DESIGN OF E-SHAPED DIELECTRIC RESONATOR ANTENNA FOR ULTRA WIDEBAND (UWB) APPLICATIONS

A thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Technology

in

Electronics and Communication Engineering

by

Chandan Srivastava (109EC0245)

Arjun Gaihre (109EC0529)

Under the supervision of

Prof. S. K. Behera

Department of Electronics and Communication Engineering

National Institute of Technology Rourkela, 2013

Department of Electronics and Communication Engineering

National Institute of Technology, Rourkela-769008

Certificate

This is to certify that the thesis entitled, "**Design of E-shaped Dielectric Resonator Antenna for UWB Applications**" submitted by **Mr. Chandan Srivastava** and **Mr. Arjun Gaihre** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in **ELECTRONICS AND COMMUNICATION ENGINEERING** at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge, the matter embodies in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

DATE: **(Dr. S. K. BEHERA)**

Acknowledgement

We have taken efforts in completing this project. However, it would not have been possible without the kind support and help of our department (**Electronics and Communication**), supervisor (**Prof. SK Behera**), Mr. Imran Khan and other faculties. We would like to extend our sincere thanks to all of them.

We are highly indebted to our project guide and mentor **Prof. SK Behera** for his valuable guidance, encouragement and constant supervision as well as for providing necessary information regarding the project and also for his support in completing the project. His sincere sympathy and kind attitude always encouraged us to carry out our work with ease.

We would also most humbly like to express our thankfulness to **Prof. S Meher**, Head of the Department of Electronics and Communication Engineering, NIT Rourkela for providing us with best available facilities in the department. We would also like to thank **Mr. Imran Khan** for his sincere and constant support in our work.

Lastly, we also take this opportunity to record our sincere thanks to all the faculty members of the department (Electronics and Communication Engineering) for their help and encouragement. We also like to thank all our friends, well-wishers and our parents for their unceasing encouragement and support.

(Mr. Chandan Srivastava) (Mr. Arjun Gaihre)

Abstract

Past few decades have witnessed huge advancements in the field of Antennas in terms of size, cost, efficiency, bandwidth, losses, power handling capacity and gain. Dielectric Resonator Antenna (DRA) is very latest and very efficient technology in the field of Antennas. It is very small in size, larger bandwidth, low losses, lower cost and very easy to integrate with existing technology.

Here an E-shape DRA for Ultra-Wide Band (UWB) application is presented. It is very small in size. Antenna size is 24x24 mm^2. We have used a substrate of size 24x24x1.6 mm^3 with a 4.4 dielectric constant. We have used a ground plane of size 24x10 mm^2. E-shape dielectric that has been used dielectric constant 2.1 and its height is 3 mm. Microstrip line is used as feeding line with dimensions 3x15 mm^2.

This antenna works best in frequency range of 6.7995-10.933 GHz. Its resonant frequency is 7.6818 GHz. VSWR parameter should be less than 2 within operating frequency range. This can be used in short range tracking, missile guidance, marine radar etc. as it comes mostly in X-band for UWB.

Contents

Contents

LIST OF FIGURES:

Chapter 1

Introduction

Antennas are the most important parts of wireless communication systems which have grown rapidly in last few decades. These wireless systems no matter how simple or complex , cannot operate efficiently unless they utilize some transmitting and receiving elements to efficiently radiate and receive waves which carry information. Antennas utilize Electromagnetic spectrum for receiving or transmitting. In today's world of wireless communication antennas are very important. This is why there has been large advancement in field of antennas. Size of the antenna have become very smaller, cost has become very reasonable and are handier than any time.

1.1 Objective of Project:

E-shaped Dielectric Resonator Antenna is designed with the given dimensions and microstrip line feed for Ultra Wideband applications. Different parameters related to antennas like resonant frequency, return loss, VSWR, E-plane and H-plane radiation pattern and the gain of antenna are studied.

1.2 What is an antenna?

An antenna is used to transmit and receive electromagnetic waves. An antenna is a device which converts electrical waves into electromagnetic waves for Transmission and converts electromagnetic waves into electrical waves for Receiving. Each antenna has a particular frequency range in which it works best.

1.3 How does an antenna radiate?

Antennas are basically having metallic conductor electrically connected (here it is microstrip transmission line) to receiver or transmitter. Whenever electrical current starts to flow oscillating currents of electrons will create a magnetic field (H-field) around antenna and the charge of electrons also create electric field (E-field). So from the starting varying field radiates away from antenna. During reception E-field and H-field of radio waves exert force on electrons of antenna, causing them to move and so create oscillating current.

1.4 Important Parameters of Antennas

Some parameters are very important for antennas, which affects performance of antennas. So this is very important to study those parameters and adjust them to get best performance from antenna. Important parameters of antennas are:

- Radiation patterns of antenna
- Feeding technology
- Power gain
- Directivity
- Radiation efficiency
- Polarization
- Input Impedance

1.5 Applications of Antennas

Most common uses of antennas are in broadcasting radio, television broadcast, wireless communication (especially in mobile communication) etc. These are used for radar and satellite communication. Apart from these antennas are also used for different applications like: for garage door opening controller, wireless microphone, short range tracking, missile guidance, marine radar, Bluetooth devices, wireless computer networks and duplex radios. In last few decades antennas are mostly used for cellular phone, GPS, satellite, wireless LAN for computers (Wi-Fi), Bluetooth technology and radio frequency ID (RFID) devices.

1.6 What is Ultra-wide Band (UWB)?

- UWB is a technology for transmission of data using technique which spread radio energy over a wide frequency range with low power spectral density [4].
- Low power spectral density limits interference potential with conventional radio systems and high bandwidth can allow very high data throughput for communication devices or high precision for location and imaging devices [4].
- UWB is a very good alternative to existing wireless technologies such as WLAN, HiperLAN in terms of speed.
- UWB has applications in non-cooperative radar imaging. Most recent applications are sensor data collection, precision locating and tracking applications.

