DESIGN AND ANALYSIS OF UWB MIMO ANTENNA USING FRACTALS IN HFSS

Routhu Naga Vardhini[1], Kodiboina Babji[2], Chekka Sai Chaitanya[3], Ramasingu Harish[4], Asst.Prof. Mr. CH.Manohar Kumar[5]

[1,2,3,4]*Students of Department of Electronics and Communication Engineering Gayatri Vidya Parishad College for Degree and PG Courses School of Engineering Visakhapatnam, Andhra Pradesh, India.*
[5]*Professor of Electronics and Communication Engineering Gayatri Vidya Parishad College for Degree and PG Courses School of Engineering Visakhapatnam, Andhra Pradesh, India.*

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Abstract - *In this article, design and analysis of hexagonal-shaped fractal ultra-Wide band (UWB) multiple-input-multiple-output (MIMO) antenna is presented and its characteristics are investigated. The introduction of Koch fractal geometry in monopole as well as in the ground plane of the antenna generates additional resonances, which helps to achieve entire UWB operational bandwidth. The band rejection in wireless local area network band is achieved by etching a minkowski shaped slot from the monopole of the individual antenna .The application of Koch fractal geometry at the edges of hexagonal monopole provides desired miniaturization and wideband phenomena due to its self-similar and space filling properties. The two hexagonal fractal antennas are placed orthogonal to each other and used to construct UWB MIMO antenna. An L-shaped stub is used in the ground plane of the geometry to provide an improvement in the isolation. The compact dimension $40*25\ mm^2$ of the antenna exhibits nearly omnidirectional radiation pattern, with good S-parameters over the entire UWB frequency range. The measured results show good agreement with the simulated one.*

INTRODUCTION

UWB ANTENNA

The ultra-wide band (UWB) technology is growing very rapidly because of its high data transmission capacity in a wide frequency band at very low power level. UWB system attracted the interest of researchers from academia and industry after the authorization of unlicensed use of 3.1–10.6 GHz band, by Federal Communication Commission (FCC) in 2002. Secondly, now the wireless portable device need antenna operated in different frequencies for various wireless transmission functions, and operation bands and functions are increasing more and more, which may result in challenges in antenna design, such as antenna space limitation, multi antennas interference, and etc. One UWB antenna can be used to replace multi narrow-band antennas, which may effectively reduce the antenna number.

The bandwidth is the antenna operating frequency band within which the antenna performances, such as input impedance, radiation pattern, gain, efficiency, and etc., are desired. The most commonly used definitions for the antenna bandwidth are the fractional bandwidth (for narrow or wideband definition) and the bandwidth ratio (for ultra-wideband definition). Nevertheless, UWB system faces multipath fading problem due to reflection and diffraction between the receiver and the transmitter. This problem can be solved using multiple-input-multiple-output (MIMO) technology. In this technique, multiple antennas are used to transmit and receive signals with different fading characteristics, which in turn leads to improvement in system reliability and channel capacity. However, the use of multiple antennas in a smaller area will cause for the degradation of antenna characteristics due to mutual coupling among antenna elements. Several UWB MIMO antennas have been reported in the literature for UWB systems.

The UWB system faces electromagnetic interference problems with existing narrowband communication system operating in the UWB range such as IEEE 802.11 wireless local area network (WLAN) from 5.15–5.85 GHz. To achieve WLAN band rejection in the UWB range, different methods have been used such as etching the different shaped structures either from the radiator portion or from the ground plane of the UWB antenna. However, the application of these techniques for band rejection could cause additional mutual coupling between radiating structures and this affects the band rejection behavior too. Hence, the design of a UWB MIMO antenna with band-notch characteristics and low mutual coupling is a challenging task. The UWB antenna with band-notch characteristics in WLAN band are reported .Moreover, these antenna structures are large in dimensions and difficult to integrate with modern portable UWB applications. The application of fractal geometry in antenna design provides miniaturization and wideband phenomena because of itself similarity and space filling properties. The space filling property helps to increases the effective electrical path-length of the antenna in a given small area. Several fractal geometries such as Koch snowflake, hexagonal-shaped, and Sierpinski triangle are used to design UWB antenna.

