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Design and Analysis of Broadband Elliptical Microstrip Patch Antenna for Wireless Communication

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Abstract

In this paper presents the design and manufacture of a new broadband elliptical patch antenna with a microstrip feed line and optimum antenna parameters. The antenna dimension of $(30\times 21\times 1.6)\ mm^3$ *and fabricated on an FR-4 epoxy substrate having relative dielectric constant* ε_r*=4.3, loss tangent tan (δ)=0.002 and the feed line used has characteristic impedance of 50Ω.The designed antenna has the capability of operating in the bandwidth (6.95-30.94) GHz and the gain (6.8) dBi. The antenna performance was modified by inserting a slots in the ground plane to achieve impedance bandwidth (when* $S_{11}\leq$*-10dB) and slots to patch to improve the gain. The modified antenna was designed to be used for fifth generation (5G) mobile communication. The simulation results are obtained using CST software.*

Keywords: *microstrip antenna, SWR, field configuration, elliptical patch antenna, radiation pattern*

1. Introduction

The basic form of microstrip antennas consist of a conducting patch printed on a ground substrate has impedance bandwidth of (1-2) %. With a radiated patch on one side of a dielectric substrate which contains ground plane on the other side. The patch is placed above the ground plane; it is very thin and made of conducting material such as copper. Microstrip antennas offer the advantages of lightweight, low cost, thin profile, suitability to the shaped surface, and easily integrated into a system that can be used in mobile satellite communications, the direct broadcast system (DBS), remote sensing, and hyperthermia in addition to military application. The emitted radiation power increases with frequency. A microstrip antenna is made for a wide range of resonant frequencies polarization patterns and impedances and because of its operation features (i.e low power, high Q, very narrow bandwidth), it is used for 5G mobile and security systems which require narrow bandwidth. There are three common models for the analysis of microstrip antennas; they are transmission line model, cavity model and full wave model. The transmission line model is the simplest and less accurate; the full wave model is the most complex and is very accurate. The time average pointing vector can be written as [1].

$$S_{av}=\frac{1}{2}Re[E\times H^*]\quad w \tag{1}$$

In the present day, life mobile has become an essential part of our life. Earlier mobile phones were carried out for the purpose of talking to people. But now, the mobile phone application has increased to such a high extent that it has emerged an important necessity for everyone to carry out their day to day activities like shopping, trip planning, navigation etc [2].

To fulfil all the needs of the fifth generation (5G) wireless system to facilitate higher data rate, better reliability, more connectivity, lower latency and improved security features wireless system designers need a new concept and design approach. Recently some work has done by the authors in designing 5G antennas that have published the millimetre wave (mm-wave) frequencies are likely to use by fifth generation [3].

The broadband elliptical microstrip patch antenna has been investigated in literature as follows. Mohamed B. El-Mashade, Ehab A. Hegazy [4] presents four elements 28GHz micro-strip patch array antenna for future 5G mobile phone applications. Mohammed H. Abu Saada designs for microstrip antennas single element and arrays at 28 GHz, where 28GHz is one of

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the standard frequencies of the 5G communications [5]. As well as the different techniques for the broadband elliptical microstrip patch antenna that the research shown is specific to the subject [6-9].

2. Theory of Elliptical Antenna

The early communication systems supported only analog voice and now provide a wide range of different applications to a large number of users. The first generation of the mobile system supported voice only. Within last few years, we have seen the gradual development of mobile communications by birth of 2G, 3G and 4G wireless networks respectively.Digital networking communication techniques like modulations, cellular frequency reuse, packet switching and physical layer simulation etc have resulted in this change. With the increasing demand of smart devices, now a day's IP based networks has become a necessity. Resultant new multimedia applications for mobile users. Market is flooded with these applications and has open up new ventures for mobile user and service providers.The future of mobile communications is likely to be very different to that which we are used to today. While demand for mobile broadband will continue to increase, largely driven by ultra high definition video and better screens, we are already seeing the growing impact of the human possibilities of technology as the things around us become ever more connected. The upcoming 5th generation cellular network ("5G") is anticipated to exhibit a uniform Gbps data throughput experience across a vast range of user scenarios [10].