- A February 14, 2002 Report and Order by the FCC (Federal Communication Commission) authorized the unlicensed use of UWB in the range of 3.1 to 10.6 GHz [4].
- The FCC power spectral density emission limit for UWB band is -41.3dBm/MHz. However, the emission limit for UWB emitters can be significantly lower (as low as -75dBm/MHz) in other segments of the spectrum [4].

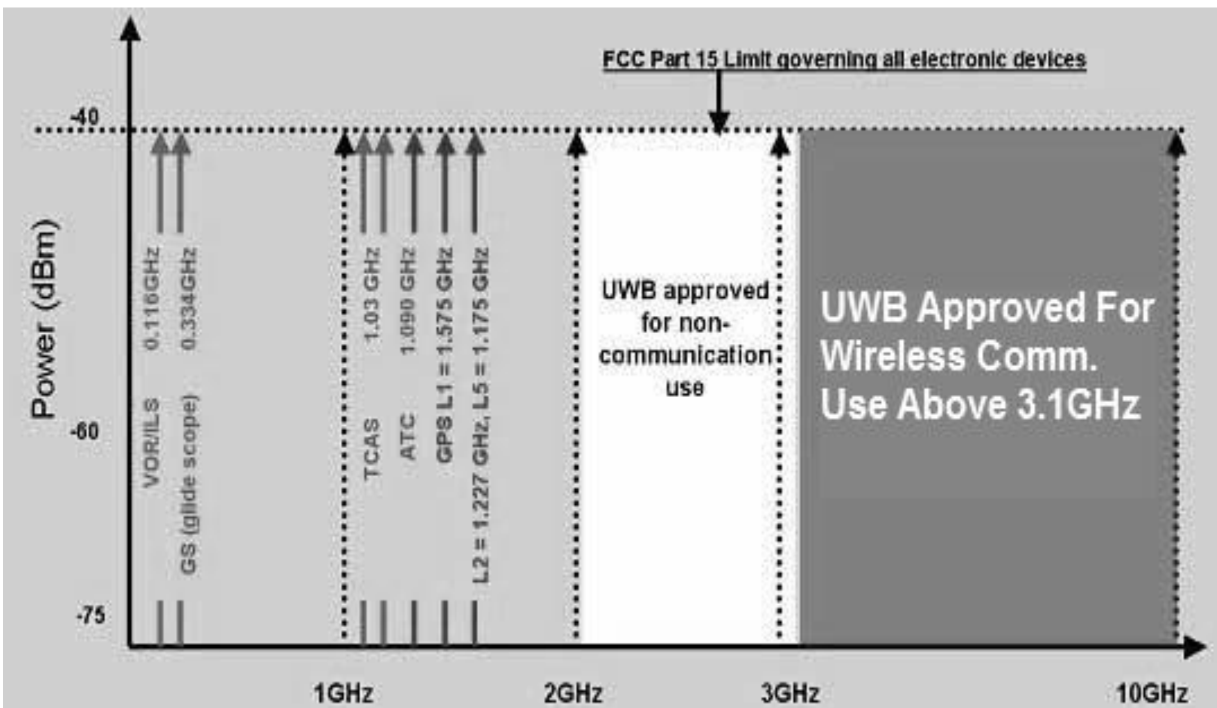

Figure 1: Spectrum of UWB

1.7 Characteristics of UWB

- Transmission energy is very low (less than 1 mW).
- Bandwidth is very high (can be upto 10 GHz).

- Low susceptibility to multipath fading: Multipath within and around buildings cause significant deterioration in the performance of conventional communication systems.
- Immunity to interference.
- Secure Communications: Because UWB signals can be made noise-like, communication using transmitter/receiver pairs with a unique timing code at millions of bits per second, have such low energy and spectral density below the noise floor of conventional receivers, and occupy such a wide bandwidth, they are more covert and potentially harder to detect than conventional radio.
- In RADAR
  - Has high precision and sub-centimeter ranging
  - Wideband excitation is used for detection of complex, low RCS target
- Low cost.

1.8 Advantages of UWB Technology

<u>Capacity</u>

It achieves very high data rate (upto 500 Mbps)

<u>Low Power and Low Cost</u>

In this communication technology un-modulated baseband pulses of very short duration are sent. This is why it is known as “Carrier free Impulse baseband radio”.

It needs very small transmission power and power is in microwatt range.

Fading Robustness

Problem of time varying amplitude fluctuations is avoided because of wideband nature of the signal.

It is also immune to Multipath Delays as time delay introduced is generally more than the signal period.

Short Range

It has very short range of operation (within 10m), so power requirement for transmission is low and also interference with other short range devices is very less. It comes under WPAN (Wireless Personal Area Network).

Security Aspects

It behaves as noise for other NB (narrow band) systems operating in that frequency range; but it does not affect them because of its low signal power. It only increases SNR (sound noise ratio) for those systems. Using PN (Pseudo Random) codes UWB systems can be made undetectable by other receivers and can be protected from Jamming.

Chapter 2

Dielectric Resonator Antenna

2.1 What is dielectric resonator antenna (DRA)?

A **dielectric resonator** or **dielectric resonator oscillator (DRO)** is an electronic component that exhibits resonance for a narrow range of frequencies, generally in the microwave band. The resonance frequency is determined by the overall physical dimensions and the dielectric constant of the material.

Hence **Dielectric Resonator Antenna** (DRA) is a radio antenna used at microwave frequencies and higher, consists a ceramic material block of different shapes called **dielectric resonator**, mounted on a metal surface called **ground plane [2]**.