MIMO ANTENNA

In this article, a MIMO UWB antenna with WLAN a band-notch characteristic is presented. To achieve the compactness and wideband phenomena, Koch fractal geometry is applied at the edges of hexagonal-shaped monopole. The band rejection in WLAN band is obtained by introducing the minkowski model slot in the fractal monopole (FM) of the structure. The rectangular slots are introduced in the ground plane to achieve the UWB operational band. A decoupling L-shaped grounded stub is introduced between the two monopoles, which enhance the isolation between the antenna elements. The prototype of UWB MIMO antenna is fabricated and measured results show good agreement with the simulated one.

FRACTALS

Fractals take less area due to the many contours of the shape. The different fractals in nature. Fractals are used to obtain high radiation pattern and input impedance similar to a longer antenna. Today's wireless and satellite communication and advanced military systems, required antennas of high performance, high gain, wider bandwidth, low cost and smaller design dimensions. To fulfill all these requirements researchers looking for more advanced antennas designs. One such field of advanced antenna design is fractal antennas. There are three types of fractals:

1. Koch model

2. Sierpinski model

3. Minkowski model

ANTENNA DESIGN

ANTENNA CONFIGURATION

The proposed antenna is generated by combining the Koch fractal and the hexagonal geometry. The recursive procedure for generation of Koch fractal
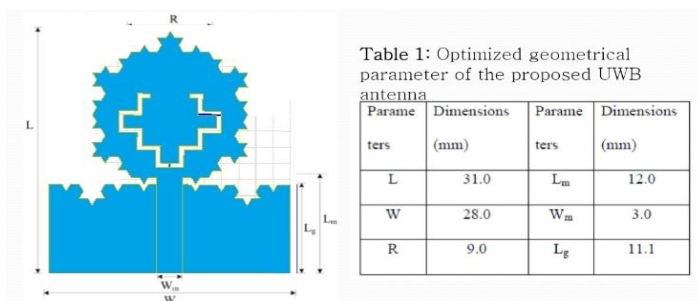

Figure 1: fractal geometry model of UWB antenna and its parameters

geometry is shown in Fig. 1. The first iteration divides the initial length in three equal parts, and Koch structure is created. This iterative process is repeated for higher-order iteration. The Koch fractal geometry is further applied to the edges of the hexagonal geometry as shown in Fig. 2. Here, this hexagonal shape works as an initiator, and Koch fractal works as a generator in the evolution of initial antenna design .The initial structure of the antenna without application of fractal geometry is shown in Fig. 2a. Figs. 2b and c display the structures of the antenna after applying first and second iterations of the Koch geometry at the edges of monopole, respectively. The introduction of Koch geometry in the ground plane of antenna structure is shown in Fig. 2d. The proposed structures (with and without Koch fractal) is simulated using high-frequency structure simulator v.13 on a rectangular substrate (W × L), FR4, having a dielectric constant (εr) 4.4, loss tangent (tan δ) 0.023 and thickness (h) 1.6 mm. The rectangular substrate is chosen as a basic structure of the proposed antenna because of its characteristics of wideband operability and good radiation property [9]. The hexagonal monopole with the edges of length R is connected to a 50 Ω micro strip line of width (W_m) and length (L_m) for impedance matching. Ground plane is positioned on the other side of the substrate having length (L_g) and width (W).
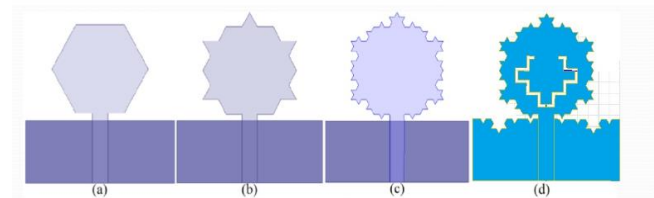

Figure 2: Evaluation of fractal UWB antenna with application of Koch geometry (a) Antenna -1(b) Antenna -2(c) Antenna-3(d) Antenna -4

The values of above-mentioned parameters are same as given in Table 1.The reflection coefficient (S11) for the various antenna structures generated in the evolution process is shown in Fig. 2. It is observed that addition of Koch geometry with monopole increases the electrical path length of monopole. Moreover, fractal monopole possesses greater perimeter length in a smaller area as compared with other geometries such as circle, ellipse and hexagon etc. The lower operating frequency changes slightly with the increase in iteration of Koch geometry. These modifications in the geometry improve the S11 characteristics significantly in the mid as well as high-frequency ranges of UWB spectrum. The fractal geometry produces multiple resonances and by combining these resonances wideband bandwidth is achieved. The introduction of Koch geometry into the ground plane further improves bandwidth because of change in the electrical path length and excitation of additional resonances. Tuning the ground plane has been useful to increase bandwidth of the antenna elements [10–

