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Design and Performance Analysis of a Quad-Spherical Shape UWB Micro-Strip Patch Antenna.

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Abstract:

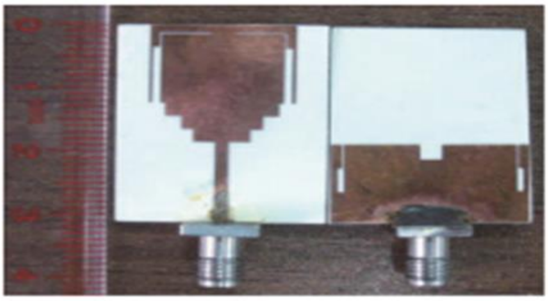
Ultra Wide Band (UWB) antennas are widely used in communication systems of today, this type of antenna system is an improvement of the Wide Band antennas. The problem of UWB antenna is poor Antenna design resulting to poor performance of the antenna with a very high negative reflections, which result to poor Voltage Standing Wave Ratio (VSWR). This research work focused on the design of a quad spherical UWB antenna system, the antenna was designed to have 4 elements patch that makes it suitable for Multiple Input and Multiple Output (MIMO) technology application. Quad spherical shape antenna is a compact MIMO ultra wideband antenna designed for carrying out massive transmission and reception of communication signals at a very low power consumptions rate. The purpose of this research work is to design a quad spherical shape antenna that would be effective in terms of the radiation power and better VSWR according to the ITU standards. The method adopted in this research work is the micro strip patch antenna design technique, part of the materials use are FR4, copper, and Nickel. The Simulation results of the antennas system show's that the antenna has a voltage standing wave ratio of 1.30 with an output power rating of 1.6 watts out of 2 watts stimulated power with a loss of 0.4 watts due to the absorption of power in the antenna conductor. In conclusion, the antenna system designed is feasible and fit to be implemented. Improvement of antenna arrays and efficiency was recommended for further studies in this research.

Keywords — **Antenna, Bandwidth, Feed-line, MIMO, UWB, VSWR.**

I. INTRODUCTION

Antennas are known as a device which can send and receive signals. Hence, the speed of this send and receive process is a challenging interest especially when fast development of communication technologies matters. On the other hand, the swift development of the communication systems, both fixed and portable, required high data rate transition for a more covering are due to the network user increment. Thus, they needed a broad bandwidth (BW) to cover mobile and all wireless services [1].

This can be possible by using wide-band and ultra-wideband (UWB) antennas with low profile to reduce the complexity and the fabrication cost. This article provides the state of the art on the field of UWB antennas designed for wireless communication applications. Figure 1 shows an example of a UWB antenna.



(a)

Fig. 1: Ultra-Wide Band Antenna [8]

The parameters that can be considered for improvement are return loss, gain, directivity, and bandwidth. To design and apply the UWB antenna, the related working BW should be considered according to the Federal Communications Commission (FCC) and the required frequency bandwidth area. For example, the UWB standard used in USA and Canada is 3.1-10.6GHz which is unlicensed and has no restrictions on the BW [2]. Many UWB antennas were presented and then their design procedure, techniques, contributions, and performances were investigated. The antenna used for communication applications was preferred to be of one of the following types: 3D, 2D, and planar [4][6]. Choosing these antennas depends on their applications' requirements; for instance, some of them are going to be taken for stabile devices and the others for portable devices. In some other applications like antennas used for mobile devices and wireless sensors on body networks, the transceivers should be in low profile to consume less area of printing board. Furthermore, for wireless body networks, antennas should be more flexible when they have to bend even close to 90 degrees [1].

Before designing the UWB antennas, the design principles, procedures, and antennas' characteristics would be considered and known. Moreover, the micro- strip antennas' design techniques, different structures and shapes, analysis, and feeding methods applied to improve the antennas' characteristics and performances. A radio wave is an electromagnetic wave which emanates from a radiating source (Antenna).