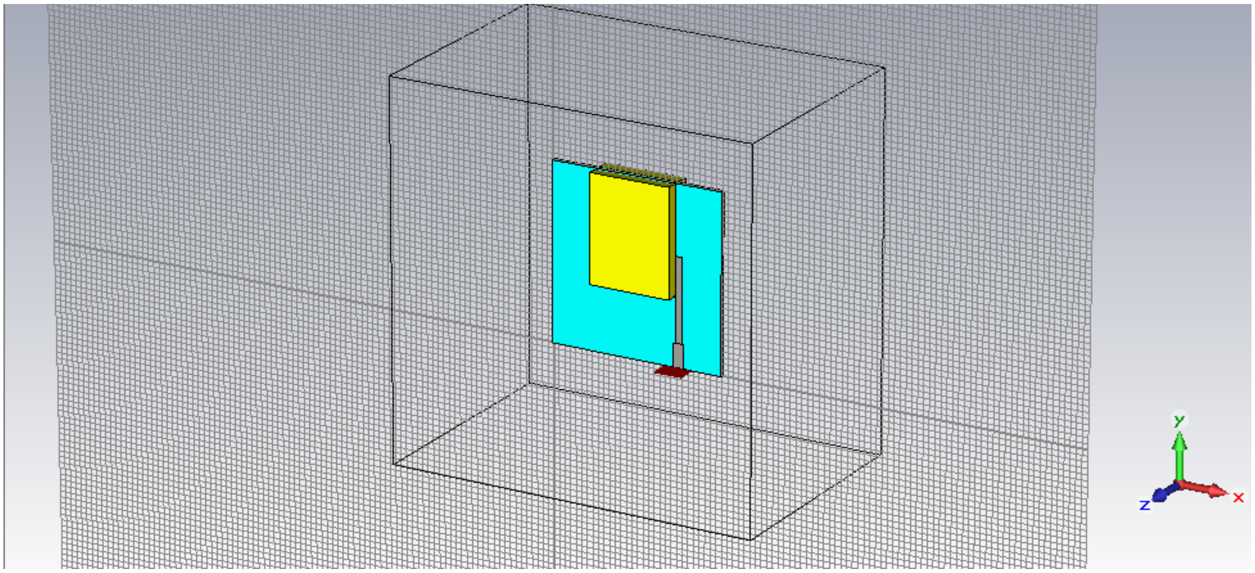

Figure 2 Geometry of DRA with Microstrip feed Line [5]

2.2 History

Microwave resonators in form of dielectric spheres and toroids were first theoretically demonstrated in 1939 by Richtinger [6] and there modes were first analyzed in early 1960s by Okaya and Barash [7]. Development of low-loss ceramic materials opened the way for the use of these resonators as high-Q elements for circuit applications such as filters and oscillators, offering a more compact alternative to the waveguide cavity resonator. For these applications, dielectric resonators are typically machined into different shapes out of materials having a relatively high dielectric constant ($\varepsilon_r >= 35$), to maintain compactness.

The study of DRAs began in the early 1980s with the examination of characteristics of cylindrical, rectangular and hemispherical shapes by Long, McAllister and Shen [9]. In early 1990s, emphasis was placed on realizing various feeding mechanisms to excite the DRAs and on applying various analytical or numerical techniques for determining input impedance and Q-factor.

Since 1990s more researchers have entered in this field and emphasis has been on compact design to address the needs of portable wireless applications, new DRA shapes and bandwidth enhancement [8].

2.3 Types of DRA

The three basic shapes of DRA are Hemispherical, Rectangular and Cylindrical. Many other shapes are also available. Many of them are derived from these three basic DRAs. A fourth group is also available which does not fit in any of these three shapes. Finally, a fifth category containing hybrid antennas that combine DRA with another antenna for enhanced bandwidth.

DRAs of first three shapes are commonly used. Hemispherical DRA is of limited practical value due to difficulty in fabrication and lack of freedom in choosing design parameters.

The cylindrical DRA offers greater design flexibility, where the ratio of radius/height controls the resonant frequency and Q-factor. Fabrication is also simpler than Hemispherical DRA.

Rectangular DRA offers the greatest design flexibility of the three basic shapes (length/width and depth/width). Several aspect ratios can be chosen to all resonate at a given frequency, while offering different radiation Q-factors.

