DOI: 10.36297/vw.jei.v5i3.72

VW Engineering International, Volume: 5, Issue: 3, 129-147

Modelling and Analysis of Defected Ground Structured Microstrip Antennas for S-Band and Satellite Communication Applications

Khalid Jalal Bhat*, Lakhvir Kuar, Pooja Sharma

Department of Electronics & Communication Engineering, Doaba Institute of Engineering & Technology, Mohali, Punjab 147301, India
*Corresponding Authors Email: khalid.jalal302@gmail.com

Received: Nov. 15, 2023
Accepted: Dec. 19, 2023
Published online: Dec. 19, 2023

Abstract: Focus on Basic introduction to antenna and its parameters and their overview.Focuses on Literature review regarding multiband, wideband as well as ultrawideband and ultrawideband notched antennas. The focus on design and analysis of multiband antenna. To obtain multiband characteristics the patch of the antenna and the ground is slotted with spiral shaped ring. Due to that ring the antenna is getting multiband characteristics. The proposed antenna designed using ANSYS HFSS and etched on a FR4 Substrate. The designed antenna works in the band of WIFI and X-band applications. Though the model has obtained multiband characteristics multiband antenna has its effects on gain and efficiency the gain is low on lower bands and high at higher bands is observed.the focus on design and analysis of wideband antenna. To obtain wideband characteristics the patch of the antenna is taken triangular and the ground is closed to the structure. The antenna works up to 7.6GHz covering all the commercial bands from 2GHZ and the proposed antenna designed using ANSYS HFSS and etched on a FR4 Substrate. The designed antenna works in the band of WIFI and X-band applications. The model is having low gain at lower bands and high radiation efficiency at the higher bands is observed.The Final work focused on design and analysis of ultrawideband Notched antenna. To obtain ultrawideband characteristics the patch of the antenna is taken rectangular and it is added with T shaped stub and ground is enclosed with a rectangular ring which is enclosed both sides of the feedline. Due to that ring the antenna is getting enhanced gain and efficiency characteristics. The proposed antenna designed using ANSYS HFSS and etched on a FR4 Substrate. The designed antenna Gets notched in WiMAX(3.5GHz) and 4.8-6GHz bands which intern takes most of the working in the ultrawideband region. This modal works in almost all commercial wireless applications and with gain efficient at that bands is observed.

Keywords: Defected Ground Structured; Microstrip Antennas; Satellite Communication

1. Introduction

In communication systems antennas are very important components and they are defined as the devices which are used to send a signal i.e.., RF signal whose path is a conductor to electromagnetic wave in free space. antennas work on a property called 'reciprocity' i.e, antennas work with the same characteristics irrespective of its function either as transmitter or receiver. Antennas which are used are commonly resonant antennas which means operates efficiently at specific frequency band. An antenna is generally fed with the signal and antenna emits radiations which are plotted graphically, and this plotting is called radiation pattern.In general antenna characterization and analysis of the antenna varies with more theoretical approach using Maxwell equations but now a days EM tools plays a vital role for antenna characterization for different environments. Softwares such as HFSS plays a vital role for improving antenna characterization in N number of ways. Calculation using finite element influenced methods makes

HFSS a comfortable software for antenna designers.The electromagnetic environment based application have vital properties for novel structures, miniaturized modules the current trend of application have huge impact on IOT modules which has its relevant advantages in wide band antenna design the modules should be Omni directional and its radiations properties differ with wide impedance band width the services such as defense services focused in getting width band width circular current distributions with the approach of antenna and its operations the primitive design is most important for the antenna for wider operations bands.The wideband antennas play a vital role for its favorable conditions as enhanced bandwidth, impedance characteristics and gain enhancements. Some type of structures which are used for increment of bands and slotted structures which are used for the

notch band characteristics. Though the antenna is very much incasing to operate ate 10db reference return loss level antenna can be served furthermore from the original signal. Those communication requires the characteristics of low power consumption with high capacity and complexity working efficiently. The antenna having wider bandwidth with good radiation characteristics having low profile will tends to use at different frequencies. Compact antennas have very good requirement in the antenna

market having nature of resonant and narrow so that wider bandwidth procedure have incorporated and discussed in this section.

Bandwidth

The range of antenna working is termed to be bandwidth. It is measured in terms of frequency(hertz) for which the SWR is in the ratio 2:. Bandwidth can be calculated using the formula.

$Fh - Fl$ $BW = 100 \times$ Fc	(. 1)

Here *Fh* – Frequency at highest point

Fl – Low cut off frequency or frequency at lowest point

Fc – Center Frequency

From the formulae it is concluded that bandwidth is directly proportional to frequency. the band width of different antennas is different.

Gain

Physical quantity which is not termed is called gain of the antenna. In other words, it is mentioned as differentiation input power radiated to output radiated. The antenna Gain is determined with deviation with standard antenna such as dipole or Horn. These antennas are called reference antennas and the most known reference antennas are isotropic antenna and half wave dipole antenna. The gain patterns are shown in Fig . .

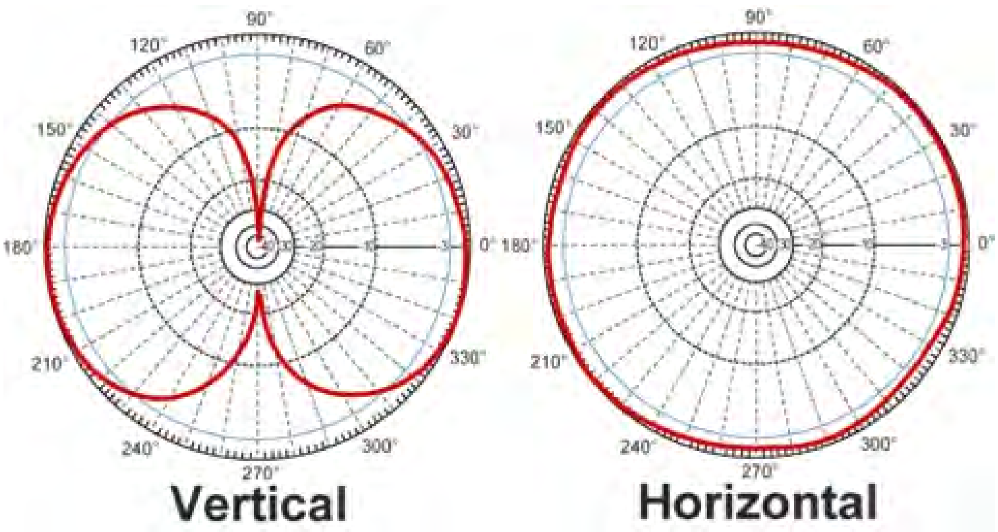


Fig . 1 Gain Patterns

Radiation pattern

The orientation of antenna radiation in a sphere from generation of signal and emission of radiation is termed as radiation pattern. The plotting of the radiation patterns lies in two-way i.e.., rectangular format and polar format.

The rectangular plot is a general plot that done with frequency and other antenna terms and is simple to study. the polar plot specifications are bit different from rectangular plot. This polar plot is classified into two types i.e.., linear and logarithmic plotting. By plotting the analytical values in the graph lobes are formed in the polar plot and the losses in the designed antenna is observed by the number of side lobes and back lobes

formed. Generally we plot voltage in the polar plot rather than other parameters like power. The voltage is plotted in the form of dB. An example of these two plotting is shown Fig . 2 and Fig . 3.

Input impedance

Generally, Impedance of a antenna is a vital parameter in which the conductor is conducting when a source is applied to it. Each and every branch or the sub parts of the antenna must be divided equally to get the antenna working at 50ohms for impedance matching in the setup

Return Loss

The mismatch can be expressed in different ways and the logarithmic measurement of mismatch is known as return loss. It is the comparison of power fed and power reflected by an antenna. Return loss is SWR dependent.

