NOVEL DESIGN AND ANALYSIS OF KU-KA ANTENNA

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Abstract

In this paper reports the design a compact antenna size, Tri band characteristics, Quad arm shaped patch antenna is presented. The fabrication of the proposed antenna is performed with variable rectangular slots and a FR4 Epoxy dielectric substrate material with 1.2mm thickness. The Electric field distributions of this proposed antenna exposed that most of the element area and its radiated at both resonances and fed by coaxial feeding techniques. In order to obtain Tri band operation in conventional the multi length rectangular slot is introduced in the shape of arm. The Proposed antenna impedance bandwidth (1.2:1VSWR) achieved is 0.8GHz (16.4-17.2GHz) on the lower (Ku) band and 1.3 GHz (25.9-27.2GHz) on the upper (Ka) band. An extensive analysis and investigate of the return loss, radiation pattern, gain and efficiency of the proposed antenna using Ansoft HFSS in this paper. The Omni directional radiation pattern format, stable peak gain, small group delay and transfer function variation was observed on the whole band frequency range, which makes it suitable for being used in the Ku/K/Ka band for wireless sensor network (WSN) and future LTE MIMO Systems.

Keywords: Ku/K/Ka Band, LTE, MIMO System, Quad Arm shape Patch antenna, Rectangular Slot, Tri-band, WSN.

Introduction

Background and Motivation

In Rapid growth of Communication world the Wireless Sensor Networks performs tremendous operation and also we called as Environmental Sensor Networks (ESN), Object Sensor Networks (OSN), Medical Sensor Networks (MSN) and so on, In Recent technological advances have fueled the development of a miniature, low-cost, and low-power node which is applicable to a wide range of applications for WSNs. It is expected that WSN and its technology will be penetrated into our daily life and become a rife communication that promises an unprecedented ability to monitor, instrument and eventually control the physical world. These networks are usually short-lived and created in short-frequency to respond to a change in stimuli in the area under observation.

The Federal Communication Commission (FCC) [3]-[6] as the frequency band that from 500 MHz to 40 GHz is broken into several groups such as 500-1000 MHz for VHF, 1-2 GHz for L band, 2-4GHz for S band, 4-8 GHz for C band, 8-12.4 GHz for X band, 12.4-18 GHz for Ku band, 18-26 GHz for K band and 26.5-40 GHz for Ka band. Among these bands all wireless communication devices developed. From the above frequency spectrum are motivated to design an antenna that operates in Ku, K and Ka band in unique pattern. Many researchers have worked and presented the techniques for getting multiband operation using multi stack patches [10]. Using U-slot loaded patch stacked with H-shaped parasitic elements [11]. In [12] an annular ring patch is loaded with a slot, where the loaded slot makes the design capable for dual band operation. Two asymmetric horizontal strips are used as additional resonator to produce the lower and upper resonant modes [13]. Although U-slot patch antenna is used is concerned with broadband capabilities, however since the U slot introduces another resonance; a dual band antenna can be obtained, to obtain triple band a second slot is needed [14]. Multi frequency operation can also be achieved using spiral printed antennas, Bowtie patches loaded with slots, multiple patches, cutting rectangular patch with

L-shaped slit, U-slot and inserting slits [8]-[9], [15] -[16]. PIFA (planar inverted F structures antenna) structures can be used for multiband applications [17]. Dual frequency operation in Ku band is achieved loading notches and slits in antenna patch [18]. In the reference[19] a new X shaped slotted multiband antenna was designed with a 1.905 mm high dielectric material substrate with bandwidths of 528 MHz (15.104 GHz–15.632 GHz) , 576 MHz (17.336 GHz– 17.912 GHz) and 804 MHz (18.476 GHz-19.280 GHz) and 4.80 dBi , 6.72 dBi and 3.91 dBi peak gain. As the Literature rectangular Micro strip antenna is its narrow bandwidth and lower gain. The bandwidth of Micro strip antenna may be increased using various techniques such as use of a thick or foam substrate, cutting slots or notches like W slot, E shaped, plus shaped patch antenna, introducing the parasitic elements either in coplanar or in stack configuration, defected ground plane and modifying the shape of the radiator patch by introducing the slots [20 -25]. To overcome the Narrow bandwidth and lower gain generally Quad arm with rectangular slot Micro strip patch antenna in this paper. It radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Micro strip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance [26-30].