Table 1: Optimized geometrical parameter of the proposed UWB antenna

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
L	31.0	L_m	12.0
W	28.0	W_m	3.0
R	9.0	L_g	11.1

13], this helps to achieve the operational bandwidth up to122%. The optimised structure of the UWB antenna is shown in Fig. 4, which has the operational bandwidth from 3 to 12.8 GHz with three resonant frequencies at 3.07,4.28,6.13GHz, and optimized parameters in Table 1.The surface current density distribution on the fractal monopole and fractal ground plane at resonant frequencies is shown in Fig. 4. At 6.13GHz resonant frequency, the surface current distribution is mainly concentrated at the edges of the fractal structure of monopole and ground as can be seen from Fig. 4a. This shows that Koch fractal affects the impedance matching significantly at lower frequencies. Fig. 4b shows the surface current distribution at 4.285GHz. It is observed that the fractal edges of the monopole and lower portion of the ground plane have more effect on the impedance matching. At 3.07GHz resonant frequency, the surface current distribution is shown in Fig. 4c, which illustrates that the current distribution intensity is significant at the fractal edges of the ground plane and junction of the monopole and feed. This demonstrates that the application of the Koch structure in the ground plane has more significant impact at higher frequencies as compared with lower frequencies, which is also reflected in the S_{11} behavior as depicted in Fig. 3. The surface current distribution at monopole is more uniform at lower frequency as compared with higher frequency because of the change in nature of the current. At lower frequencies, the wavelength of the electromagnetic (EM) waves is long and small segments of the Koch structure contribute less in the overall radiations. However, at higher frequencies, the segment dimensions become comparable with the wavelength, which enhance the radiation characteristic significantly.
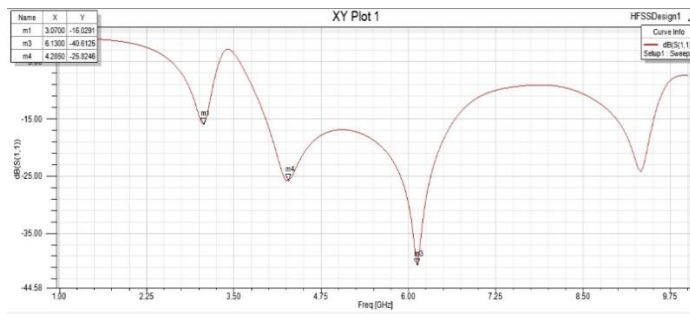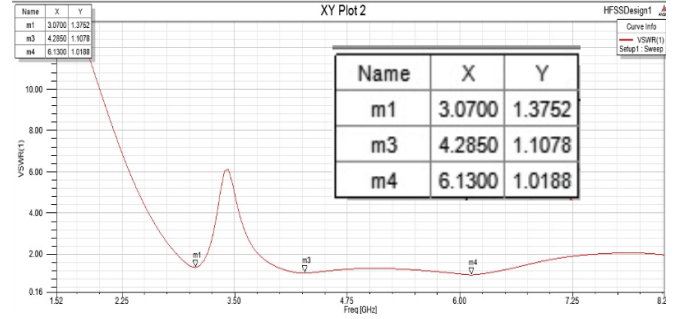
RESULT