Directivity

The antenna ability to direct its total radiation energy in a desired direction when transmitting and receiving a signal is known as directivity. when an antenna transmits energy in all directions equally them that is known as omni-directional antenna.

Polarization and its effects

The orientation of the wave through electric field in the electromagnetic scenario is called polarization. In general, it is of elliptical polarization and the other of two types are linear polarization and the other is circular polarization. The different types of polarization effects are shown in Fig . 4.

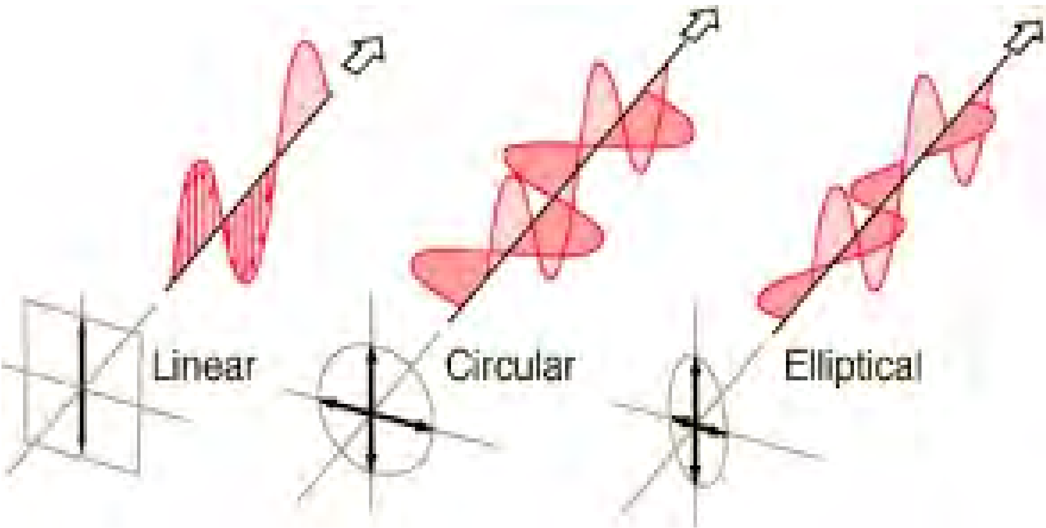


Fig. . 4 Different types of polarization

When the alignment of antennas is not done properly then the set-up is said to have polarization Mismatch and this lead lo loss of energy from the antenna set up. To overcome this problem an impedance matching circuit is placed and in this way polarization mismatching is handled.

Beam width

The antenna radiation is carried through different paths they are mentioned in the form of main lobe and side lobes. In this way when the side lobes of the antenna is increased it is mentioned that he antenna has unwanted directions propagated at the desired direction. This application can be mainly considered in the war fields. The beam width of an antenna is shown in Fig . 5.

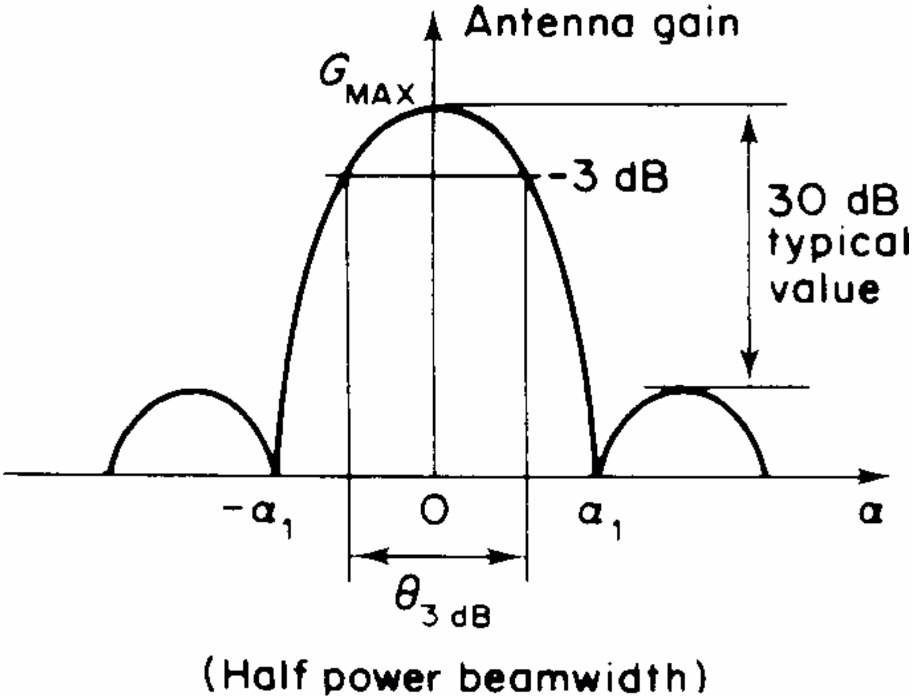


Fig . 5 Beam Width

Power density

Every parameter of the antenna is generally measured at the far field and the power pattern is obtained by having the average power density radiated by that antenna as a function of the direction. Observations are made over a sphere of constant radius extends into the far field.

VSWR

VSWR (Voltage Standing Wave Ratio), is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into a load (for example, from a power amplifier through a transmission line, to an antenna). In an ideal system, 100% of the energy is transmitted. This requires an exact match between the source impedance, the characteristic impedance of the transmission line and all its connectors, and the load's impedance. The signal's AC voltage will be the same from end to end since it runs through without interference. The VSWR of an antenna is shown in Fig . 6.

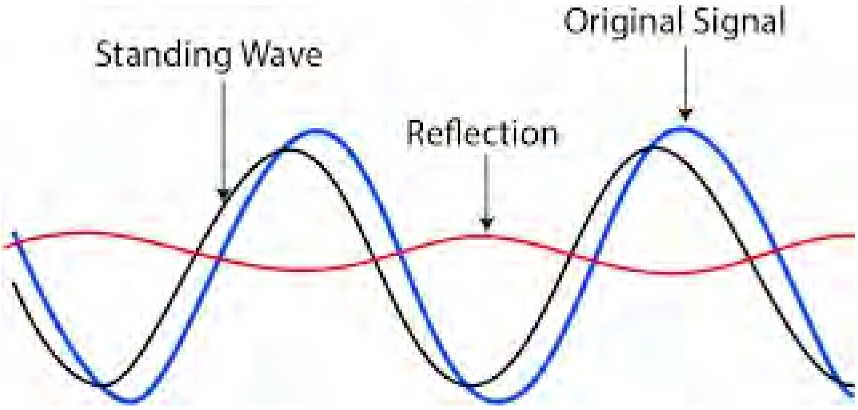
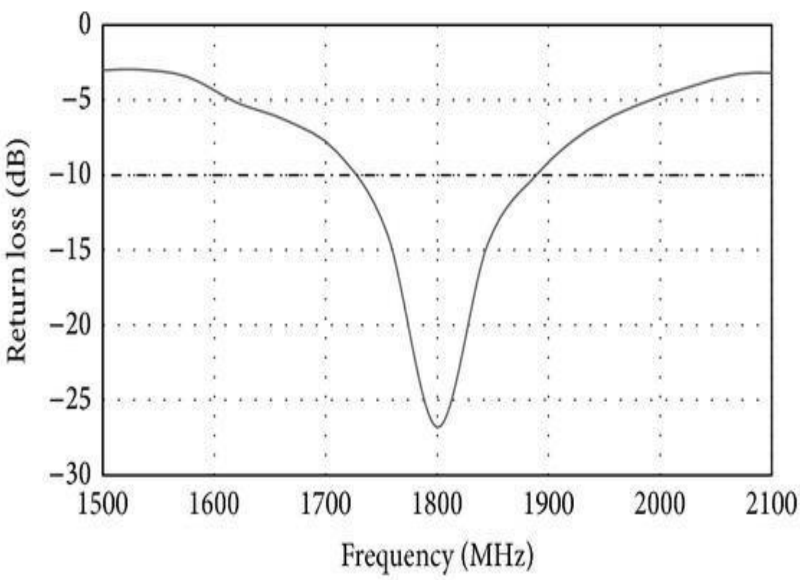


Fig . 6 VSWR of an antenna

This is the simplest and convenient methodology to calculate the input and output of the signal sources. It may be same that once the load is mismatched the full power isn't delivered to the load there is a facility which is named loss, and this loss that's came back is named the Return loss and is shown in Fig . 7.