Scope and structure of the paper

With reference of above background and motivation and Based on our occurrence we have attempted to design Multi length Quad arm-oriented, tri band antenna which should satisfy the following specifications.

- Display a bandwidth at 800 MHz in the vicinity of 16.4-17.2GHz at 16.8GHz, thus a fractional bandwidth FBW ≥ 4% and VSWR is 1.21 i.e., VSWR<2
- Display a bandwidth at 1200 MHz in the vicinity of 19-20.2GHz at 19.8GHz, thus a fractional bandwidth FBW ≥ 6% and VSWR is 0.657 i.e., VSWR<2
- Display a bandwidth at 1300MHz at the lower end of the 22.2-23.5GHz at 23.0GHz range, thus a fractional bandwidth FBW ≥ 5% and VSWR is 1.354 i.e., VSWR<2
- Display a bandwidth at 1300 MHz in the vicinity of 25.9-27.2GHz at 26.4GHz, thus a fractional bandwidth FBW ≥ 4% and VSWR is 0.952 i.e., VSWR <2
- Achieve total radiation efficiency over both bands are above >95%. The simulated antenna has 4.6GHz bandwidth (at VSWR < 2) and lower band has 1.37 db and higher band has 3.3 dB, Peak gain is 4.98dB and Peak directivity is 8.35dB.

This paper describes the design of Quad arm shape Patch antenna that has been linearly polarized and coaxial feeding techniques with rectangular slots. The effect of the size of the ground plane on both frequency bands was also investigated. Section 2 discusses design and modeling issues. Section 3 Parametric Study and numeric results. Section 4 discusses the results and discussion.Section5 concludes the paper [31- 35].

Antenna Architecture and Optimization

Fig.1. shows the geometry of the proposed quad arm shape Patch antenna. It shows the layout of a coaxial probe-fed slotted patch antenna. First the ground plane of Length L and Width W is made and then a rectangular patch of same dimensions is fabricated above the ground plane .The proposed quad arm shape Patch antenna is located on the x–y-z plane. This antenna is fabricated on a low-cost FR4 epoxy substrate with the thickness of 1.2 mm, relative dielectric constant of 4.4, and loss tangent of 0.008. On the front surface of the substrate of each quad arm shape Patch antenna, fed by a Micro strip line 50Ω with 1mm of width. The ground plane size is 60 × 60mm2, and the distance between the radiating patch to the ground plane printed on the back surface substrate is 1mm [36 – 40].

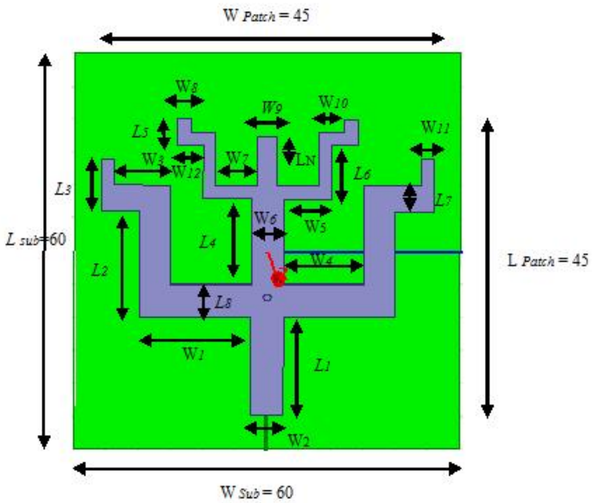

Fig. 1. Geometry of the proposed Quad arm shape Patch antenna

The Optimal dimensions of various size rectangular slot and Quad arm shape of proposed antenna as follows: Wsub = 60mm, Lsub = 60mm, LPatch = 45mm, WPatch = 45mm, W1= 7..5mm, W2 = 2mm, W3 = 3mm, W4 = 2mm, W5 = 2mm, W6 = 3mm, W7 = 3mm, W8 = 4mm, W9 = 3mm, W10 = 2mm, W11 = 2mm, W12 = 2mm, L1 = 6mm, L2 = 3mm, L3 = 3mm, L4 = 3mm, L5 = 2mm, L6 = 2mm, L7 = 2mm, and LN = 7.3mm.The Height of the feed gap between the main patch and ground plane t=1mm is also important parameter and its define the impedance bandwidth since t is the thickness of the substrate. In the broad view the ground plane serves as an important impedance matching circuit and its tuning the resonant frequencies. By adjusting t, the electromagnetic coupling between the ground plane and patch can be controlled. When adjusting LN Length of the rectangular slot or cutting the slot to see the different resonant frequency [41 – 45].