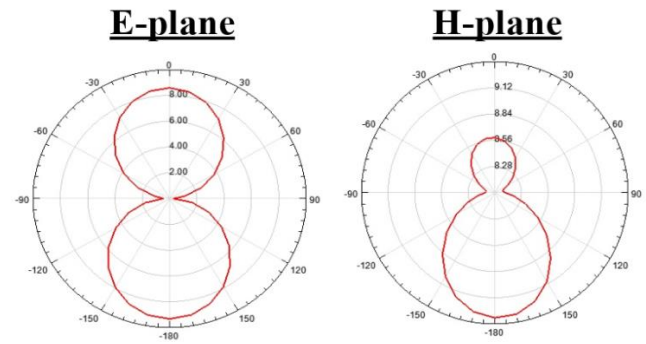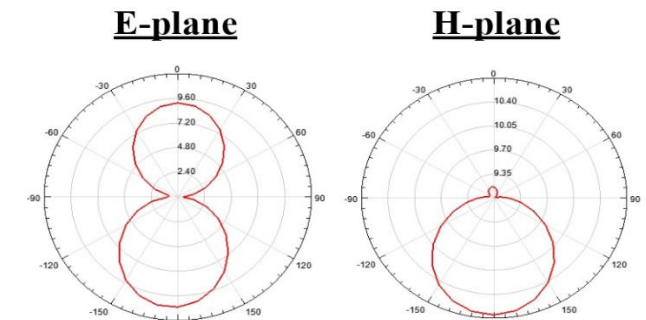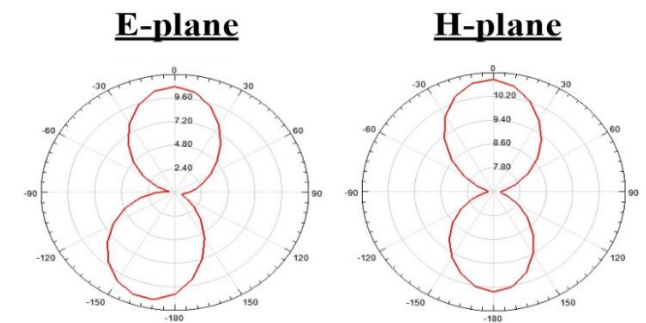Figure 3: (a) s11 parameters for antenna 4

Figure 3: (b) VSWR of UWB antenna 4

(a)

(b)

(c)

Figure 4: measured radiation pattern with co polarization and cross polarization H-plane and E-plane at (a) 3.07 Ghz (b)4.28 Ghz (c)6.13 Ghz

HFSS

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S -Parameters, Resonant Frequency, and Fields.

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques.

The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep (ALPS). Today, HFSS continues to lead the industry with innovations such as Modes-to-Nodes and Full Wave Spice.

Ansoft HFSS has evolved over a period of years with input from many users and industries. In industry, Ansoft HFSS is the tool of choice for high-productivity research, development, and virtual prototyping.
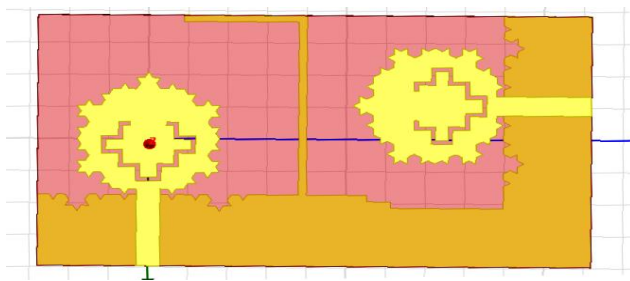
2x2 MIMO ANTENNA

Figure 5: design of UWB MIMO antenna in hfss

To verify the concept of present UWB MIMO antenna, the prototype of the antenna is fabricated and is measured using Agilent E5071C vector network analyzer. The simulated and measured S11, S22, and S21 of the UWB MIMO antenna are shown in Figure 5.The measured S11and S22 results are in good agreement with simulated results. The mutual coupling behavior of antenna is less than 215 dB. Thus ,the presented UWB MIMO antenna satisfies the desired characteristics in

the UWB operating range, so the antenna is an appropriate choice for portable UWB MIMO system .Figure 9 shows the measured radiation pattern in E-plane(xz-plane) and H-plane (yz-plane) at different resonant frequencies. It is observed that radiation pattern is quasi-omnidirectional in H-plane. Figure 6.2(a) shows the radiation pattern at resonant frequencies when port 1 is excited, whereas port 2 is terminated using a 50Ω matched load. The radiation pattern at higher frequencies shows small distortion compared with lower frequencies due to the reflection at edges from the FM of antenna. The bends and curves of fractal geometry cause for the change in current path, which in turn leads to enhancement in radiation characteristics of the antenna . Figure 6.2 shows the measured gain of the proposed antenna for both ports in the UWB band. The gain response is within 3 dB variation range outside WLAN notch band. The gain response is suppressed significantly in the notch band. The envelope correlation coefficient (ECC) is an essential parameter to estimate the diversity performance of a MIMO antenna and calculated using S-parameters :