5G is more than just a new wireless radio technology. It is a door opener to new communications possibilities and use cases, many of which are still unknown. Enabled by 5G, a programmable world will transform our lives, economy and society. Data throughput will be enhanced by more than a hundred fold. Figure 1 illustrates the analytical model of an elliptical microstrip which is excited by a coaxial probe extending through the ground plane and substrate [11]. In this model, the current distribution of the probe can be modelled as (2).

$$J_s = \hat{Z}\, I_o/\pi r_o \tag{2}$$

where I_o is the total current flowing on the cylinder of diameter r_o

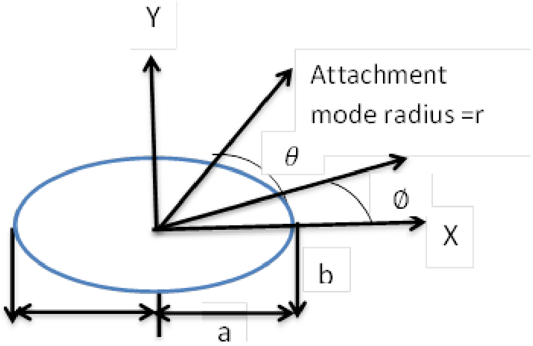


Figure 1. Elliptical microstrip antenna

The elliptical patch is modelled by two circular patches whose radii pertain to the major and minor axes of the elliptical patch respectively, so the total currents on the patch can be expressed as the sum of currents on the two circular patches.

$$J_{1(\rho,\phi)}= \sum_{n=1}^{\infty} a_n^1\ F_n^1\,(\rho,\phi) \tag{3}$$

$$J_{2(\rho,\phi)}= \sum_{n=1}^{\infty} b_n^1\ F_n^2\,(\rho,\phi) \tag{4}$$

where $F_n^1(\rho,\phi)$ and $F_n^2(\rho,\phi)$ are the basic functions of the unknown currents on the each circular patch and a_n^1 and b_n^1 are complex coefficients of the unknown currents on each circular patch. The basic functions could be expressed in terms of modal electric fields in an infinite electric conductor and the same functions were used for test functions, that is, the procedure was followed. The attachment mode needs special types of basic functions to model the current in the vicinity of the probe patch junction and can be usually negligible for thin substrates but cannot be ignored for thick substrates. Therefore, attachment mode is assumed to exist on the fictitious small circle and replaced by the coaxial waveguide with an inner radius $\frac{r_o}{2}$ and outer radius r. The total currents on the patch and probe are expanded into.

$$J_{s(\rho,\phi)} = \sum_{n=1}^{N} a_n F_n(\rho,\phi) + \sum_{m=1}^{M} b_m F_m(\rho,\phi) + (F_{at\ tach}) \tag{5}$$

where $F_n(\rho,\phi)$ and $F_m(\rho,\phi)$ is are the basic functions on the patch and on the probe respectively and, $(F_{at\ tach})$ is the attachment mode [12].

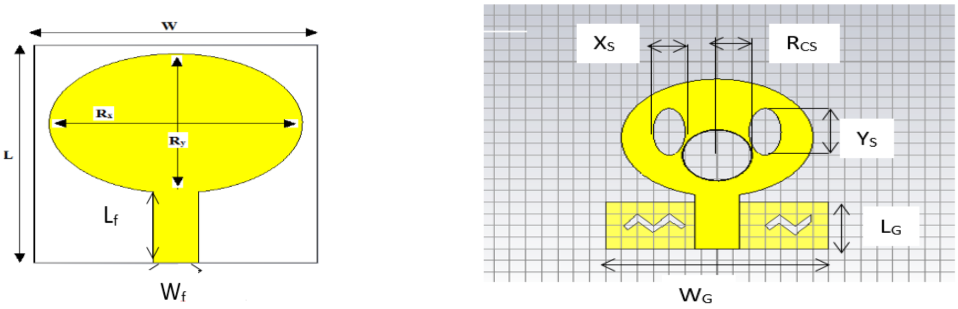
Most of the rapid advances in microstrip antennas these were driven by defense and space applications. Then this technology is growing rapidly in the commercial sector. Specifications for defense and space application antennas typically emphasize maximum performance with little constraint on cost. On the other hand, commercial applications demand low cost components, often at the expense of reduced electrical performance. Thus, microstrip antennas for commercial systems require low cost materials, simple and inexpensive fabrication techniques. Some of the commercial systems that presently use microstrip antennas are listed in the Table 1 [13], and more information about to subject shows in references [14-21].