Different Patch Antennas

Different shapes of microstrip patch antennas are considered for designing antennas. They have been fashioned to contest peculiar characteristics. For millimeter wave frequencies, the utmost natural forms are square, circular ellipse and rectangular are shown in Fig . 8.The substrate materials should have properties to alter temperature, humanity, and alternative coincidental spectrum and thickness required to vary resonant frequencies as well as impedances. The bandwidth of microstrip antennas plays vital role as the thickness and dielectric constant changes over the material.

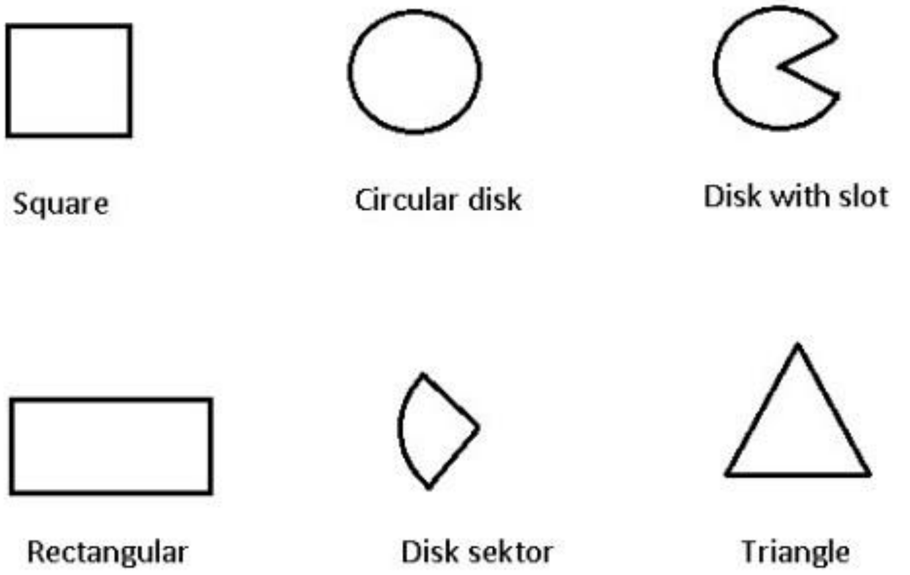


Fig . 8 Different shapes of microstrip patch antennas

The following approach are some of the feeding techniques of microstrip feedline techniques which are used for various applications and manufacturing industries. Different types of feeding techniques of antenna are shown in Fig . 9. the general prototype of rectangular antenna was shown in Fig . 10.

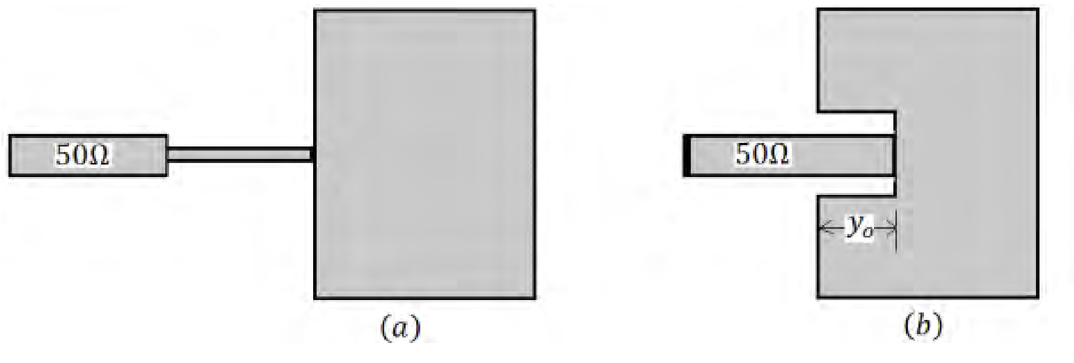


Fig . 9 (a, b) Microstrip patch antennas with feed from side

The feed point location is traced to match impedances characteristics of the antenna and hence to find the impedance of the patch the formulae is given by

$$Z_a = 90\frac{\varepsilon r^2}{\varepsilon r-1}\left(\frac{L}{W}\right)^2$$	(. 2)

The impedance characteristics determined

$$Z_T = \sqrt{50 + Z_a}$$	(. 3)

The transition line width is computed from

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}}ln(\frac{8d}{W_T} + \frac{W_T}{4d})$$	(. 4)

The width of the 50Ω micro strip feed can be found using the equation

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon reff}\left(1.393+\frac{W}{h}+\frac{2}{3}\ln\left(\frac{W}{h}+1.444\right)\right)}$$	(. 5)

The length of the strip can be found fro

$$R_{in(x=0)} = cos^2(\frac{\pi}{L}x_o)$$	(. 6)

The transition line is the quarter wavelength of the transition line

$$l = \frac{\lambda}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon reff}}$$	(. 7)

 DOI: 10.36297/vw.jei.v5i3.72

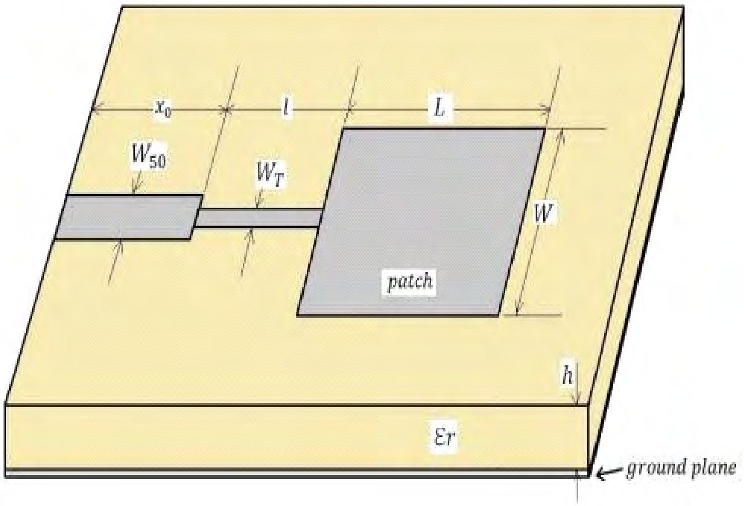


Fig . 10 General Rectangular Microstrip patch antenna with patch, ground and substrate.

Meander line:

A meander is an arc which is termed a flow of typical river flow which is inspired from erodes of water because the inner region of the river has some energy which will be carried forward and it will split into different directions or flows which bends to flow in the reversible directions which is equivalent to resonant frequencies. In meander line the down streaming of the network can be considered as the energy flow

There is not still adequate consistency or standardization of scientific phrasing recycled to characterize watercourses. An assortment of symbols and schemes happen. Parameters positioned on mathematical formulae or numerical evidence differs, build upon on the database recycled by the theorist. Excepting that differently characterized in a definitive scheme "meandering" and "sinuosity" are compatible and mean any repetitive arrangements of bends, or waveforms. In some proposals, "meandering" exercises only to rivers with exaggerated circular loops or secondary meanders. The structure of Meander lines in antenna geometry was shown in Fig . 1.