The proposed antenna exhibits tri-band characteristics. The two operating bands 17GHz (Ku-band)an having return loss-20db and 19GHz ,20.2GHz, 22.6GHz,23.4GHz(K band) an having return loss -15.6db,-27.7db,-16.3,-17.0 and 26.4GHz (Ka-band) frequency an having return loss -26.3db frequency bands. The Coaxial feed or probe feed is a very common technique used for feeding Micro strip patch antenna .In this paper coaxial feeding techniques were used. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. In this proposed antenna when compared to the loss tangent and permittivity of substrate material the FR4 epoxy is having very less permittivity value is 4.66 and loss tangent value is 0.0012. In below the Table 1 showing the different substrate material property value.

Table 1. Substrate Magnetic Properties

Material	Permittivity	Loss Tangent
Duroid6010	10.2	0.0023
Al203	9.8	0.0009
FR4 Epoxy	4.66	0.0012

The simulated voltage standing wave ratio (VSWR) of the proposed antenna without band-rejected is analyzed in this paper. The parameters of the reference antenna are optimized to get a VSWR that is less than 2 and to get stable radiation characteristics throughout the frequency band 16 GHz to upper than 30GHz.To overcome the unwanted electromagnetic interferences of communication systems with K series band, the half wavelength vertical up rectangular slots are inserted in both side of the radiating patch. To increase the length of the LN rectangular slot or to cutting the slot shown in Fig.1.to achieve the different gain with VSWR value show in Return loss graph. The geometry of the proposed triple band without notched antenna is depicted in Fig.3. The HFSS software is employed to perform the design process [45 – 50].

The patch can also be fed with a probe through ground plane. The probe position can be inset for matching the patch impedance with the input impedance. This insetting minimizes probe radiation. The ease of insetting and low radiations is advantages of probe feeding as compared to Micro strip line feeding. The dimension of proposed quad arm shape patch antenna is shown in Fig.1.designed at operating frequency from 16 GHz to 26.4 GHz.

The length, width, VSWR, and return loss of the patch antenna can be calculated from equation (1) is presented in [7], where L and W are the length and width of the patch, C is the velocity of light, εr is the dielectric constant of the substrate, h is the thickness of the substrate, $f0$ is the target centre frequency, εe is the effective dielectric constant, and ρ is the radiation coefficient. In order to achieve wide-band operation, the tuning parameters of the matching network have been studied. By adjusting the Length of the Rectangular micro strip line, it has been a trade-off between impedance bandwidth and initial frequency is employed.

Parametric Study and Numeric Results

A parametric study of the proposed quad arm shape Patch antenna was carried out .By adjusting the total length of each slot to be about a half-wavelength at the desired notched frequency, a vicious interference can take place, and triple band at 16.8/19/23/26.4 GHz frequencies center are achieved. Details of the influence of each parameter on the proposed triple band antenna will be studied in this section. The discussed parameter is changed, and the other parameters are kept unchanged.Fig.2.shows the effects of the Rectangular slots LN =5.4mm in the conventional rectangular shape to triangular slot patches sequentially Rectangular slots with LN =5.4mm It is clearly said that the proposed reference antenna reflection coefficient is better than others [51 – 56]. In Fig.2 the authors have investigated the different size of rectangular values of LN. From these Figures, it could be easily observed that the LGnd=60mm, WGnd=60mm, P1length=45mm, P1width=45mm and LN =7.3mm are the best parameter for good impedance bandwidth and reflection coefficient.

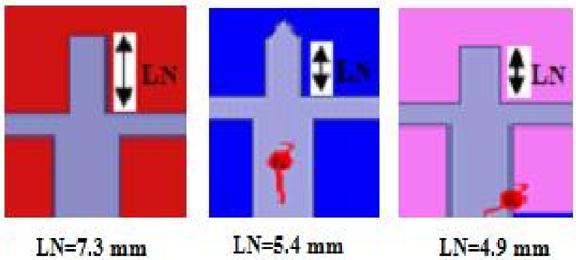

Fig. 2. Geometry of the proposed Quad arm shape Patch antenna LN = 7.3 mm with LN = 5.4 mm and LN = 4.9 mm