Table 1. Microstrip Antenna Applications

Application	Frequency
Global Positioning Satellite	1575 MHz and 1227 MHz
GSM	890-915 MHz and 935-960 MHz
Wireless Local Area Networks	2.40-2.48 GHz and 5.4 GHz
Cellular Video	28 GHz
Direct Broadcast Satellite	11.7-12.5 GHz
Automatic Toll Collection	905 MHz and 5-6 GHz
Collision Avoidance Radar	60 GHz, 77 GHz, and 94 GHz
Wide Area Computer Networks	60 GHz

3. Design Antenna and Simulation Result

The geometry of the proposed antenna for future 5G wireless mobile communications is shown in Figure 2(b) and manufactured is shown in Figure 3. The patch of the antenna in the shape of an ellipse and its all dimensions are illustrated in Table 2. The antenna is designed on a compact FR-4 substrate with relative Permittivity (ε_r) of 4.3 having dimensions $(30 \times 21 \times 1.6)$ mm^3.The proposed geometry is simulated in CST and the bandwidth with reflection Coefficient (S11) is observed shown in Figure 4 and the gain is around (6.8) dBi as shown in Figure 5.



(a) (b)

Figure 2. The Elliptic antenna (a) prototype antenna, (b) improvement antenna Patch, microstrip and ground

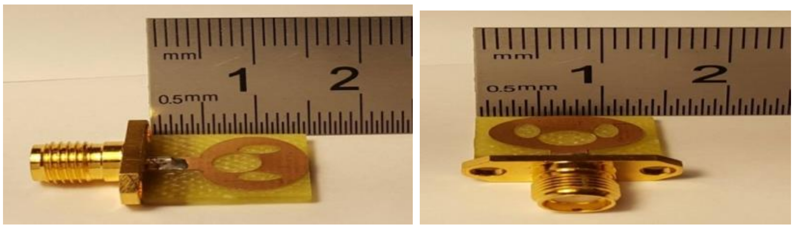


Figure 3. The practical proposed antenna

Table 2. Design Parameters

Parameters	Values in mm	Parameters	Values in mm	Parameters	Values in mm
W	30	L	21	H	1.6
Rx	6	Ry	5	Wf	2.8
Lf	5	XS	1	YS	2
RCS	2.2	LG	4	WG	14

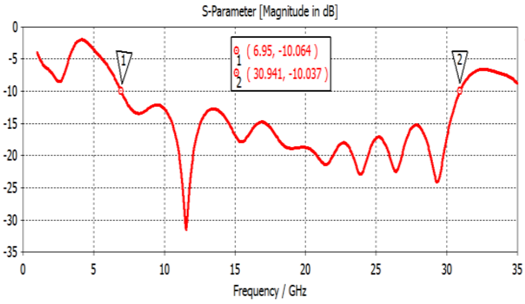


Figure 4. The Reflection Coefficient Versus frequency

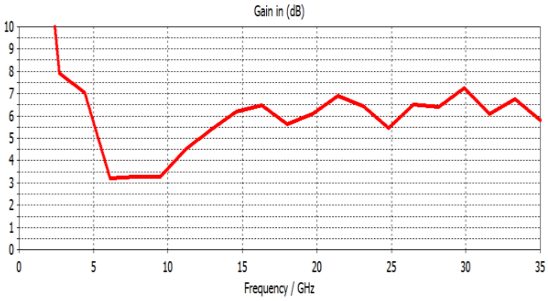


Figure 5. Variation of gain with the frequency of the proposed antenna

The Practical Reflection Coefficient Versus frequency to 20 GHz as shown in Figure 6. The proposed antenna practically has been good results have been obtained compared to the simulation results shown in Figure 7. The slight difference in process results and simulation is due to the feeder soldering as well as the connections of the vector network analyzer.

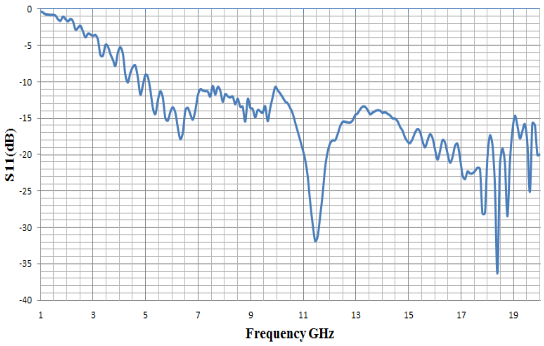


Figure 6. The Reflection Coefficient Versus frequency of practical results

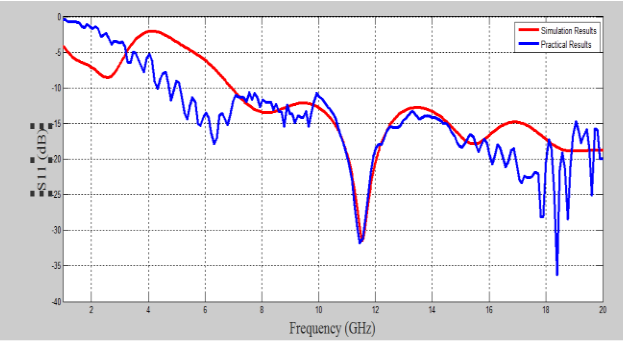


Figure 7. The compere reflection coefficient Versus frequency of results simulation and practical