The micro strip patch antenna is the best selection for the UWB, because of many advantages such as being a low-cost material, being lightweight, and also being easy to fabricate. In micro strip patch UWB antennas, the major issues related to this antenna are poor VSWR, poor radiation efficiency and low output radiated power due to poor design of the antenna. This problem has really been a setback to UWB antennas, thereby causing too many negative reflections and reducing the speed of the antenna for effective purpose

Quad spherical shape UWB antenna is an antenna with 4 different disc like shape of antenna with an ultra- wide-band frequency orientation. However, this research work is limited to designing, simulation and observing the performance of the quad antenna using computer simulated technology (CST) and FR4, copper and nickel materials for the designs. The importance of this research work is not based on transmitting signals alone but transmitting signals with an improved VSWR, and designing an antenna with a good radiation efficiency with a good radiated output power for a quality transmitted signal.

A. *Review of Related Works.*

According to [5] in their research work, they analysed the effects of using DGS, composed of CSRR and CSRR-D structures, on electrical size, percentage bandwidth, efficiency, directivity, and gain for the rectangular micro strip patch antenna are investigated in comparison to the ordinary rectangular micro strip antenna. The results obtained in their research work show that both DGS based antennas which are studied in the study reduced the electrical size, however, decrease the gain due to the reduced directivity as compared to the reference antenna because of the back radiation caused by the defected ground design [5].

According to [8], the authors reviewed a research work concerning wide-band and ultra-wideband (UWB) antennas used for wireless communication purposes in terms of the materials as well as a numerical analysis is presented. These antennas which are taken into account are listed as wide-band micro strip antenna, wide-band monopole antenna over a plate, wide-slot UWB antenna, stacked patch UWB antenna, taper slot (TSA) UWB antenna, metamaterial (MTM) structure UWB antennas, elliptical printed monopole UWB antenna, and flexible wearable UWB antenna [8]. The radio wave assumes all the properties of a plane wave; the wave front is the plane which contains the Electric (E) and Magnetic (H) vectors and is at a right angle to the direction of propagation and power flow. Usually, it is convenient to carry out studies in terms of the electric component, E of the wave which is known as the electric field strength of the radio wave [9].

According to [7], in their research work that communication systems have been driven towards the fifth generation (5G) due to the demands of compact, high-speed, and large bandwidth systems. In this research, a 28 GHz rectangular micro strip patch antenna is designed and simulated [7]. The patch has a compact structure of 6.285 mm × 7.235 mm × 0.5 mm. The proposed antenna resonates at 27.954 GHz with a return loss of -13.48 dB, bandwidth of 847 MHz, gain of 6.63 dB and efficiency of 70.18% [8].

After studying various related works on micro strip patch antennas, it was observed that their antennas designs were good, but most of them have poor VSWR, and for antennas with just a single radiation patch, it has a lesser speed in transmission of radiated signals and lower radiation efficiency. This research will be designing a quad spherical shape micro strip patched antenna, with higher radiation efficiency and good VSWR using the design and simulation method

II. MATERIALS AND METHODS

Before live implementation, testing of the developed technique is required. Most of the time, testing and evaluating the protocols or theories proposed is not practically feasible through real experiments as it would be more complex, time-consuming and even costly. So, to overcome this problem, "SIMULATORS and TESTBEDS are effective tools to test and analyze the performance of protocols and algorithms proposed [10].

A Materials Used in the design Analysis

The materials used in achieving this research work are as follows:

i. Computer Studio Technology (CST Studio 2021)
ii. Copper
iii. FR-4 Substrate
iv. Nickel
v. Spherical Patch
vi. Brick shape Feed-line

B. Quad Spherical Shape UWB Antenna Design

The quad spherical shape antenna was designed in an orthogonal form, this positions are designed to reduce interference and mutual coupling. From figure 2, we can clearly see the front view of the spherical quad UWB antenna. As we all know this kind of UWB antenna is designed for MIMO purpose multiple input multiple output. The antenna was designed to be operated from 3.1 – 10.5 GHz. In order to design the quad spherical shape antenna, the CST software is used to carry out the designs simulation. After calculations of the length and spherical shape of the antenna, a substrate was built using an fr4 dielectric material, then the ground plain is etched partially on each of the back of the spherical shape antennas, then the spherical shape is also etched on the top of the substrate using copper, then finally the feed-line of the antenna was created.