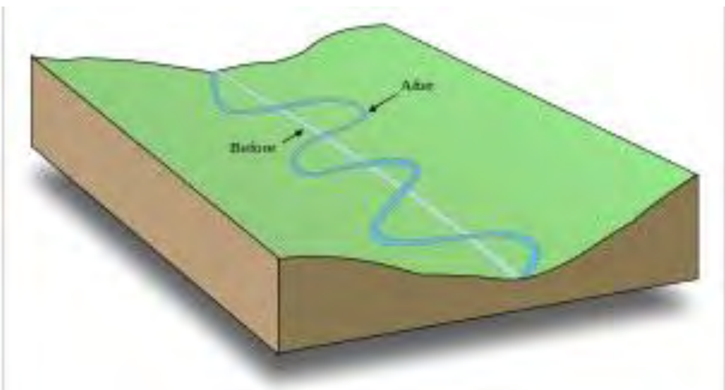


Fig . 11 Meander line Arc on microstrip patch antenna.

The meander line structure shows advance properties which tends to have useful frequencies working at different communication channels

Advantages of Microstrip Antennas

Most the advantages of the antenna using microstrip patch are listed below:

- Weight is low with inclusion of volume as well as size.
- The advancement of antenna such as conformal or wearable which tends to bend can be easily done with the help of microstrip patch antennas.
- Cost of fabrication is low and easy fabrication is accessed in now a day scenario
- Supports both, linear as well as circular polarizations with same size and shape.
- The microstrip patches can be integrated very easily with microwave integrated circuits (MICs).
- Capable of multiple frequency operations.

Disadvantages

Micro-strip patch antennas suffer from more drawbacks as compared to conventional big size antennas. Some of their major disadvantages are given below:

- Narrow bandwidth which are only in MHz and sometimes GHz.
- Low efficiency of radiation from patch.
- Low Gain due to insufficient slots.
- Extraneous radiation from feeds and junctions

Applications

Microstrip antennas are used in Tremendous Day to Day application:

- Applications in Space craft
- Applications in Aircraft
- Application in Low profile antennas

Mobile communication:

The most of the mobile application antennas should be small in size and weight. Microstrip Antennas are preferable for this application. Various types of antenna designs are made and used for marine and RADAR applications.

Satellite Communication:

Antennas play an important role in satellite communication. Usually parabolic antennas are used in Satellite communication for transmitting information and broadcasting. Circular polarisation is must in Satellite communication. A Microstrip antenna as a substitute of parabolic antenna can be used to produce polarisation by using different feeding techniques.

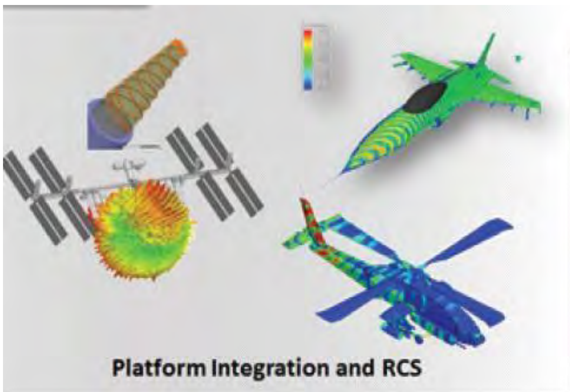
Application in Medical Science

Microstrip antennas which are light in weight are used in medical applications in case of emergency. Mostly annular ring and circular patch antennas are preferable for these applications.

Introduction to HFSS

In general antenna characterization and analysis of the antenna varies with more theoretical approach using Maxwell equations but now a days EM tools plays a vital role for antenna characterization for different environments. Softwares such as HFSS plays a vital role for improving antenna characterization in N number of ways. Calculation using finite element influenced methods makes HFSS a comfortable software for antenna designers.

Time complexity, space complexity, design complexity is far more reduced using the HFSS. The main importance is that it provides automotive, high accuracy, efficiently precise solutions to overcome the design challenges. By this tool the scientific advancement has been increased and a lot of design have come to existence. The Engineers are provided with various design variations and optimization procedures like sequential nonlinear programming (SNLP). This high range of analytical study provides the overall performance, thus having good results overall the process improves in building the real design. Different designs such as Platform Integration, Phased Array antennas, Integrated Mobile Devices, Biomedical and Commercial Platform Integration are shown in Fig . 12 (a), (b), (c), (d) and (e)



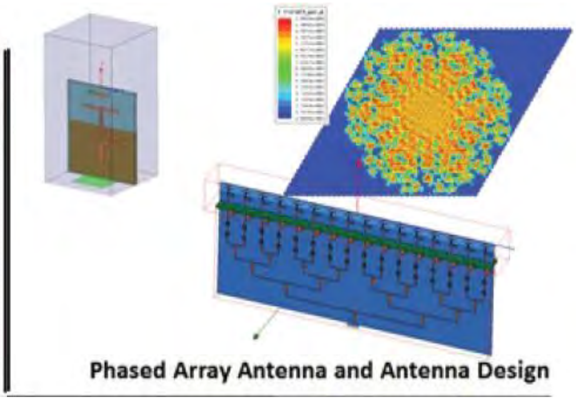


Fig . 12 (a) Platform integration and RCS

Fig . 12 (b) Phased array antenna

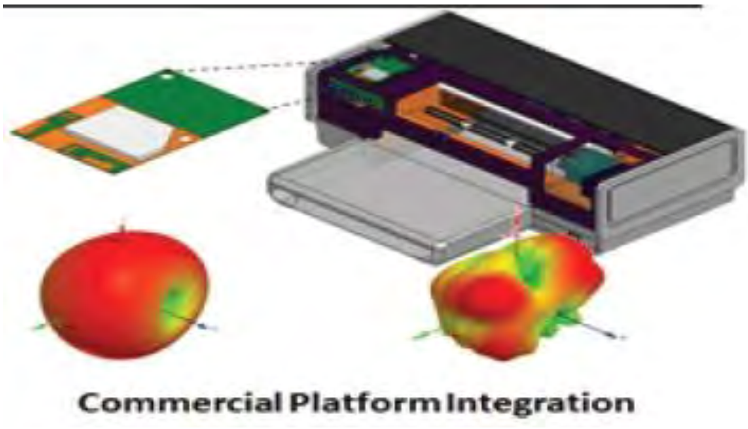


Fig . 12 (c) Commercial Platform Integration

2. Technologies of Antenna Simulation

The proposed software simulation and their techniques are mentioned as follows

- HFSS with finite element method
- Integral equations in HFSS
- Optic physical sciences enclosed with HFSS integral equations
- Transient FEM based solver
- Designer Antenna Tool kit

Finite Element Method

In a design the differential equations are solved by a method known as finite element method .This method has been predominantly used in structural mechanics, this method not only used in structural mechanics but also in thermodynamics as well, Even though this methods mathematical roots are far earlier but this importance is lied in meeting

the requirements of present day design. A model of FEM techniques is shown in Fig . 13.

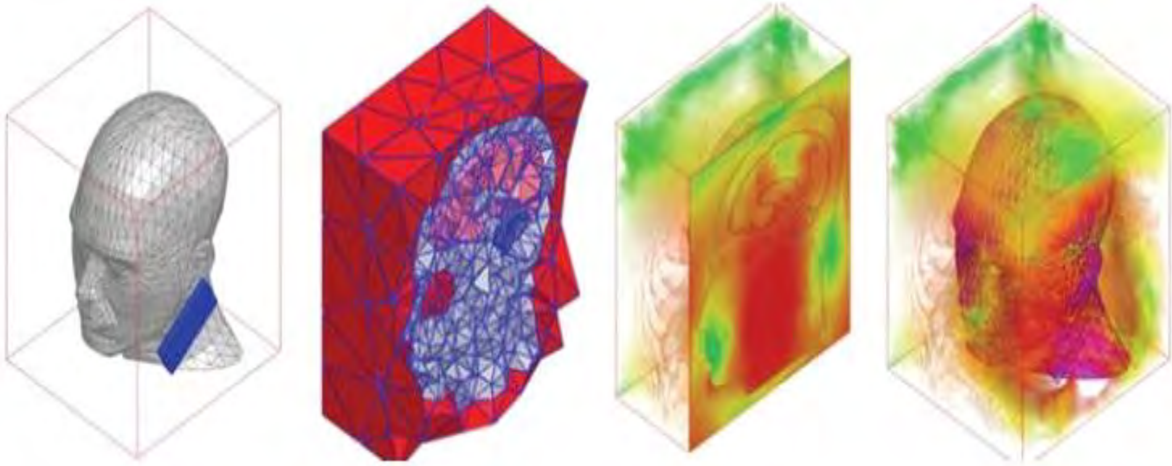


Fig . 13 Fem Technique

The above figure diagrams indicate biomedical analysis of human phantom model in HFSS which uses object not entire volume. In this type of analysis, the antenna should be in ideal radiation characteristics and to measure specific absorption rate etc so many inclusions are now adays coming in upcoming software's for generic analysis of each antenna design. This helps in organize the sequential growth of antenna in various fields different measurement and optimization characteristics. Different radiation patterns in the design are shown in Fig . 14 (a) and (b).