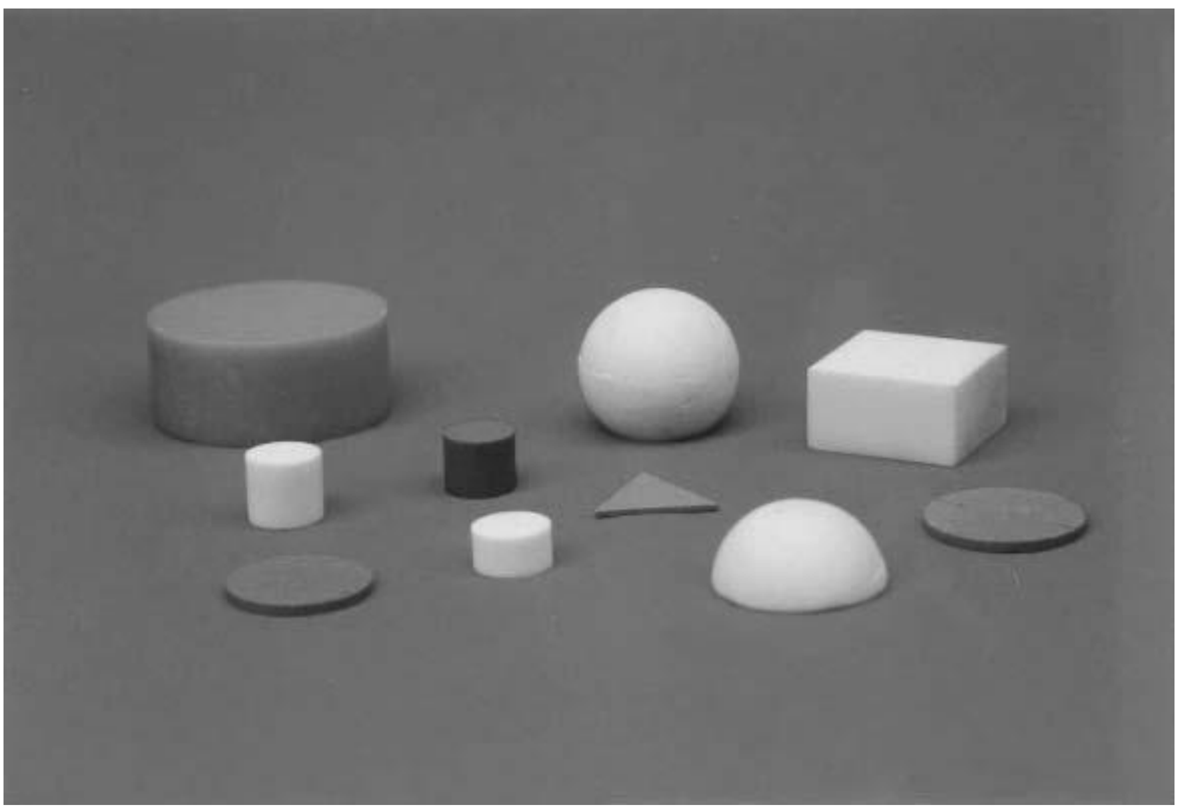

Figure 3 DRAs of various shapes [3]

2.4 Coupling of DRAs

The selection of coupling and its location both play an important role in determining which modes are excited. Feeding mechanism also have a significant impact on resonant frequency and Q-factor.

Aperture Coupling

Most common method is an aperture in the ground plane upon which DRA is placed. Small rectangular slot is most widely used aperture. By keeping slot dimensions electrically small, amount of radiation beneath ground plane can be minimized [2].

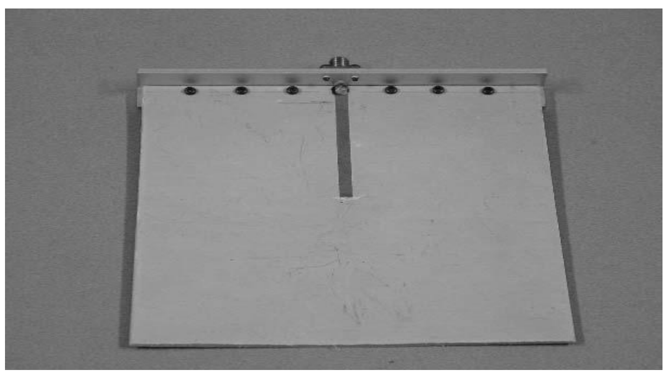

Figure 4 Aperture Coupling [3]

Probe Coupling

Probe usually consists of center pin of a coaxial transmission line that extends through ground plane. Center pin can also be soldered to a flat metal strip that is placed adjacent to DRA, whose length and width can be changed to improve impedance match [2].

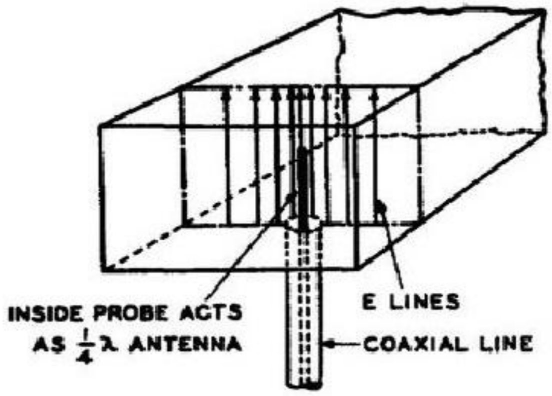

Figure 2.4 Probe Coupling

Microstrip Line Coupling

A common method for coupling to dielectric resonators is by proximity coupling to microstrip lines [2]. It can be used to excite $TE^{x}_{\delta 11}$ mode of rectangular DRA or $HE_{11\delta}$ mode of cylindrical DRA.

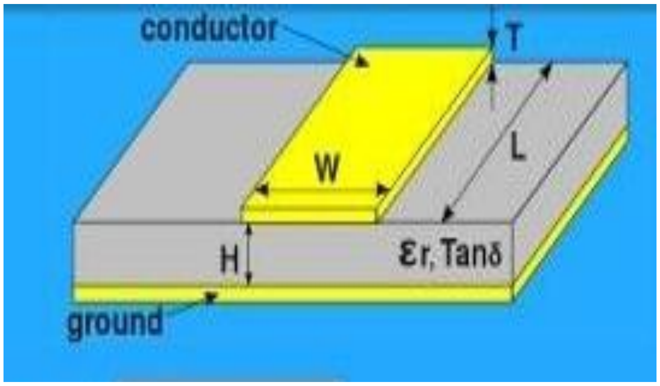

Figure 5 Microstrip Line Coupling

Coplanar Coupling

Open-circuit coplanar waveguide can be used to directly feed DRAs. Additional control on impedance matching can be achieved by inserting stubs or loops at the end of the line [2]. Coupling level can be adjusted by changing the position of DRA over the loop.

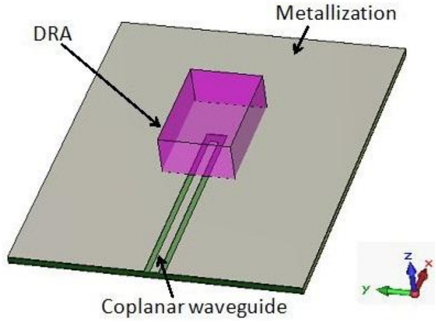

Figure 6 Coplanar Coupling

Dielectric Image Guide Coupling

Dielectric image guides offer advantages at millimeter-wave frequencies, since they do not suffer severely from conductor losses [2]. Amount of coupling to DRAs is generally quite small but it can be increased by operating guide closer to cut-off frequency.