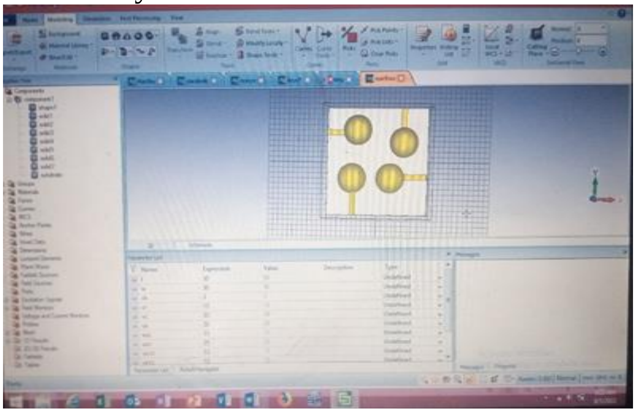


Figure 2: Quad spherical shape UWB antenna

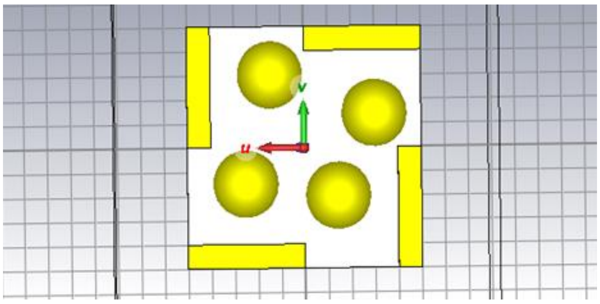


Figure 3 : Quad spherical shape ground plane view UWB antenna

Figure 3 is the back view of the quad spherical UWB antenna, this view describes the ground plane of the antenna, the ground plane was designed in such a way that it appears partial plated with copper, the reason is for the antenna to act as an ultra-wide band antenna system

When designing the UWB antenna shape, we first of all consider length, width and the thickness of the substrate and the dielectric constant of the material. We can say that,

$$\frac{c}{2fr\sqrt{\varepsilon_r}} = L \qquad (1)$$

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

$\varepsilon_r = 4.3$

Where L is the length of the substrate and W is the width of the substrate, Fr is the resonance frequency and ε_r is the dielectric constant

So we can also consider the ground plane of the antenna length to be

$$g_l = \frac{L}{4} \quad (3)$$

$$g_w = W \quad (4)$$

We can get the diameter of the spherical antenna using resonance frequency of the proposed antenna. In case of circular disc monopole based ultra-wide band antennas, the resonance frequency is determined by using the disc diameter (D) which roughly corresponds to the quarter wavelength λ. Therefor the relationship is given by

$$D = 2R \approx \frac{\lambda}{4} \quad (5)$$

Where the Quad antenna diameter is

$$D_Q = D \times 4 \quad (6)$$

For the velocity of light, $C = 3 \times 10^8\, ms^{-1}$ and dielectric constant, ε_r , the corresponding wavelength at a given frequency, f can be determined from the following equation

$$\lambda = \frac{C}{f\sqrt{\varepsilon_r}} \quad (7)$$

By using equations 6 and equation 7, for the substrate the dielectric constant, $\varepsilon_r = 4.3$, then the radius R is 7.5 mm while the diameter D of the circle is 15mm.

Where L_{eff} is the Effective length of the antenna and is given as:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (8)$$

Where ε_{reff} is Effective dielectric constant, given as;

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{W}\right]^{-\frac{1}{2}} \quad (9)$$

A micro strip feed line was used to feed the patch which is the radiating element. The input impedance of the micro strip patch, Zp was calculated as:

$$Z_p = \frac{90 \times (\varepsilon_r)}{\varepsilon_r - 1} \times \left(\frac{l}{w}\right)^2 \quad (10)$$

Where Z_p is the input impedance of the micro strip patch feed-line, l is the length of the micro strip patch feed-line and w is the width of the micro strip patch feed-line.

C. Quad Spherical Shape Antenna Diversity Gain

The diversity gain of the antenna system is closely related to the calculated ECC value of the UWB antenna system. The relationship between ECC and DG can be expressed by the Equation (11)

$$10\sqrt{1 - |\mathrm{ECC}|^2} = \mathrm{DG} \quad (11)$$

D. Quad Spherical Shape Antenna Radiation Efficiency

We can easily say that the radiated efficiency of the antenna can be denoted as;

$$E_R = \frac{p_{radiated}}{p_{input}} \quad (12)$$

Where E_R is the antenna radiated efficiency, p_{input} is the input power and $p_{radiated}$ is the radiated power. We can further denote our total efficiency to be

$$E_T = E_R . M_L \quad (13)$$

Where E_T is the total efficiency and M_L is the mismatched loss.

