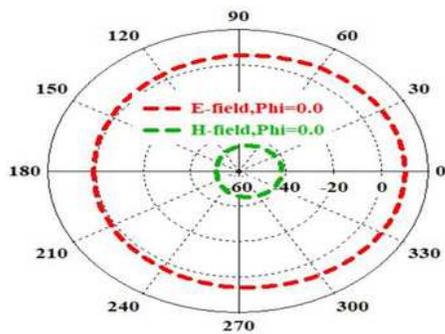
Phi / Degree

(c)



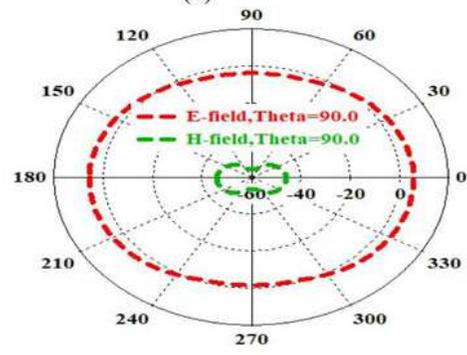
Theta / Degree

(d)



Theta / Degree

(e)



Phi / Degree

(f)

Figure 4

Far field behavior of proposed array antenna (a) Current distribution (b) Directivity (c) and (d) Directivity variation in conical and planar cut (e) E and H field distribution for Phi = 0 degree and (f) for Phi = 90 degree