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1-(|S_{11}|^2+|S_{21}|^2))(1-(|S_{22}|^2+|S_{12}|^2))}$$

It is observed that ECC value is less than 0.01 across the entire UWB range due to its efficient design, whereas for good diversity performance, its value should be less than 0.5 . This indicates the good diversity performance is achieved by the proposed UWB MIMO antenna. Similarly, in a rich multipath environment, quality of UWB MIMO system is estimated in terms of capacity loss (b/s/Hz) also. This parameter is used to define the upper bound of rate of transmission for reliable transmission in a communication channel. In case of a 2×3×2 MIMO antenna, its value should be less than 0.4 b/s/Hz for reliable transmission and it is calculated using the correlation matrix as follows :

$$C_{loss} = 1/4\ 2\log_2 \det \psi^R \quad (3)$$

where ψ^R is the correlation matrix of the receiving antenna and expressed mathematically as:

$$\psi^R = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}, \ \rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right)$$

$$\rho_{ij} = -\left(S_{ii}^* S_{ij} + S_{ji}^* S_{ij}\right), \text{ for } i,j = 1 \text{ or } 2.$$

It is observed that the capacity loss value are always less than 0.3 b/s/Hz in the UWB operating range, except for WLAN notch band, where it is higher than the threshold value of 0.4 b/s/Hz.

EFFECT OF L-SHAPED GROUND STUB

Figure 4 shows the effect of L-shaped stub on the S-parameters of the antenna. It is observed from Figure 6(a) that the impedance bandwidth S11 < - 10 dB improves significantly at lower and higher frequencies in the UWB operating band after the introduction of L-shaped ground stub, which helps to obtain the operating bandwidth from 3.3–10.8 GHz with three resonant frequencies at 3.0, 4.2, and 6.1 GHz ..

The effect of L-shaped ground stub can be expressed in terms of the surface current distributions of UWB MIMO antenna at 4 and 9.6 GHz resonant frequencies. It is observed from Figures 6.1(a) and 6.1(b), when port 1 is excited, that at 4 GHz resonant frequency, significant amount of surface current is coupled to the ground stub, which leads to the reduction of surface currents at FM2 of the antenna from FM1. Thus, increment in impedance bandwidth and decoupling bandwidth at low frequency is also observed. When port 2 is excited at 4 GHz, Figures 6.1(c) and 6.1(d) show that significant amount of current is coupled to the stub and flow of surface current from FM2 to FM1 is reduced significantly. Figures 6.2(a) and 6.2(b) show that at 9.6 GHz, when port 1 is excited, the surface current intensity at both the FMs increases as compared with lower resonant frequency, which leads to improvement in S11 and S21 in the UWB spectrum as well as radiation characteristics of the antenna. Similarly, for Figures 6.3(a) and 6.3(b) when port 2 is excited, at 9.6 GHz, stub blocks the flow of currents from FM2 to FM1 when compared with the case without the stub and with the stub.
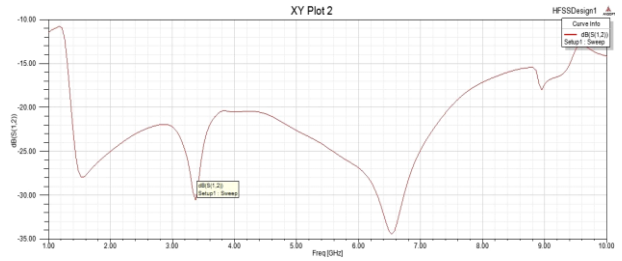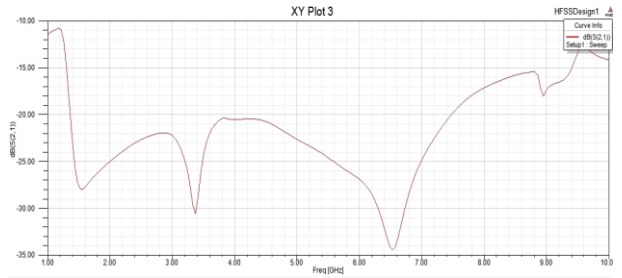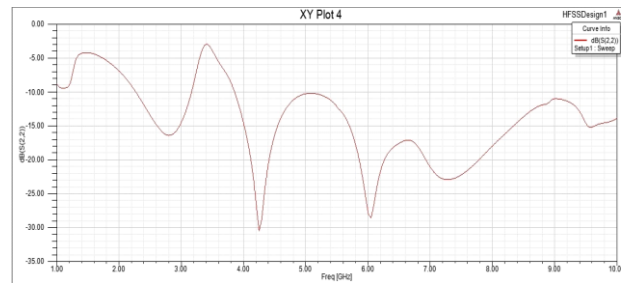
RESULTS OF 2x2 MIMO ANTENNA