Fig . 14 (a) Variation 1 Radiation **Fig . 15 (b) Variation 2 Radiation**

- **Integral Equations**

The main use in providing the integral equations is to make the designer utilize the option of method of moments. In the design process there were many irregular ailments like scattering and open radiation, these problems can be eradicated by method of moments technique. This option is available in HFSS desktop. By the recognisive effort

in the integral equations helps in providing a path for intellectual design. Different types of design techniques in modeling a missile are shown in Fig . 15 (a), (b) and (c).

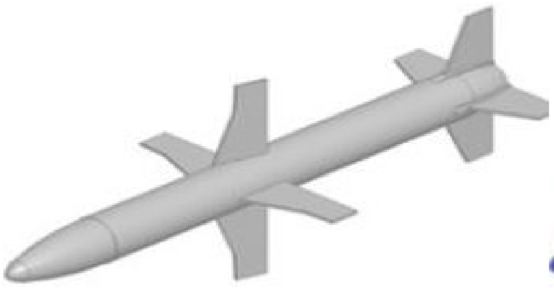


Fig . 15 (a) Missile Geometry **Fig . 15 (b) Surface Mesh**

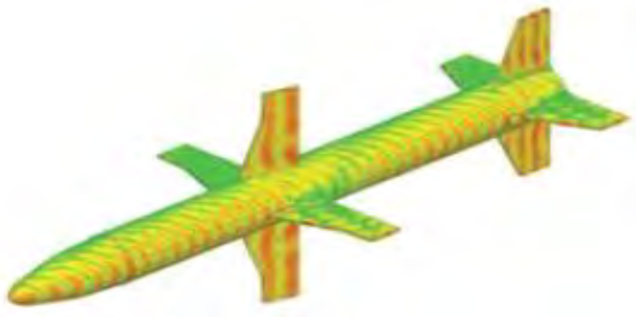
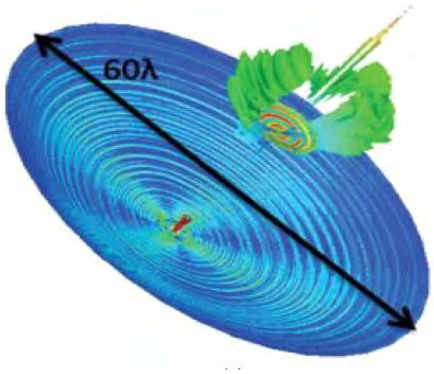


Fig . 15 (c) Currents On Surface

3. **Hybrid FEM-IE Solution**

In HFSS it provides the ability to influence a system by the strength of finite element method and integral equations method .This hybrid technique is an important process in overcoming the use of finite element method volume mesh, here the procedure is used in solving field propagation in modelling precise geometry. As we know in this when the solution is pushed from one domain to another because of hybrid IE and FEM regions. Different designs such as Reflector antenna and Satellite with conformal Boundary are shown in Fig . 16 (a) and (b).



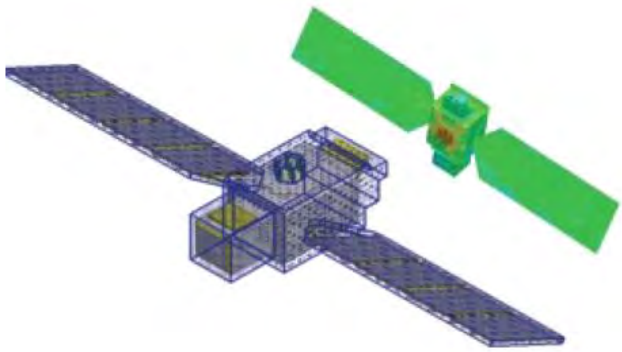


Fig . 16 (a) Reflector Antenna Fig . 16 (b) Satellite With Conformal Boundary

- **Physical Optics Solver**

Here the HFSS is providing an ease in designing the antenna and also helps in solving the electrically complex problems. In the physical optics radiation source, the illumination of the geometry is given by a radiation source. In the design if there were any scattering drawbacks the physical optics abolishes the problems and provides positive results. Thus, this is capable of organizing large error of large objects like ships and aircrafts. Here we have large reflector antenna simulations which helped in cracking out the antenna design problems. Different results of Reflector and Horn antenna such as Electric Field surrounding Horns, surface currents on the reflector and Far Field patterns are shown in Fig . 17 (a), (b), (c) and (d).

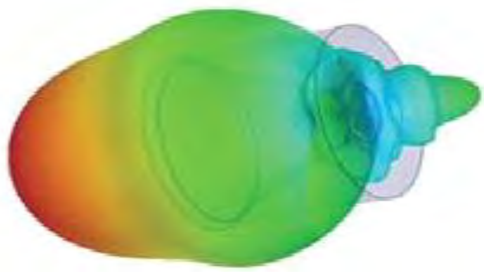
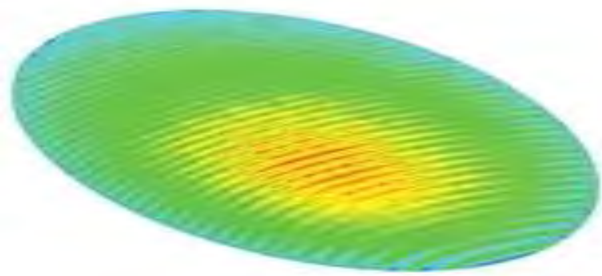


Fig . 17 (a) Reflector Antenna. **Fig . 17 (b) Electric Field Surrounding Horn**



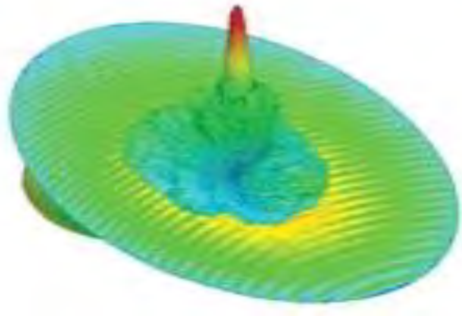
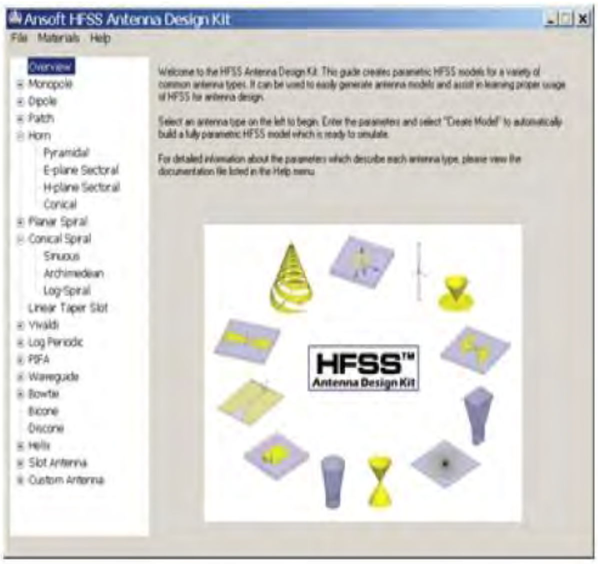


Fig . 17 (c) Surface currents on the Reflector **Fig . 17 (d) Far-field pattern**

- **Antenna Design Kit**

The Antenna design toolkit is an awesome choice in the HFSS, here we get accessed to the geometry creation which is of antenna design geometry. Here we also have solution setup as well as post processing reports for almost fifty famous antenna elements. By using this the designers can easily analyze the antenna types, if in case of new designers who are not aware of the HFSS, some assistance is given to them through step by step procedure. The antennas designed by the design kit are simulated using HFSS. Antenna design tool kit and design kit are shown in Fig . 18 (a) and (b).