E. Quad Spherical Shape Voltage Standing Wave Ratio Antenna Evaluation

The voltage standing wave ratio is then equal to:

$$VSWR = \frac{v_{max}}{v_{min}} = \frac{1+p}{1-p} \quad (14)$$

At some points along the line the two waves interfere constructively, and the resulting amplitude is the sum of their amplitudes

$$v_{max} = v_{fwd} - v_{rev} = v_{fwd} - p^v{}_{fwd} = v_{fwd}(1 + p) \quad (15)$$

Where at other points, the waves interfere destructively, and the resulting amplitude V is the difference between their amplitudes

$$v_{min} = v_{fwd} - v_{rev} = v_{fwd} - p^v{}_{fwd} = v_{fwd}(1 - p) \quad (16)$$

Where VSWR is the voltage standing wave ratio,
$p^{v}{}_{fwd}$ is the forward peak voltage of the signal,
$p^{v}{}_{rev}$ is the reverse peak voltage of the signal,
v_{fwd} is the forward voltage of the signal,
v_{rev} is the reverse voltage of the signal,
v_{max} is the maximum voltage,
v_{min} is the minimum voltage,
$(1+p)$ is the positive forward voltage and
$(1-p)$ is the negative reveres voltage.

(Reflected wave and forward wave) Y_r is a complex number that describes both the magnitude and the phase shift of the reflection. The simplest cases, when the imaginary part of Y_r is zero, are:

i. $Y_r = -1$: maximum negative reflection, when the line is short-circuited.
ii. $Y_r = 0$: no reflection, when the line is perfectly matched.
iii. $Y_r = +1$: maximum positive reflection, when the line is open-circuited.

For the calculation of VSWR, only the magnitude of Y_r, is denoted by ρ, is of interest. Therefore, we define:

$$p = Y_r \quad (17)$$

Reflections occur as a result of discontinuities, such as an imperfection in an otherwise uniform transmission line, or when a transmission line is terminated with other than its characteristic impedance. The reflection coefficient Y_r is defined thus:

$$Y_r = \frac{V_{rev}}{V_{fwd}} \quad (18)$$

In order for the design of the antenna to be successful, the shapes of the spherical shape were determined, the shape of the substrate was also determine alongside the length and width of the feed-line of each of the spherical antenna. Table I shows the design parameters of the quad shape spherical antenna.

TABLE I THE QUAD SPHERICAL SHAPE UWB ANTENNA DESIGN PARAMETERS.

Antenna Shapes (mm)	Substrate Width (mm)	Substrate Length (mm)	Patch antenna circumference (mm)	Ground	Microstripe Feedline length (mm)	Microstrip feedline width (mm)
Spherical 1	20	20	15	0.5	10	5
Spherical 2	20	20	15	0.5	10	5
Spherical 3	20	20	15	0.5	10	5
Spherical 4	20	20	15	0.5	10	5

III. RESULTS AND DISCUSSIONS

A. S-Parameters of the Quad Spherical Shape Antenna

Figure 4 shows the result of the first scattering parameters of the quad spherical shape antenna, having a frequency bandwidth from 3.1 GHZ to 10.5 GHz with a resonating frequency at 5.8GHz. This described the orthogonality of the antenna whereby the antennas won't radiates at same resonance in order to reduce mutual coupling when compared to other of the antennas in the quad shape spherical antenna, it is seen that they all have different resonating frequency but same bandwidths.

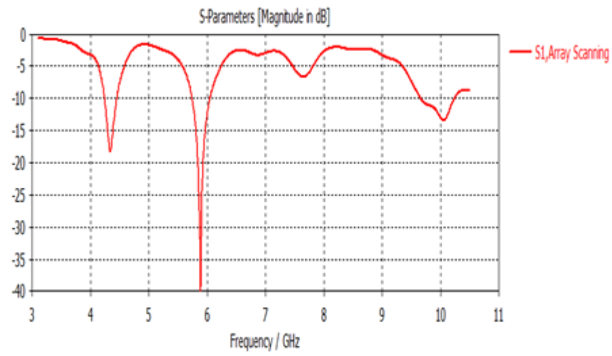


Figure 4. The first spherical antenna in the quad formation

Figure 5 shows that the frequencies are same but the resonating frequencies are different. It shows that the second antenna resonating frequency is at 6GHz.