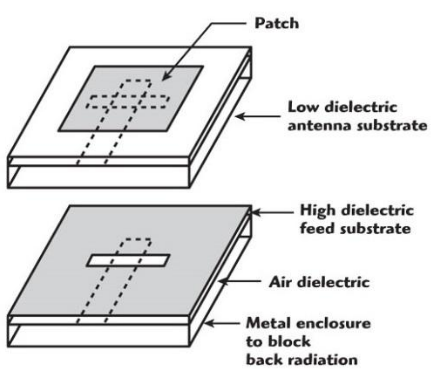

Figure 7 Dielectric Image Guide Coupling

2.5Analysis of Rectangular DRA

For rectangular DRA with dimensions d>h or a given in figure below, lowest order mode will be $TE^{x}_{\delta 11}$ [2]. This leads to the following fields within DRA

$$H_x = \frac{k_x k_y}{j\omega\mu_0} \sin(k_x x)\cos(k_y\, y)\sin(k_z z)$$

$$H_y = \frac{k_x k_y}{j\omega\mu_0} \sin(k_x x)\sin(k_y\, y)\sin(k_z z)$$

$$H_z = \frac{k_x^2 + k_y^2}{j\omega\mu_0} \cos(k_x x)\cos(k_y\, y)\cos(k_z z)$$

$$E_x = k_y \cos(k_x x)\sin(k_y\, y)\cos(k_z z)$$

$$E_y = -k_x \sin(k_x x)\cos(k_y\, y)\cos(k_z z)$$

$$E_z = 0$$

Where,

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2$$

$$k_z \tan\left(\frac{k_z l}{2}\right) = \sqrt{(\varepsilon - 1)k_0^2 - k_z^2}$$

$$k_0 = \frac{2\pi k f_0}{c}$$

$$k_x = \frac{n\pi}{l}$$

$$k_y = \frac{n\pi}{m}$$

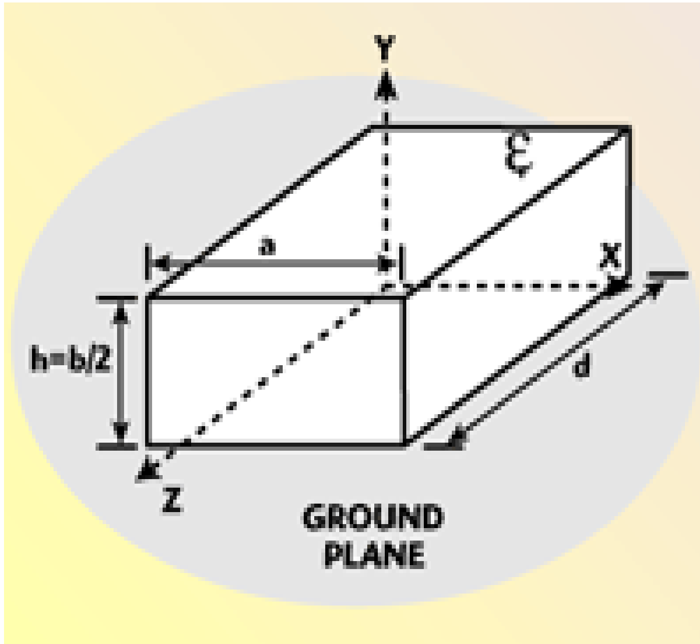

Figure 8 Rectangular Dielectric Resonator Antenna

2.6 Advantages of DRAs

Main advantage of DRA is its high flexibility and versatility, allowing designs to suit a wide range of physical or electrical requirements of varied applications. It has many other advantages:

- Size of DRA is proportional to $\lambda_0/\sqrt{\varepsilon r}$, where λ_0 is free space wavelength at resonant frequency and ε_r (it can vary from 4 to 100) is dielectric constant of material. Hence we can control physical size of DRA and its bandwidth.
- Resonant frequency and Q-factor will also be affected by aspect ratio of DRA, hence giving more design flexibility.
- Since here metal parts are very less hence total loss in radiation is also very less.

- By selecting a material with low-loss characteristics, a high-radiation efficiency can be maintained, even at millimeter wave frequencies.
- DRAs can be designed to operate over a long range of frequencies, with as low as 1 GHz to as high as 40 GHz or more.
- Several modes can be excited within DRA producing either broadside or omnidirectional radiation patterns for different requirements.
- Many feeding mechanisms can be used, so it is very easy to integrate with existing technologies.
- DRAs have a **high dielectric strength** and hence **higher power handling capacity**. Moreover the temperature-stable ceramics enable the antenna to **operate in a wide temperature range**.

Chapter 3

Antenna Design

3.1 Design of E-shape DRA

We have used a dielectric substrate of dielectric constant 4.4 with dimensions height=1.6mm, width=24mm, length=24mm. And ground plane of metal surface has dimensions length= 24mm width= 10mm. E-shaped dielectric resonator has dimensions length= 16mm width= 15mm height= 3mm and is of 2.1 dielectric constant. Distance between two horizontal lines of E-shape is 5mm and width of horizontal lines is 2mm. The DRA was fed with direct microstrip line with the dimensions width=3mm, length=15mm.