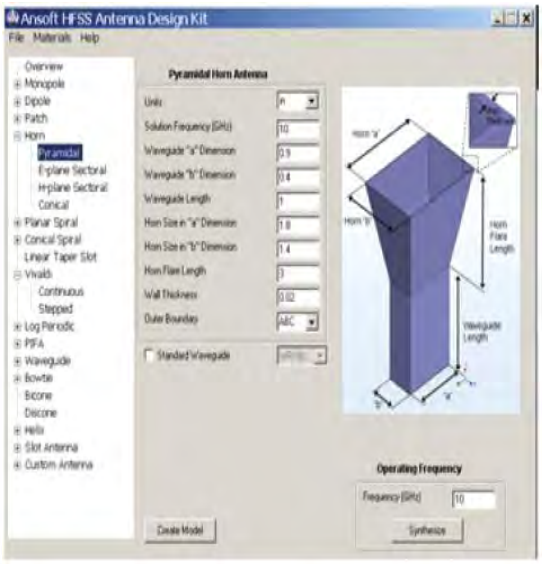


Fig . 18 (a) Antenna design tool kit **Fig . . 8 (b) Design kit**

4. Results and Discussion

The rectangular patch antenna evolution is carried out step wise as shown in Fig 5.. The simulated results which were observed in the Fig 5.3 are iteration wise reflection coefficient to approach final antenna model. The designed antenna is aimed to work at the ultrawideband notch frequencies. The proposed antenna simulation is carried out using the HFSS software.it is observed that the iteration 1 of the antenna model will be able to work in the nearest region to ultrawideband frequencies where it is notched from 6-7.5GHz.The iteration 1 is the basic rectangular patch antenna. Coming to the second iteration it is modified with the rectangular slot in the patch area.

After the incorporation of rectangular slot, the antenna got notch characteristics from 4GHz to 8GHz range. The third iteration is enclosed with a T shaped stub enclosed to the patch where the rectangular slot is etched. The antenna performance is changed with respect to notch characteristics and depth in the resonant frequency. The proposed model is modelled with incorporation of C shaped stubs placed on both sides of the feedline where the feedline is influenced. After incorporating of C shaped stub on both sides the final antenna works in the region of S-band and X-band (Satellite Communication bands).

The final model has been the depth resonance of about -45db in the working region and a sharp rejection is also observed in the notch band region. A combination of analysis of notch as well as working with moderated gain in the working bands leads this antenna model a good candidate for modern S band and satellite communication application. The principle of antenna mainly lies with on how elements based on the antenna geometry. The antenna radiation patterns and all effects will depend on the orientation of the elements placed in the antenna geomentry.The VSWR plot 5.4 indicated the antenna performance of how impedance is characterized in notch as well as in working bands in Fig 5.4.The simulated and measured reflection coefficient performance can be seen in Fig 5.5.

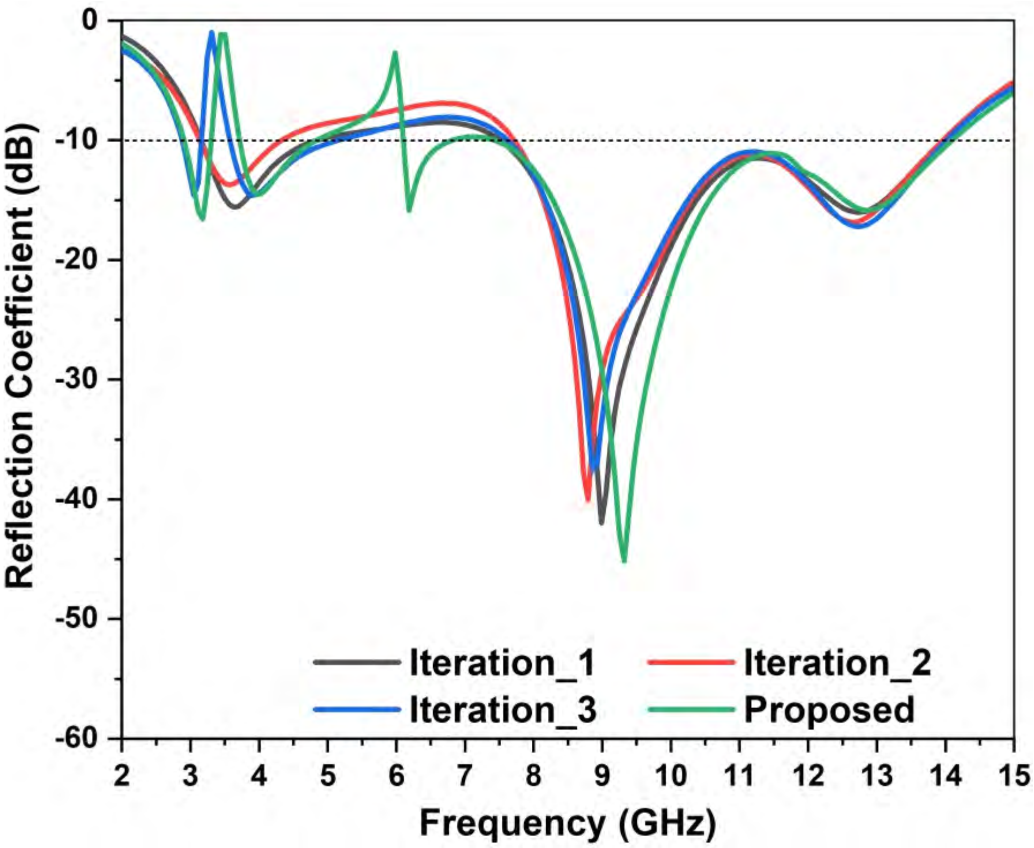


Fig 5.3 Iterative wise Reflection Coefficient for obtaining proposed antenna approach