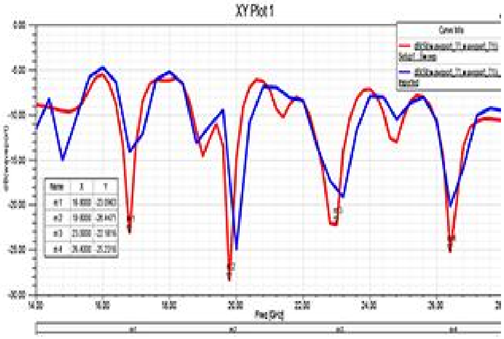

Fig. 3. Return loss VS Frequency of proposed antenna LN = 7.3 mm with different length LN = 5.4 mm

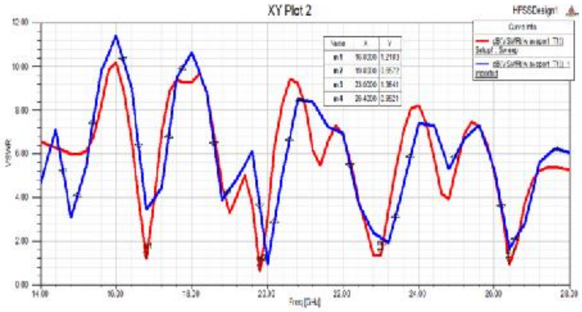

Fig. 4. VSWR VS Frequency of proposed antenna LN = 7.3 mm with different length LN = 5.4 mm

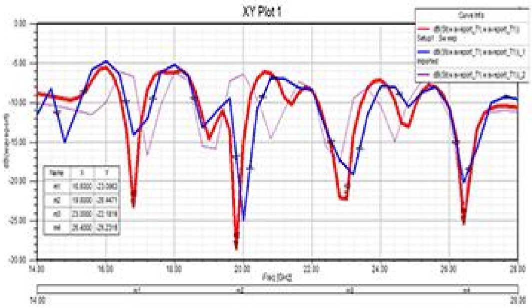

Fig. 5. Return loss VS Frequency of proposed antenna LN = 7.3 mm with different length LN = 5.4 mm and LN = 4.9 mm

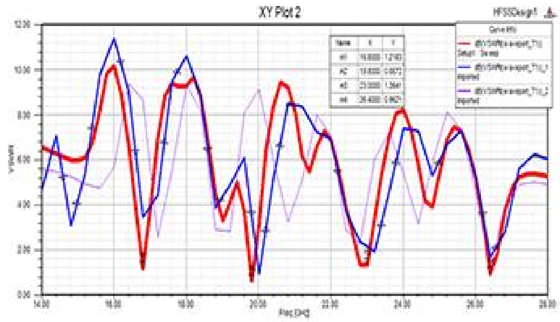

Fig 6. VSWR VS Frequency of proposed antenna LN = 7.3 mm with different length LN = 5.4 mm and LN = 4.9 mm

1. **Koch curve fractal geometry characteristics with length LN = 5.4 mm and triangular slot is 2.4mm.**

The various bands can be achieved by properly changing the parameters of the filter structure. The notched function is chiefly determined by LN. The first notched band corresponds to the length of the rectangular slot as it seen in Fig.2., upon decreasing LN is 5.4mm and cutting triangular slot from rectangular at 2.4 mm with other parameter is constant, the first notched band moves to a lower frequency 16.8GHz but the return loss 14db and second frequency is 20GHz but the return loss is 20db,while compared to proposed antenna structure the return loss is less is shown in Fig.3 and the VSWR of proposed antenna with length is shown in Fig.4. The third resonant frequency characteristics in the same length Ln the frequency 23.5GHz and return loss is 19dB and fourth band frequency is 26.4GHz and return loss is 20dB.In the reference of LN =4.9 mm antenna structure the overall notched frequency characteristics was decreased.

2. **Tri band geometry characteristics with length LN = 4.9 mm**

The parameter LN mainly determines by second notched band Fig.2.illustrate the impact of the parameters LN. Upon increasing LN with other parameters constant, the second notched band moves to a lower frequency. The first frequency in this second notched band 16.8GHz but the return loss 14dB and second frequency is 20GHz where as the return loss is 20dB, while compared to proposed antenna structure the return loss is less is shown in Fig.5. The third resonant frequency characteristics in the same length LN the frequency 23.5GHz and return loss is 19db and fourth band frequency is 26.4GHz and return loss is 20dB.In the reference of LN =4.9 mm antenna structure the overall frequency characteristics was decreased .The comparison of VSWR VS Frequency of proposed antenna LN = 7.3 mm with different length LN = 5.4 mm and LN = 4.9 mm is shown in Fig.6 from these parametric study the optimum frequency produced at length LN = 7.3 mm.