The group time delay of the antenna designed should be able to transmit the electrical pulse with minimum distortion is calculated of the proposed antenna is around to zero with variation is than 0.1 sec due the frequency band from (6.95-30.94) GHz as shown to Figure 8 and the voltage standing wave ratio (VSWR) is also less than ≤ 2 as shown in Figure 9 so that the VSWR is the ratio of maximum voltage or current to minimum voltage or current at any point it considers as measure for the mismatch between the line and the load. The final antenna has an impedance bandwidth of (6.95 to 30.94) GHz real and imaginary parts of the input impedance is shown in Figure 10 and Figure 11 respectively.

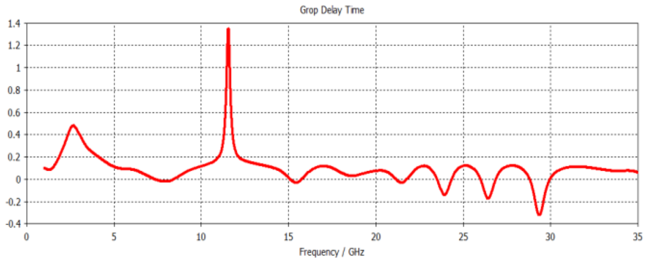


Figure 8. The group time delay to the proposed antenna

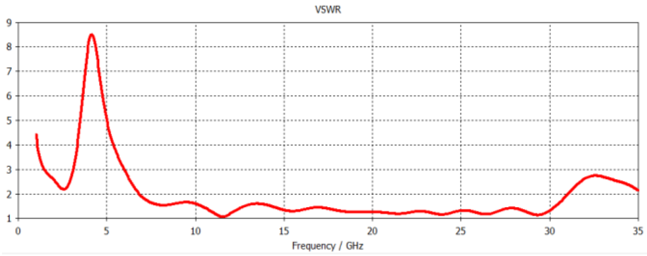


Figure 9. The VSWR of proposed antenna

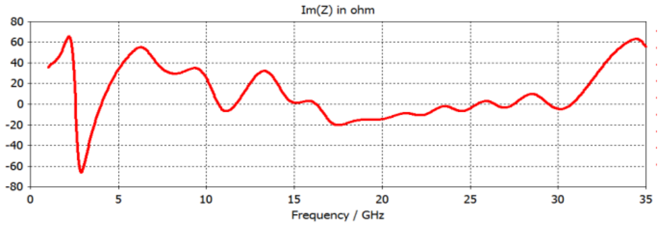


Figure 10. The real impedance of the proposed antenna

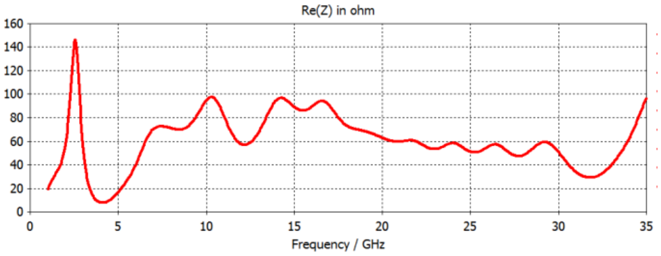
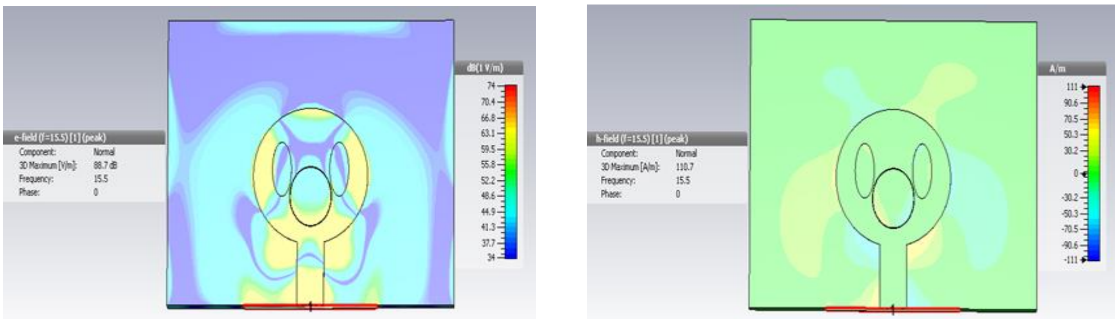