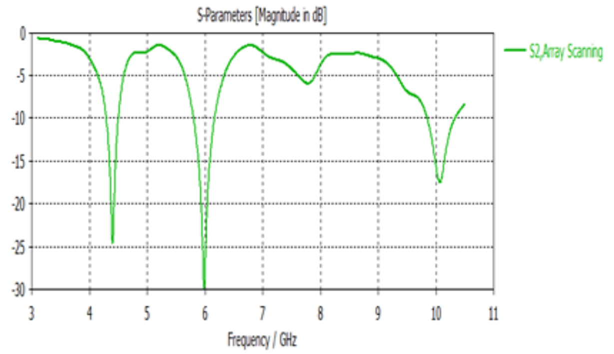


Figure 5: The second spherical antenna in the quad formation

The third antenna scattering parameters has also made it clear that mutual coupling has been reduced due to the fact that all antennas are placed orthogonally to each other and operates at same frequency ranges but different resonating frequencies as the third , the figure 6 resonates at 5.88 GHz.

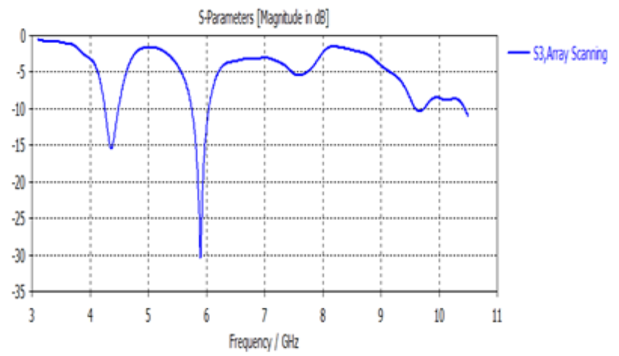


Figure 6: The third spherical antenna in the quad formation

The fourth antenna resonating frequencies at 6.1 GHz has really shown in figure 7 that the quad shape spherical antenna has really obeyed the orthogonal method of antenna arrays. It is shown that the antenna resonates at 6.1GHz thereby contributing in the reduction of mutual coupling. Hence the entire system of the antenna operates at 3.1 to 10GHz.

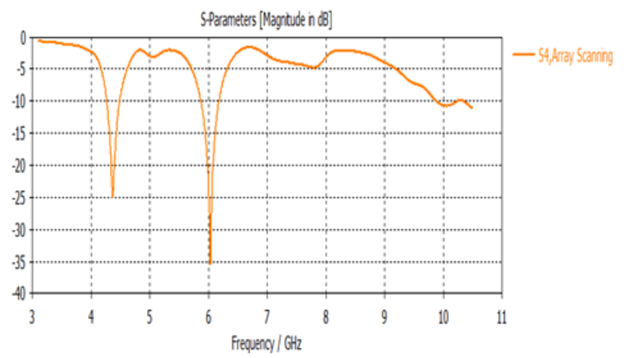


Figure 7: The fourth spherical antenna in the quad formation

From figure 8, it can be seen that the scattering pattern of the quad spherical shape antenna can be observed. Despite sharing same frequency bands but mutual coupling was reduced. The mutual coupling was reduced due to the fact that the antennas are orthogonal to each other. The orthogonal is a simple fact that the 4 antennas don't radiate same frequency at same directions, this effect thereby reduces the mutual coupling in them which would have leads to massive losses, loss of radiating output power and interference. As we can see from the results, the radiated power, output power and acceptance power are ideally good.