Results and Discussion

The proposed antenna with triple band characteristics has been fabricated and simulated. The photograph of the prototyped antenna front view is shown in Fig.7. The optimized dimensions of the band structures are shown.

1. VSWR Measurement

The VSWR is a measure of the impedance mismatch between the transmitter and the antenna. The higher the VSWR, the greater is the mismatch. The minimum VSWR which corresponds to a perfect match is unity.Fig.8.shows the measured and simulated voltage standing wave ratio (VSWR) results for the proposed antenna with bands characteristics, an excellent agreement between them is observed. The bandwidths for each of the band are very suitable to suppress the disturbances from Satellite and mobile systems. The simulated return loss of the proposed antenna is shown in Fig.8.The measured frequency range covers commercial application i.e.,17GHz (Ku-band)an having return loss -20db and 19GHz ,20.2 GHz, 22.6GHz,23.4GHz(K band) an having return loss-15.6db,-27.7db,-16.3,-17.0 and 26.4GHz (Ka-band) frequency an having return loss -26.3db. The simulated VSWR of the proposed antenna is shown in Fig.9. The standard value of VSWR is less than 2 for the operational bands of the microstrip patch antenna. The value of VSWR achieved is less than 2 in the desired operating bands. The simulated total gain of the proposed antenna is shown in Fig.10.The achieved gains are -15.6dB on the lower band and -27.2 dB on the upper band. The radiation efficiency versus Theta of the proposed antenna is 95% efficiency was observed over the entire operating band of Ku,K and Ka band applications.

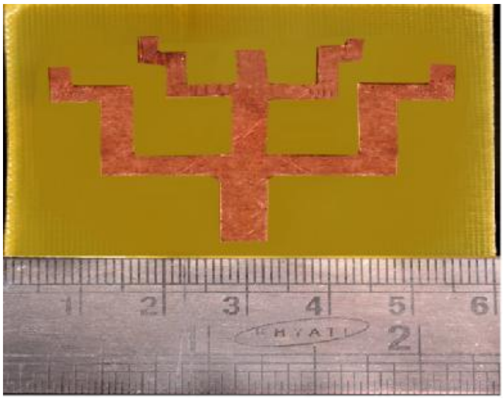

Fig. 7. Proposed Prototype Model Front View

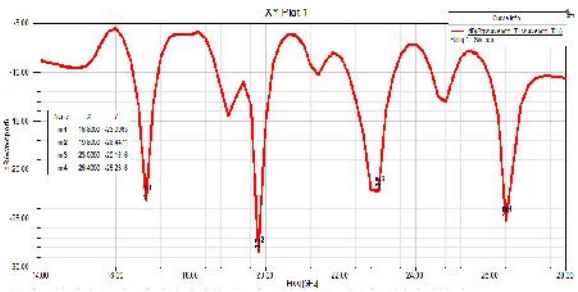

Fig. 8. Return loss VS Frequency of proposed

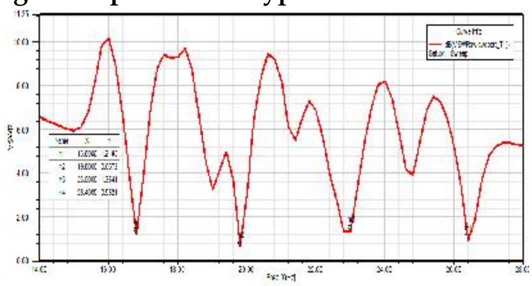

Fig. 9. VSWR VS Frequency of proposed antenna antenna

Radiation Pattern

Fig.10 shows the normalized farfield radiation patterns of total gain for the proposed antenna in two principle planes at different operating frequencies 17GHz, 19GHz, 20.2GHz, 22.2GHz, 22.6GHz, 23.4GHz and 26.4GHz. At higher frequencies, the radiation pattern deteriorates because the equivalent radiating area changes with frequency over K series band unequal phase distribution and significant magnitude of higher order modes also play a part in the deterioration of the radiation pattern. Omnidirectional characteristics and radiation bandwidth can be improved if the ground plane length is approximately the same size as that of the radiating structure width. Also they can be further improved by using a thin substrate or a substrate with low dielectric constant . The proposed quad arm shape Patch antenna has nearly omnidirectional radiation characteristic in the E-plane copolar radiation patterns over operating frequencies are roughly symmetric.