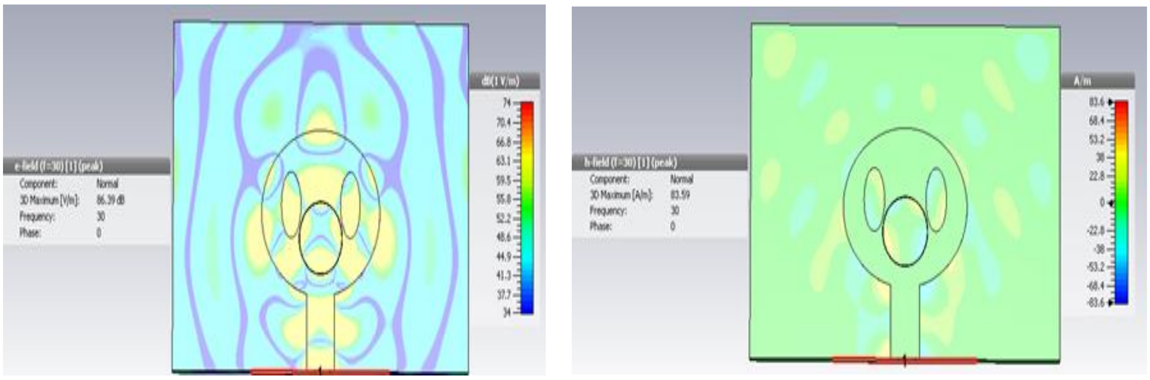
Figure 11. The imaginary impedance of the proposed antenna

The result 2D/3D as shown in Figure 12. Figure 12 show to E-field and H-field distribution for frequency 15.5 GHz and 30 GHz in Figures 12 (a,b,c,d) respectively and current surface distribution in Figure 12 (e,f). Figure 12 (g,h) show far-field polar form and gain pattern in frequency 15.5 GHz is 6.48 dB and frequency 30 GHz is 5.16 dB.


e-field (f=15.5) [1] (peak)
Component: Normal
3D Maximum [V/m]: 88.7 dB
Frequency: 15.5
Phase: 0

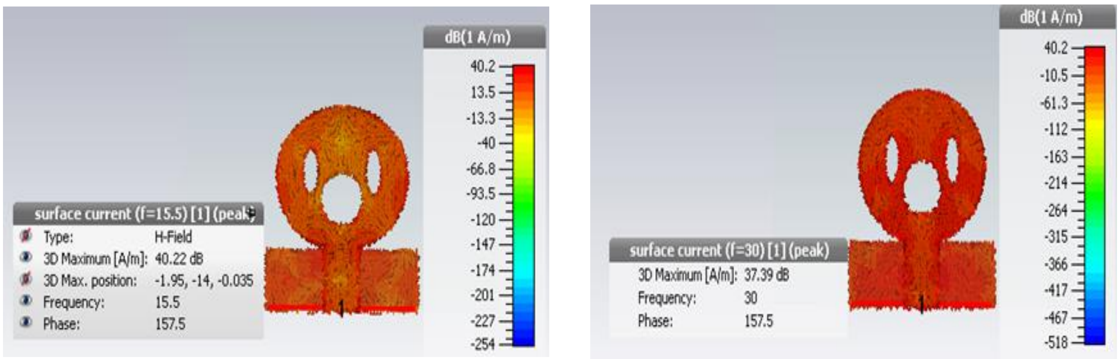
h-field (f=15.5) [1] (peak)
Component: Normal
3D Maximum [A/m]: 110.7
Frequency: 15.5
Phase: 0

(a) E-Field distribution at f=15.5 GHz (b) H-Field distribution at f=15.5 GHz


e-field (f=30) [1] (peak)
Component: Normal
3D Maximum [V/m]: 86.39 dB
Frequency: 30
Phase: 0