S-PARAMETERS OF 2×2 MIMO ANTENNA

6.1 (a) S11
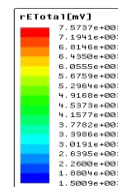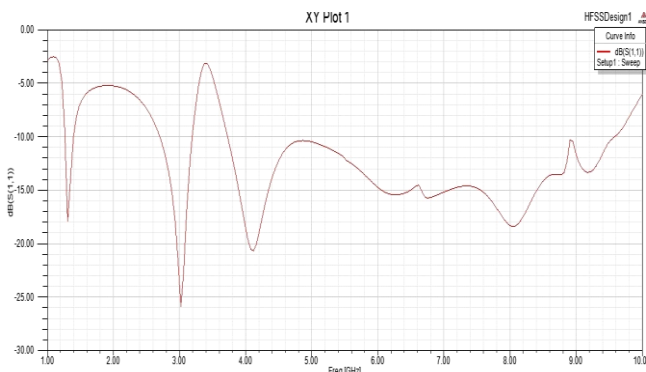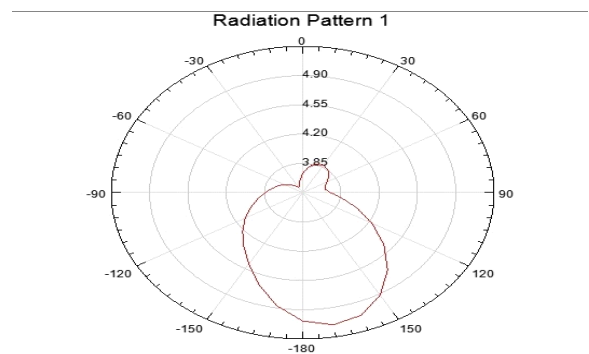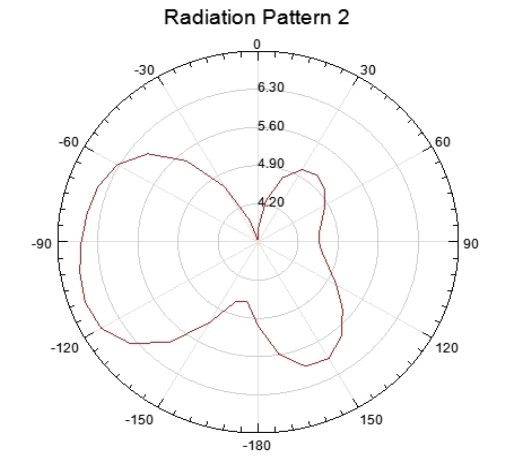

6.1(b).S12

6.1(c). S21

6.1(d). S22
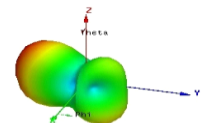
Figure:6.2 3D polar plot of radiation pattern for 2×2 MIMO antenna

E-PLANE

H-PLANE

Figure:6.3 radiation pattern chateristics of 2×2 MIMO antenna.

CONCLUSION

A fractal UWB MIMO antenna with WLAN band-notched characteristics is presented in this article. The application of Koch and minkowiski geometry provides miniaturization and wideband phenomena. The L-shaped ground stub helps to improve the isolation between orthogonally placed fractal monopole (FM) antennas. The band rejection at 5.5 GHz notch band is obtained by etching minkowski shaped slot from the monopole antenna. Moreover, the application of fractal geometry helps to obtain the stable radiation pattern at higher resonant frequencies in the UWB band of 3.0,4.2,6.1 GHZ. The proposed antenna has a compact dimension of 40×25 mm². This design approach provides a good solution for wideband compact antenna with excellent antenna characteristics. Thus, the proposed antenna is suitable for UWB MIMO applications.

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