Group Delay and Transfer Function

Group delay is an important parameter to characterize the degree of distortion of the pulse signal for K series Band impulse-based system. It is desired that the group delay response is stable over the K series frequency band. In addition, the shape of the transmitted pulse should not be distorted. Two identical antennas are arranged face to face at a distance of 32 cm which achieves the far-field condition of the antenna. The group delay variation of the proposed antenna is very small, which is less than 1 ns in the pass band. The characteristic of the group delay indicates that the phase of the antenna is linear in the far field and the pulse signal is not distorted between transmitting and receiving antennas in the pass band. The magnitude of the transfer function has narrow over the operating band with steady state indicating that the proposed design is suitable for K series band applications.

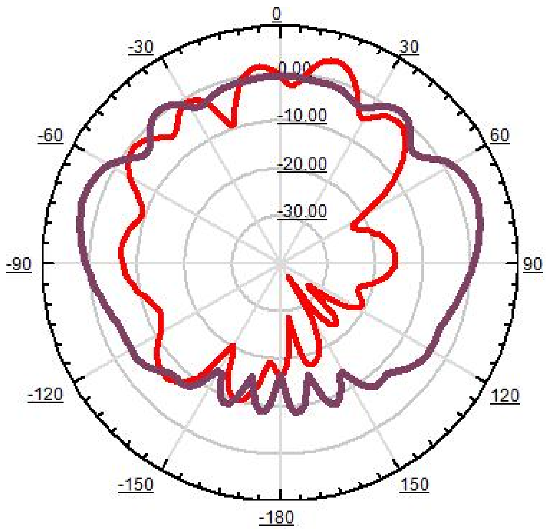

Fig. 10. Radiation pattern of Total Gain of proposed antenna

Gain and peak Gain

The ratio of the intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.Fig.11.shows the antenna gain in 3D patterns and Peak gain. The gain of proposed antenna obtained peak gain at 4.10dB.The comparison of the peak gain of the proposed antenna with that of the without band-notched structures is shown in Fig.11. The peak gain of the proposed triple band antenna almost follows the peak gain of the reference antenna without band-notched structures over Tri band frequency. Three significant drops of the peak gain can be observed in the operating frequency. The peak gain decreases drastically to −6.17/−2.15/−3.17dBi at around the bands which demonstrates that the band function is good.

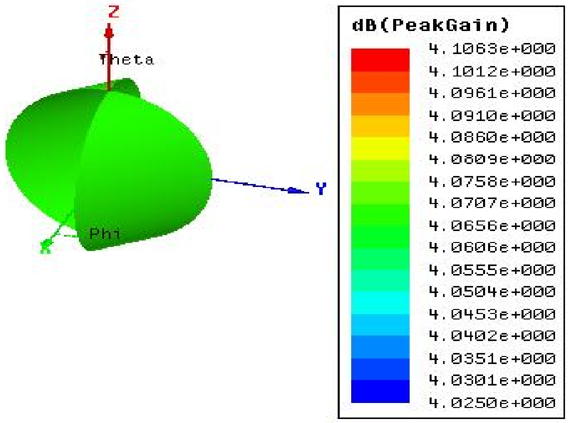

Fig. 11. 3D Gain and Peak gain of proposed antenna

Conclusions

By simply adjusting the length of the rectangular slot in the centre patch and cutting the slot in triangular slot of the corresponding band structure, the Ku/K/Ka band frequency bands can be achieved. Finally, a quad arm shape Patch antenna with triple band characteristics is successfully simulated and prototyped, showing a near omni directional radiation pattern, a stable peak gain, and small group delay and transfer function variation over the whole Ku/K/Ka band. Consequently, the advantages of simple structure, compact size, easy to fabricate and excellent performances make this antenna a good candidate for practical Ku/K/Ka band applications and MIMO systems operating for several wideband applications. The proposed optimization successfully increases the return loss, VSWR, bandwidth, and gain. The simulated antenna has 4.6GHz bandwidth (at VSWR < 2) and lower band has 1.37 dB and higher band has 3.3dB with Peak gain of 4.10dB and peak directivity of 8.35dB which is highly required for MIMO systems and future LTE band application.

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