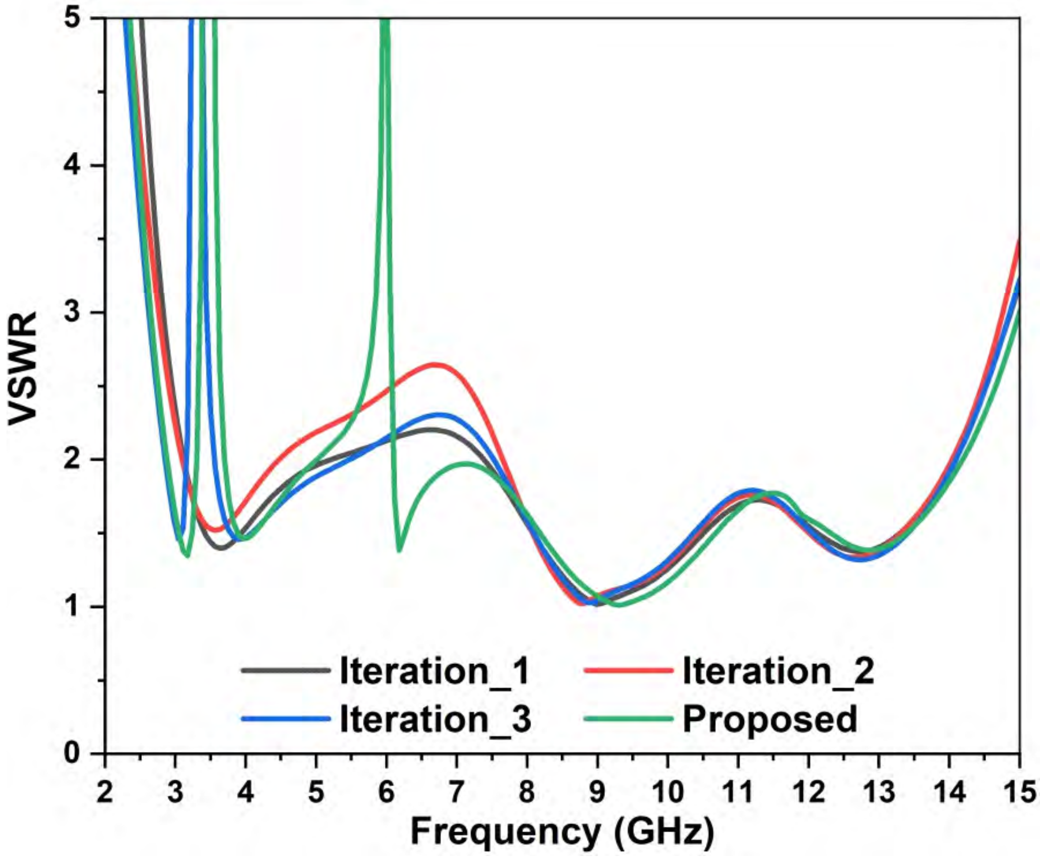


Fig 5.4 Iterative wise VSWR for obtaining proposed antenna approach

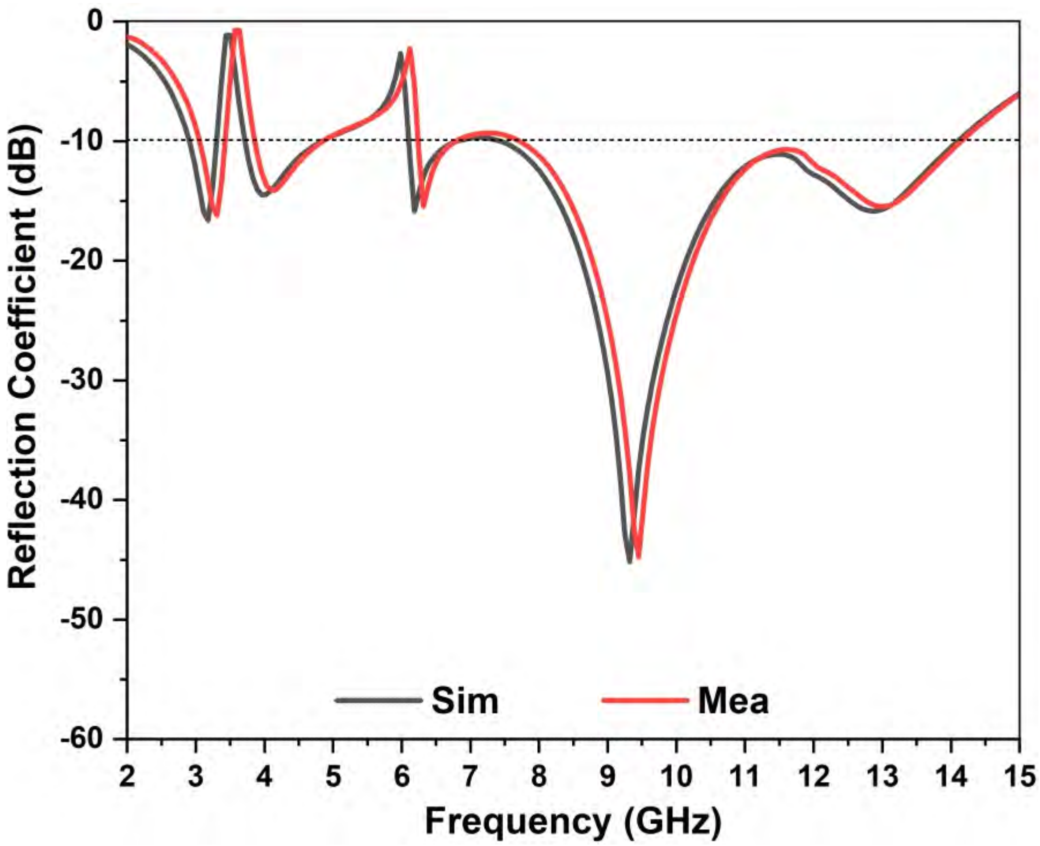


Fig 5.5 Simulated and Measured Reflection Coefficient of proposed antenna

4. Conclusions

The Design and Implementation of wideband antenna operation analyzing with respect to notch Band antenna performance has been analyzed. The Design and implementation of wideband antennas are required for most of the communication systems. Now a day's researcher is focusing on the coplanar measurement .Different types of patch regulations also help to improve the antenna performance. Different orientations will give resonance at different levels which in turn used to improve antenna characteristics. The present thesis focused how analysis of some of the monopole antenna with feeding in planar and incorporation of slots and variation in the defected ground structures to provide wideband and multiband characteristics. The focus on design and analysis of multiband antenna. To obtain multiband characteristics the patch of the antenna and the ground is slotted with spiral shaped ring. Due to that ring the antenna is getting multiband characteristics. The proposed antenna designed using ANSYS HFSS and etched on a FR4 Substrate. The designed antenna works in the band of WIFI and X-band applications. Though the model has obtained multiband characteristics multiband antenna has its effects on gain and efficiency the gain is low on lower bands and high at higher bands is observed. The work is focused on design and analysis of wideband antenna. To obtain wideband characteristics the patch of the antenna is taken triangular and the ground is closed to the structure. The antenna works up to 7.6GHz covering all the commercial bands from 2GHZ and the proposed antenna designed using ANSYS HFSS and etched on a FR4 Substrate. The designed antenna works in the band of WIFI and X-band applications. The model is having low gain at lower bands and high radiation efficiency at the higher bands is observed. The Final work the focus on design and analysis of ultrawideband Notched antenna. To obtain ultrawideband characteristics the patch of the antenna is taken rectangular and it is added with T shaped stub and ground is enclosed with a rectangular ring which is enclosed both sides of the feedline. Due to that ring the antenna is getting enhanced gain and efficiency characteristics. The proposed antenna designed using ANSYS HFSS and etched on a FR4 Substrate. The designed antenna Gets notched in WiMAX(3.5GHz) and 4.8-6GHz bands which intern takes most of the working in the ultrawideband region. This modal works in almost all commercial wireless applications and with gain efficient at that bands is observed. The total work is focused on design and analysis of simple structures which are used for multiband and wideband characteristics with the help of slots and ground variations. The proposed models can contribute excellent multiband characteristics and wideband characteristics in modern wireless communication

References

1) First Report and order, "Revision of part 15 of the commission's Rule Regarding UltraWideband Transmission System FCC 02-48, "Federal Communications Commission, 2002.
2) T.S. Rappaport, Ketan Mandke, Haewoon Nam, Lasya Yerramneni, and Christian Zuniga, "The Evolution of UWB and IEEE 802.15.3a for Very High Data Rate WPAN", EE 381K-11 Wireless Communications UWB Group, May 2003.
3) M. Ghavami, L. B. Michael and R. Kohno, "Ultra Wideband Signals and Systems in Communication Engineering", Second Edition, John Wiley & Sons, Ltd., 2007.
4) Boris Lembrikov, "Ultrawideband", Sciyo, Rijeka, Croatia, 2010
5) I. J. Bahl, and P. Bhartia, "Microstrip Antennas," Artech House, Boston, 1980.
6) W. Stohr, "Broadband Ellipsoidal Dipole Antenna," US. Patent 3, 364, 491, January 16, 1968.
7) F. Lalezari et al, "Broadband Notch Antenna", US. Patent 4, 843, 403, June 27, 1989.
8) K. Seol, J. Jung and J. Choi, "Multi-band monopole antenna with inverted U- shaped parasitic plane" Elect.Lett., vol. 42, no. 15, 20th July 2006.
9) Joong Han Yoon "Fabrication and Measurement of Rectangular Ring with Openended CPW-Fed Monopole Antenna for 2.4/5.2-Ghz WLAN Operation", Microw. Opt. Technol. Lett., vol. 48, no. 8, pp. 1480-1483, August 2006.