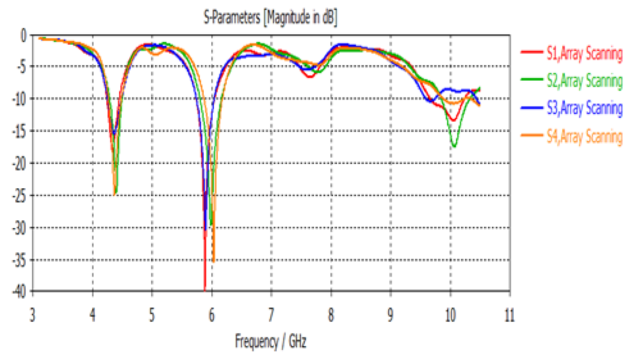


Figure 8: The scattering wave parameters of the four spherical shape antenna

B. Accepted Power of the Antenna

The design of the antenna allows the quad antenna to accept the total power for better efficiency. This mean that the antenna system is active and have enough energy to be radiated. As we can see the result in the figure, it was shown in figure 9 that the antenna has a higher acceptance rate at 1.8 watts. This effect makes it to be effective when compared to others.

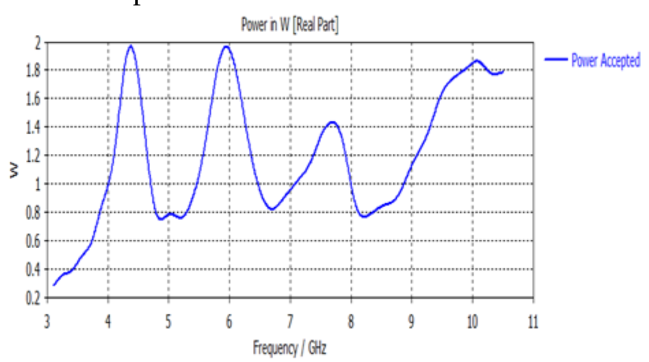


Figure 9: Accepted Power

The outgoing power is also an important part of antenna theory. The quality of signal received from the outgoing power determines what quality of signal to be received. That is to say when the power is low, the signal quality will be weak due to attenuation and poor power drive. From the result shown in figure 10, the outgoing power is 1.7 watts.

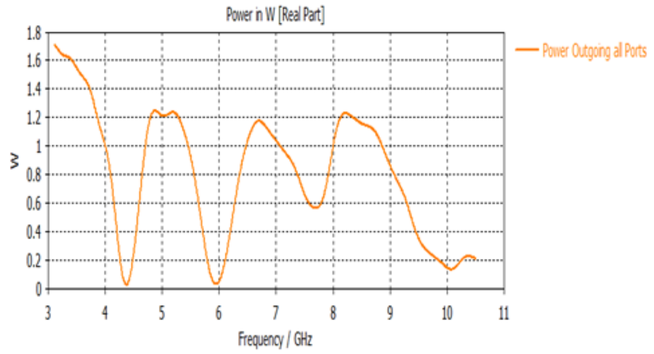


Figure 10. Outgoing power

C. Far field Radiation Pattern of the Antenna

The result in figure 11 and figure 12 shows the far field radiation pattern of the quad antennas at 3.1 GHz and 10.5GHz. It shows that the antenna system has a high radiating power at theta and phi axis. The results show's that the total radiation efficiency of the antenna falls within -1.038dB with a total efficiency of -1.5030dB at 10.5GHz and a diversity gain of 11.75dBi while the radiation efficiency of the 3.1 GHz is -4600dB with a diversity gain of 9.115dBi which is good.