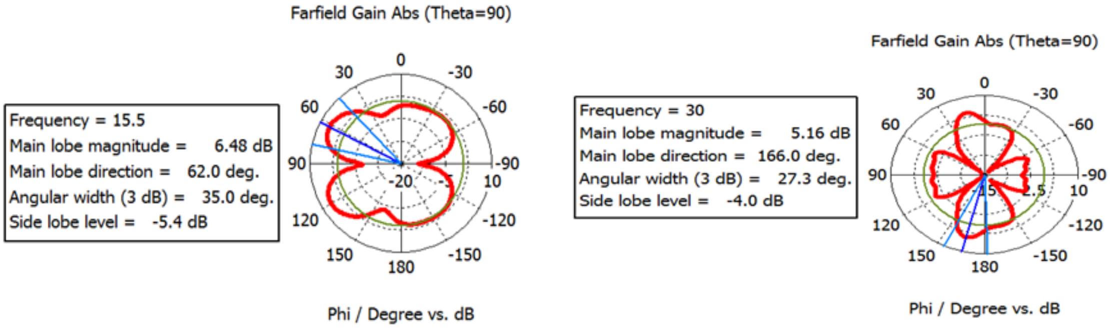
h-field (f=30) [1] (peak)
Component: Normal
3D Maximum [A/m]: 83.59
Frequency: 30
Phase: 0

(c) E-Field distribution at f=30 GHz (d) H-Field distribution at f=30 GHz


surface current (f=15.5) [1] (peak)
Type: H-Field
3D Maximum [A/m]: 40.22 dB
3D Max. position: -1.95, -14, -0.035
Frequency: 15.5
Phase: 157.5

surface current (f=30) [1] (peak)
3D Maximum [A/m]: 37.39 dB
Frequency: 30
Phase: 157.5

(e) Current surface distribution at f=15.5 GHz (f) Current surface distribution at f=30 GHz


Frequency = 15.5
Main lobe magnitude = 6.48 dB
Main lobe direction = 62.0 deg.
Angular width (3 dB) = 35.0 deg.
Side lobe level = -5.4 dB

Frequency = 30
Main lobe magnitude = 5.16 dB
Main lobe direction = 166.0 deg.
Angular width (3 dB) = 27.3 deg.
Side lobe level = -4.0 dB

(g) Farfield polar form at f=15.5 GHz (h) Farfield polar form at f=30 GHz

Figure 12. Farfield 2D/3D results (a,b,c,d,e,f,g,h)

The farfiled broadband to the proposed antenna as shown in Figure 13. Figure 13 show the total gain pattern with 3 dB angular width is 20.6 dB.

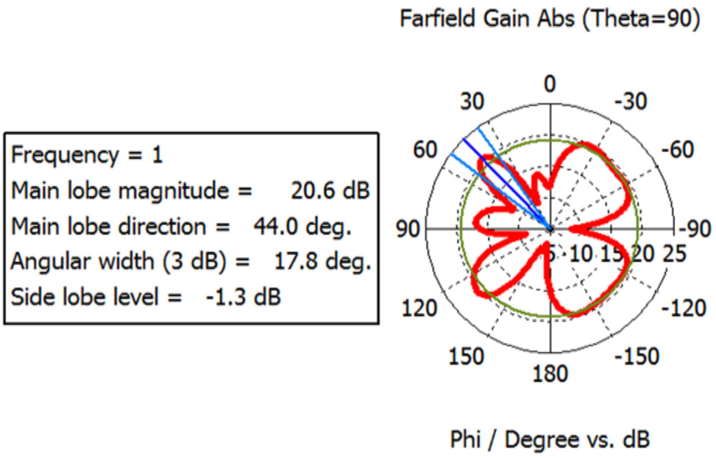


Figure 13. Gain pattern for fairfield broadband to the proposed antenna

4. Conclusion

A new broadband microstrip elliptical antenna in suggested and studied with optimum parameters using an FR-4 substrate with relative dielectric constant $\varepsilon_r = 4.3$. The bandwidth is (6.95-30.94) GHz which covers many wireless applications (such as 5G mobile communications and maximum gain of 6.8 dBi .It is also noted that the slots in the ground improve the bandwidth when as the slots in the patch modify the gain and fabricate the proposed antenna and test it using the vector network analyzer (VNR) and compare the simulation and test results it is good results. Also the gain can be improved by proposing antenna array all these suggestion are required to make the proposed antenna to serve the new generations of mobile communications. The size of the proposed elliptical antenna is $(30 \times 21 \times 1.6)\, mm^3$. The antenna has a good the bandwidth frequency is 24GHz with 2D/3D total gain broadband pattern with 3 dB angular width is 20.6 dBi.

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