10) Chien-Yuan Pan, Tzyy-Sheng Horng, Wen-Shan Chen, and Chien-Hsiang Huang "Dual Wideband Printed Monopole Antenna for WLAN/WiMAX Applications", IEEE Antennas Wireless Propag. Lett., vol.6, pp. 149-151, 2007.
11) H. W. Hsieh, Y. C. Lee, K. K. Tiong and J. S. Sun, "Design of a Multiband Antenna for Mobile Handset Operations," in IEEE Antennas Wireless Propag. Lett., vol. 8, no., pp. 200-203, 2009.
12) [12]B. Manimegalai, S. Raju and V. Abhaikumar, "A Multifractal Cantor Antenna for Multiband Wireless Applications," in IEEE Antennas Wireless Propag. Lett., vol. 8, no., pp. 359-362, 2009.
13) Q. Rao and W. Geyi, "Compact Multiband Antenna for Handheld Devices," in IEEE Transactions on Antennas and Propagation, vol. 57, no. 10, pp. 3337-3339, Oct. 2009.
14) J. Pourahmadazar, C. Ghobadi, J. Nourinia and H. Shirzad, "Multiband Ring Fractal Monopole Antenna for Mobile Devices," in IEEE Antennas Wireless Propag. Lett., vol. 9, no. , pp. 863-866, 2010.
15) J. X. Liu and W. Y. Yin, "A Compact Interdigital Capacitor-Inserted Multiband Antenna for Wireless Communication Applications," in IEEE Antennas Wireless Propag. Lett., vol. 9, pp. 922-925, 2010.
16) L. Pazin and Y. Leviatan, "Narrow-Size Multiband Inverted-F Antenna," in IEEE Antennas Wireless Propag. Lett., vol. 10, no. , pp. 139-142, 201.
17) A. Dadgarpour, A. Abbosh and F. Jolani, "Planar Multiband Antenna for Compact Mobile Transceivers," in IEEE Antennas Wireless Propag. Lett., vol.10, no. , pp. 651- 654, 201.
18) T. Zhang, R. Li, G. Jin, G. Wei and M. M. Tentzeris, "A Novel Multiband Planar Antenna for GSM/UMTS/LTE/Zigbee/RFID Mobile Devices," in IEEE Transactions on Antennas and Propagation, vol. 59, no. 11, pp. 4209-4214,Nov. 201.
19) R. Eshtiaghi, M. G. Shayesteh and N. Zad-Shakooian, "Multicircular Monopole Antenna for Multiband Applications," in IEEE Antennas Wireless Propag. Lett., vol. 10, no. , pp. 1205-1207, 201.
20) H. F. Abutarboush, H. Nasif, R. Nilavalan and S. W. Cheung, "Multiband and Wideband Monopole Antenna for GSM900 and Other Wireless Applications," in IEEE Antennas Wireless Propag. Lett., vol. 11, no. , pp. 539-542, 2012.
21) [21]M. Naser-Moghadasi, R. A. Sadeghzadeh, M. Fakheri, T. Aribi, T. Sedghi and B.
22) S. Virdee, "Miniature Hook-Shaped Multiband Antenna for Mobile Applications," in IEEE Antennas Wireless Propag. Lett., vol. 11, pp. 1096- 1099, 2012.
23) J. Anguera, A. Andújar and C. García, "Multiband and Small Coplanar Antenna System for Wireless Handheld Devices," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 7, pp. 3782-3789, July 2013.
24) S. Shoaib, I. Shoaib, N. Shoaib, X. Chen and C. G. Parini, "Design and Performance Study of a Dual-Element Multiband Printed Monopole Antenna Array for MIMO Terminals," in IEEE Antennas Wireless Propag. Lett., vol. 13, no. , pp. 329- 332, 2014.
25) Z. Wang, L. Z. Lee, D. Psychoudakis and J. L. Volakis, "Embroidered Multiband Body-Worn Antenna for GSM/PCS/WLAN Communications," in IEEE Transactions on Antennas and Propagation, vol. 62, no. 6, pp. 3321-3329, June 2014.
26) P. Cheong, K. Wu, W. W. Choi and K. W. Tam, "Yagi–Uda Antenna for Multiband Radar Applications," in IEEE Antennas Wireless Propag. Lett., vol. 13, no. , pp. 1065- 1068, 2014.
27) W. C. Weng and C. L. Hung, "An H-Fractal Antenna for Multiband Applications," in IEEE Antennas Wireless Propag. Lett., vol. 13, no. , pp. 1705- 1708, 2014.
28) V. A. Nguyen, B. Y. Park, S. O. Park and G. Yoon, "A Planar Dipole for Multiband Antenna Systems With Self-Balanced Impedance," in IEEE Antennas Wireless Propag. Lett., vol. 13, no. , pp. 1632-1635, 2014. 14.
29) K. Itoh, K. Konno, Q. Chen and S. Inoue, "Design of Compact Multiband Antenna for Triple-Band Cellular Base Stations," in IEEE Antennas Wireless Propag. Lett., vol. 14, no. , pp. 64-67, 2015.
30) Y. F. Cao, S. W. Cheung and T. I. Yuk, "A Multiband Slot Antenna for GPS/WiMAX/WLAN Systems," in IEEE Transactions on Antennas and Propagation, vol. 63, no. 3, pp. 952-958, March 2015
31) D. Wu, S. W. Cheung and T. I. Yuk, "A Compact and Low-Profile Loop Antenna With Multiband Operation for Ultra-Thin Smartphones," in IEEE Transactions on Antennas and Propagation, vol. 63, no. 6, pp. 2745-2750, June 2015.

32) M. Taghadosi, L. Albasha, N. Qaddoumi and M. Ali, "Miniaturised printed elliptical nested fractal multiband antenna for energy harvesting applications," in IET Microwaves, Antennas & Propagation, vol. 9, no. 10, pp. 1045-1053, 7 16 2015.
33) C. K. Hsu and S. J. Chung, "Compact Multiband Antenna for Handsets With a Conducting Edge," in IEEE Transactions on Antennas and Propagation, vol. 63, no. 11, pp. 5102-5107, Nov. 2015.
34) S. Ahmed, F. A. Tahir, A. Shamim and H. M. Cheema, "A Compact KaptonBased Inkjet-Printed Multiband Antenna for Flexible Wireless Devices," in IEEE Antennas Wireless Propag. Lett., vol. 14, no. , pp. 1802-1805, 2015.
35) D. Wang and C. H. Chan, "Multiband Antenna for WiFi and WiGig Communications," in IEEE Antennas Wireless Propag. Lett., vol. 15, no. , pp. 309-312, 2016.
36) Y. Cui, L. Yang, B. Liu and R. Li, "Multiband planar antenna for LTE/GSM/UMTS and WLAN/WiMAX handsets," in IET Microwaves, Antennas & Propagation, vol. 10, no. 5, pp. 502-506, 4 13 2016.
37) Y. Liu, D. Shi, S. Zhang and Y. Gao, "Multiband Antenna for Satellite Navigation System," in IEEE Antennas Wireless Propag. Lett., vol. 15, no. , pp. 1329-1332, 2016.
38) W. Lee et al., "Low-Profile Multiband Ferrite Antenna for Telematics Applications," in IEEE Transactions on Magnetics, vol. 52, no. 7, pp. 1-4, July 2016.