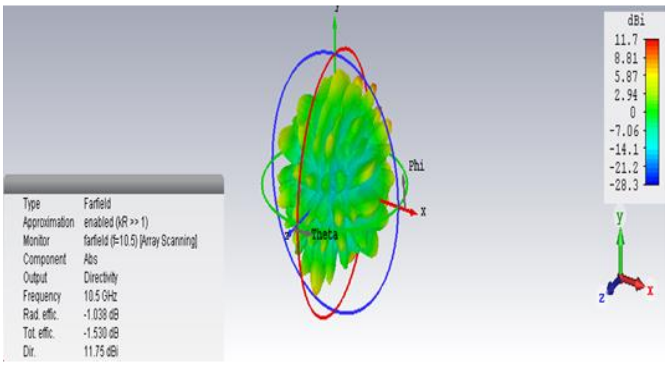


Figure 11. Far field radiation of the antenna at 10.5 GHz

The far field representation of the spherical shape quad antenna at 3.1 GHz

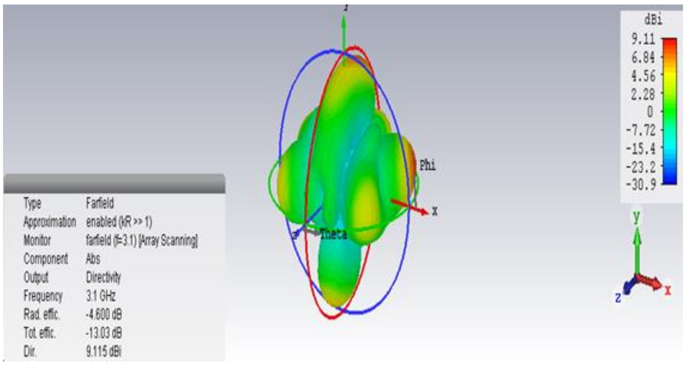


Figure 12. Far field radiation of the antenna at 3.1 GHz

The results in figure 13 shows that there several shapes of UWB antennas. But what differentiates the performance of antennas are voltage standing wave ratios. This is because in antenna system, one of the most important factors to consider while designing an antenna is the VSWR. A good VSWR is a reflection of the antenna performance characteristics. Once the antenna design is poor automatically it shows from the VSWR of the antenna. However, it is shown from figure 13 that the quad spherical shape UWB antenna has the lowest VSWR within the range of the ITU standard 1.30 which is lesser than 2 when compared to other antennas.

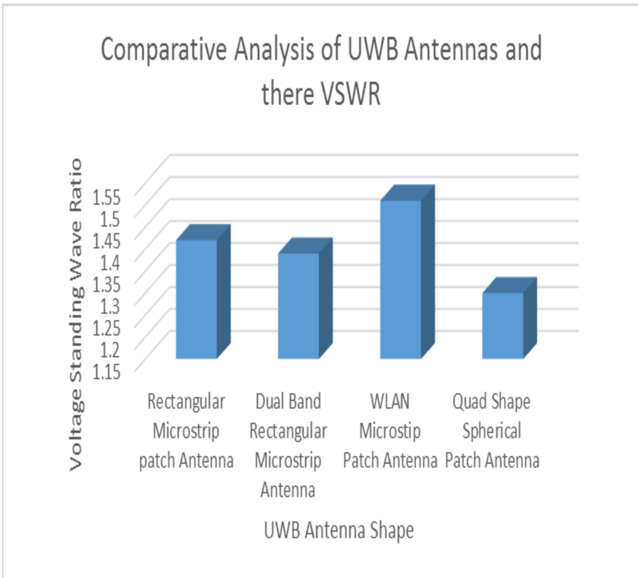


Figure 13. VSWR Comparisons of different shapes UWB of antenna

IV. CONCLUSIONS

In this research work, a Quad spherical shape antenna has been developed. The antenna are designed to be orthogonal to each other. This is because of the reduction of mutual coupling. In antenna system, precisely antenna arrays. One of the challenges the antenna undergo is interferences due to mutual coupling. However, the orthogonal designs of the antenna has been able to tackle this challenge by reducing the effect of mutual coupling.

Also these research work considered the diversity gain of the antenna. The diversity gain of the antenna gives a clear prove of why antennas designed based on the orthogonal style improve positive reflections and lower loss along the channels.

This research work also considered the radiation efficiency of the antenna. The radiation efficiency of the antenna is -1.5038dBi with a radiation power of 1.6 watts. This shows that the efficiency of the antenna is in order to radiate almost 1 and ½ of the stimulated power which is 2 watts.

In antenna designs, the most important factor to look at is the voltage standing wave ratios. As ITU recommended that for every good antenna, that the VSWR must be equals to 1, or greater than 1 or lesser than 2. However, this research work met the standard by producing a voltage standing wave ratio of 1.30 when compared to other antennas with higher standing waves ratios. The orthogonal antenna design made it so due to the lesser mutual coupling effect. The stimulated power of the antenna is 2 watts and the radiation of power of the antenna is 1.6 watts having a loss of 0.4 watts due to the copper absorptions of the antenna conductive materials.

Quad spherical shape antenna is a compact MIMO ultra wideband antenna designed for carrying out massive transmission and reception of communication signals at a very low rate of power consumptions. However, this research work is recommended for further improvement on the antenna arrays system, further reduction of losses and improvement of radiation power.

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