S.N	Elements	Parameters	Dimensions(mm)
1.	Substrate	Length Width Height Dielectric Constant	24 24 1.6 4.4
2.	Ground Plane	Length Width	24 10
3.	Dielectric Resonator	Length Width Height Dielectric Constant	16 15 3 2.1 (Teflon)
4.	Distance between two horizontal line of E-Shape	Length Width	5 2
5.	Microstrip Line	Length Width	15 3

Table 1: Design Parameters Table

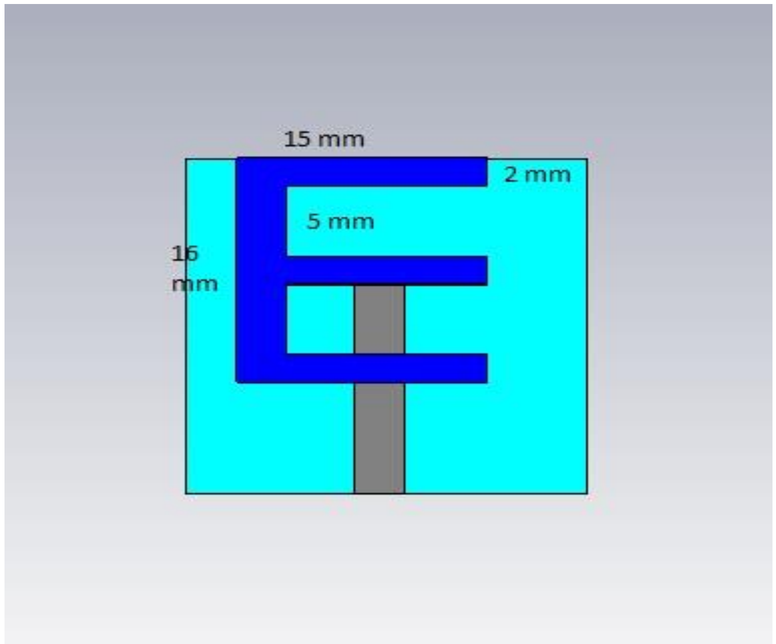

Figure 9 Shape of DRA

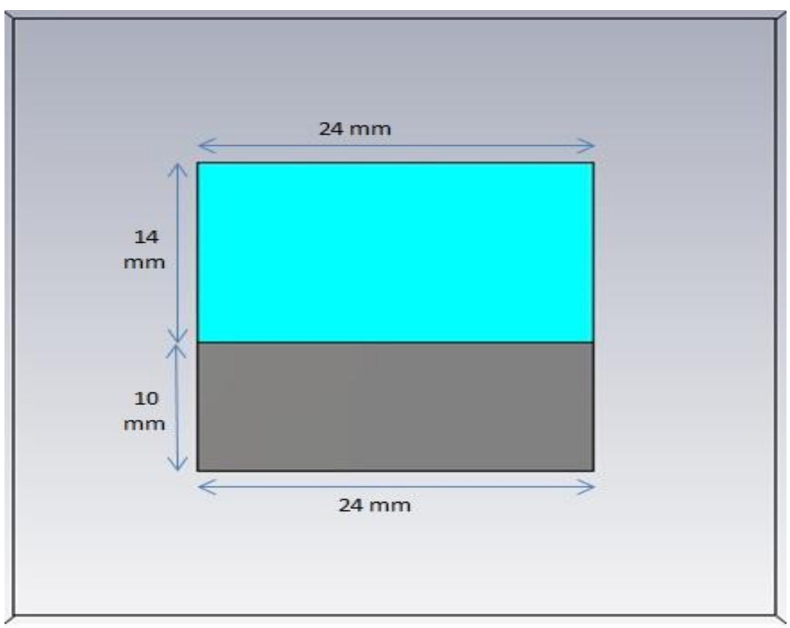

Figure 10 Ground Plane without DR (Rear View)

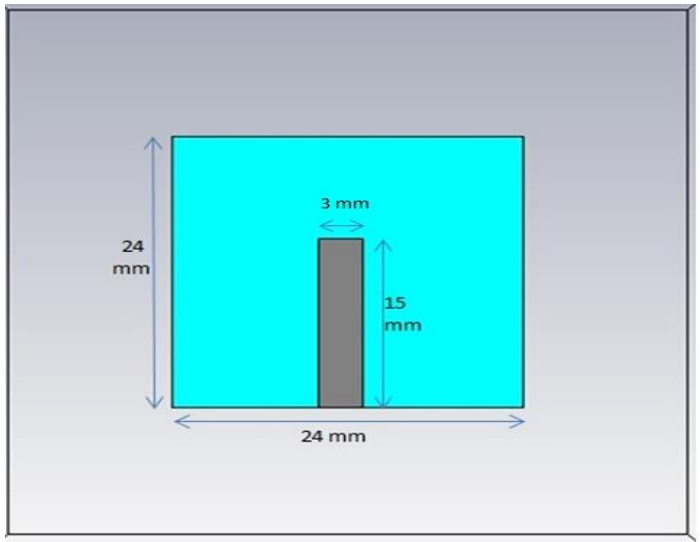

Figure 11 Feed line (without DR)

3.2Return Loss vs Frequency

Return loss is the power that is reflected by the antenna at the end of the transmitter or receiver. Lower the return loss higher will be the efficiency of antenna.

Return loss graph or |s| dB graph of this E-shaped DRA is given below:

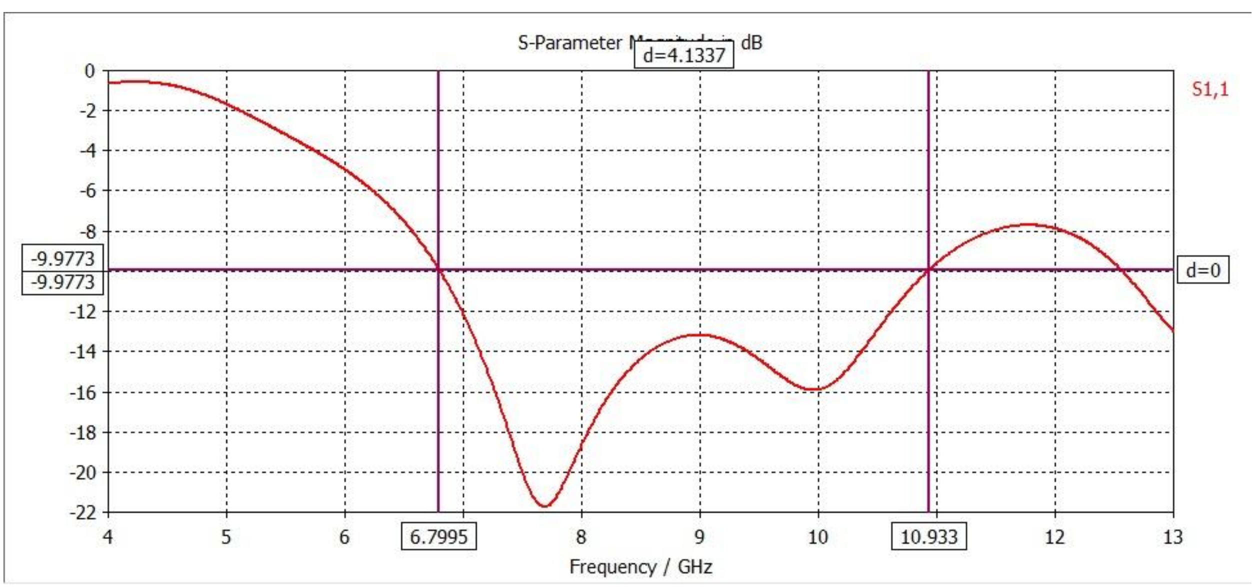

Figure 12 Return Loss Plot

We can see from above graph that return loss is less than -10 dB for the frequency range 6.7995-10.933 GHz. This range is bandwidth for the antenna. Antenna best works in this frequency range. Return loss is computed from the formula given below:

$$RL = -20\log_{10}|\Gamma|$$

Where, Γ = reflection coefficient.

3.3 Resonant Frequency

This is the frequency at which antenna radiates maximum and has lowest return loss. This frequency is shown in this graph:

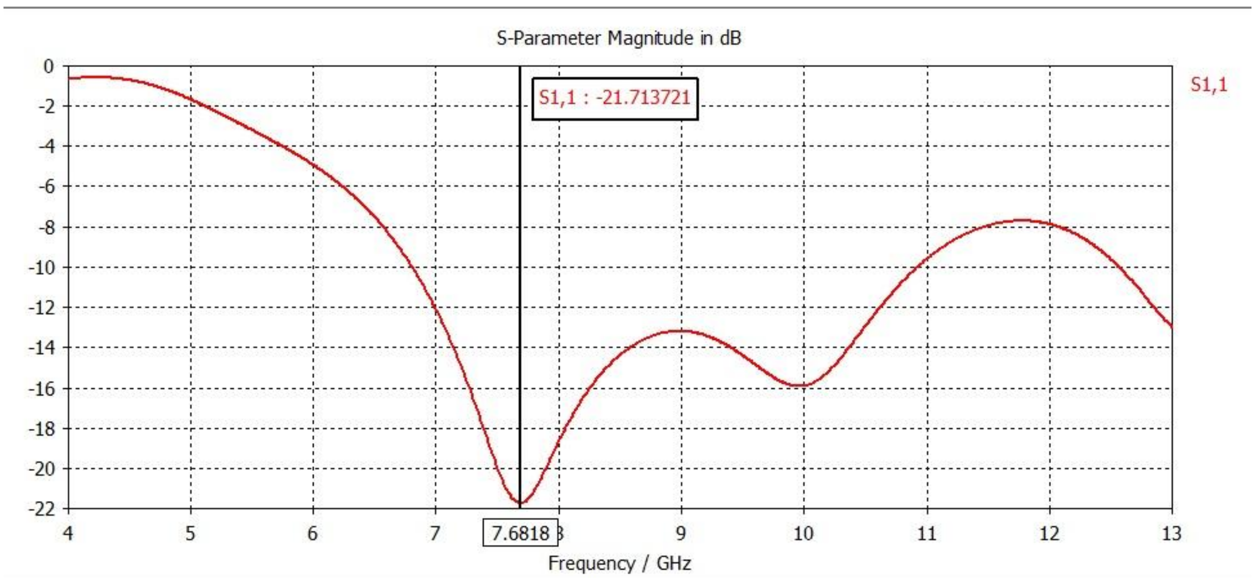

Figure 13 Resonant Frequency

From above graph it is clear that resonant frequency is 7.6818 GHz at which antenna performs best.

3.4 Voltage Standing Wave Ratio (VSWR)

VSWR is the measure of how well antenna's impedance is matched with transmission line. To deliver power to an antenna, impedance of transmission line must be matched with impedance of antenna.

VSWR is a function of reflection co-efficient, which describes the power reflected by antenna. If reflection co-efficient is Γ, then VSWR is given by:

$$\boldsymbol{VSWR} = \frac{\mathbf{1}+|\boldsymbol{\Gamma}|}{\mathbf{1}-|\boldsymbol{\Gamma}|}$$

VSWR is always real and positive for antennas.

VSWR graph for different frequencies for our designed antenna is given below:

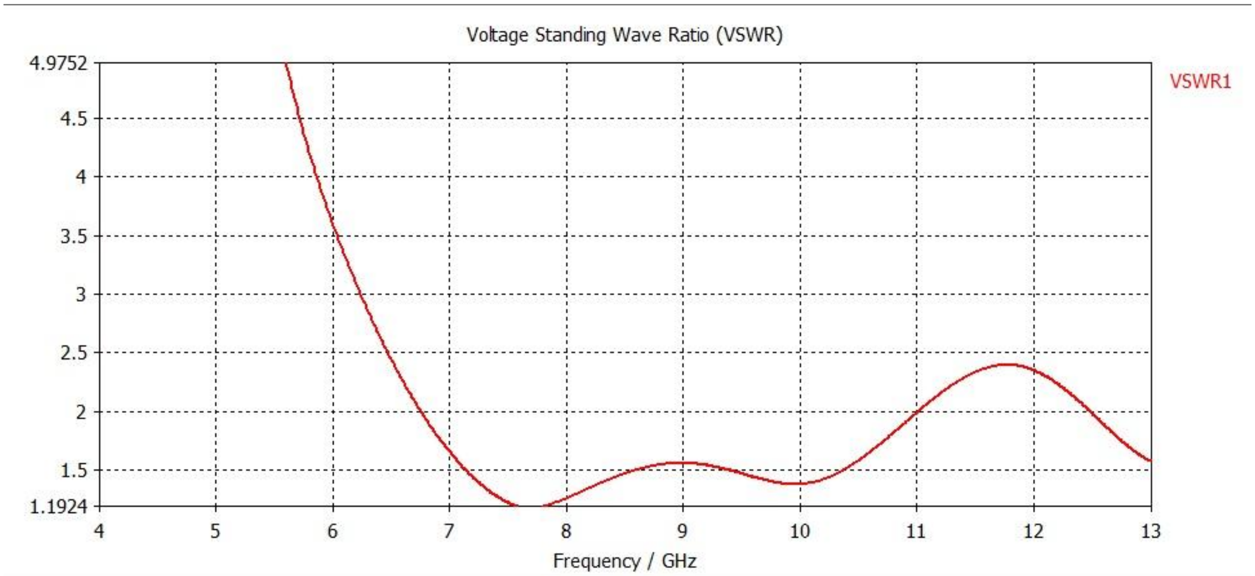

Figure 14 VSWR vs Frequency

For return loss to be less than -10 dB VSWR should be less than 2. From above graph it is clear that in the working frequency range i.e. from 6.7995 GHz to 10.933 GHz VSWR value is less than 2, hence antenna will work well in this frequency range.

3.5 Gain of Antenna

Gain of antenna is defined as "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." [1] Hence gain is given by:

$$Gain = 4\pi \frac{radiation\ intensity}{total\ (accepted) power}$$

Radiation intensity is given by U (θ, Φ)

And total power is given by P_{in}.

Gain graph for our designed antenna is given below:

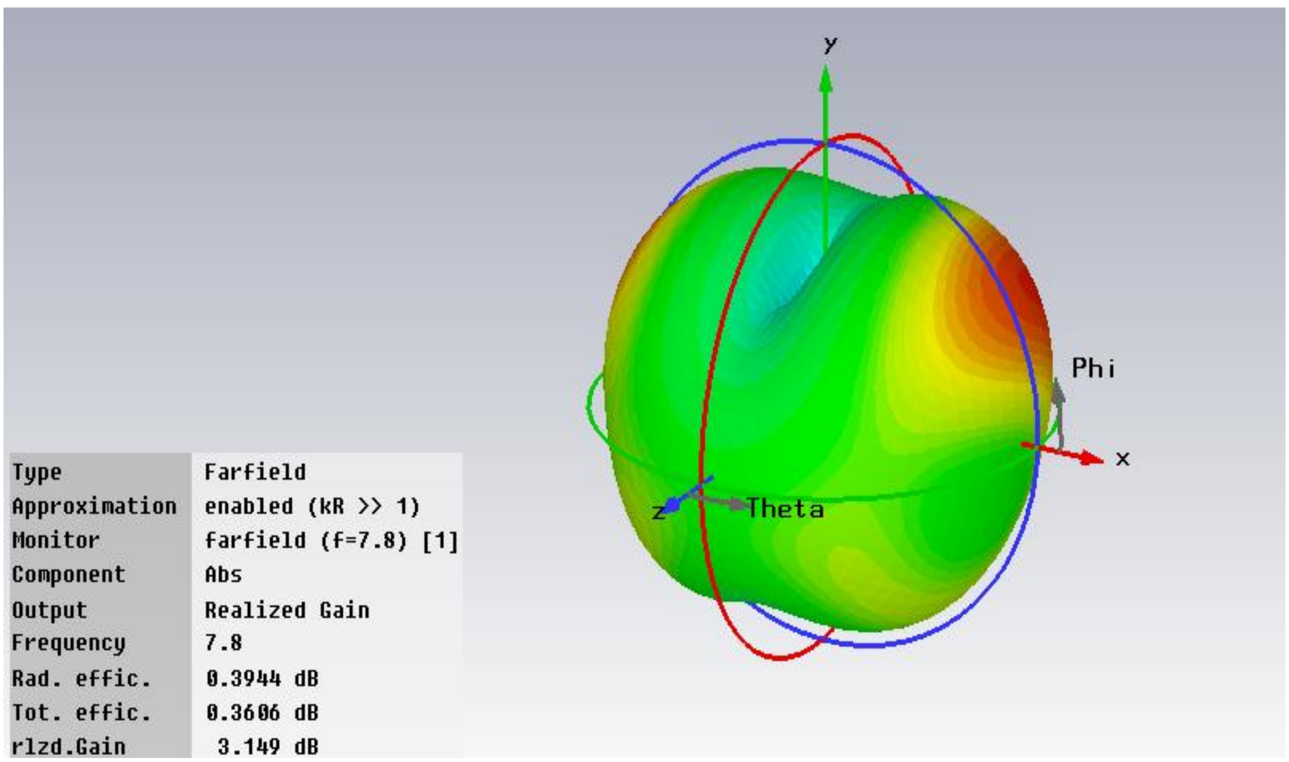

Figure 15 Gain Plot at Resonant Frequency

3.6 E-plane and H-plane Radiation Pattern

E-plane is defined as "plane containing electric field vector and direction of maximum radiation," and H-plane as "plane containing magnetic field vector and direction of maximum radiation." For figure 13, the x-z plane (elevation plane; $\varphi = 0$) is principle E-plane and the x-y plane (azimuthal plane; $\theta = \pi/2$) is the principle H-plane [1].

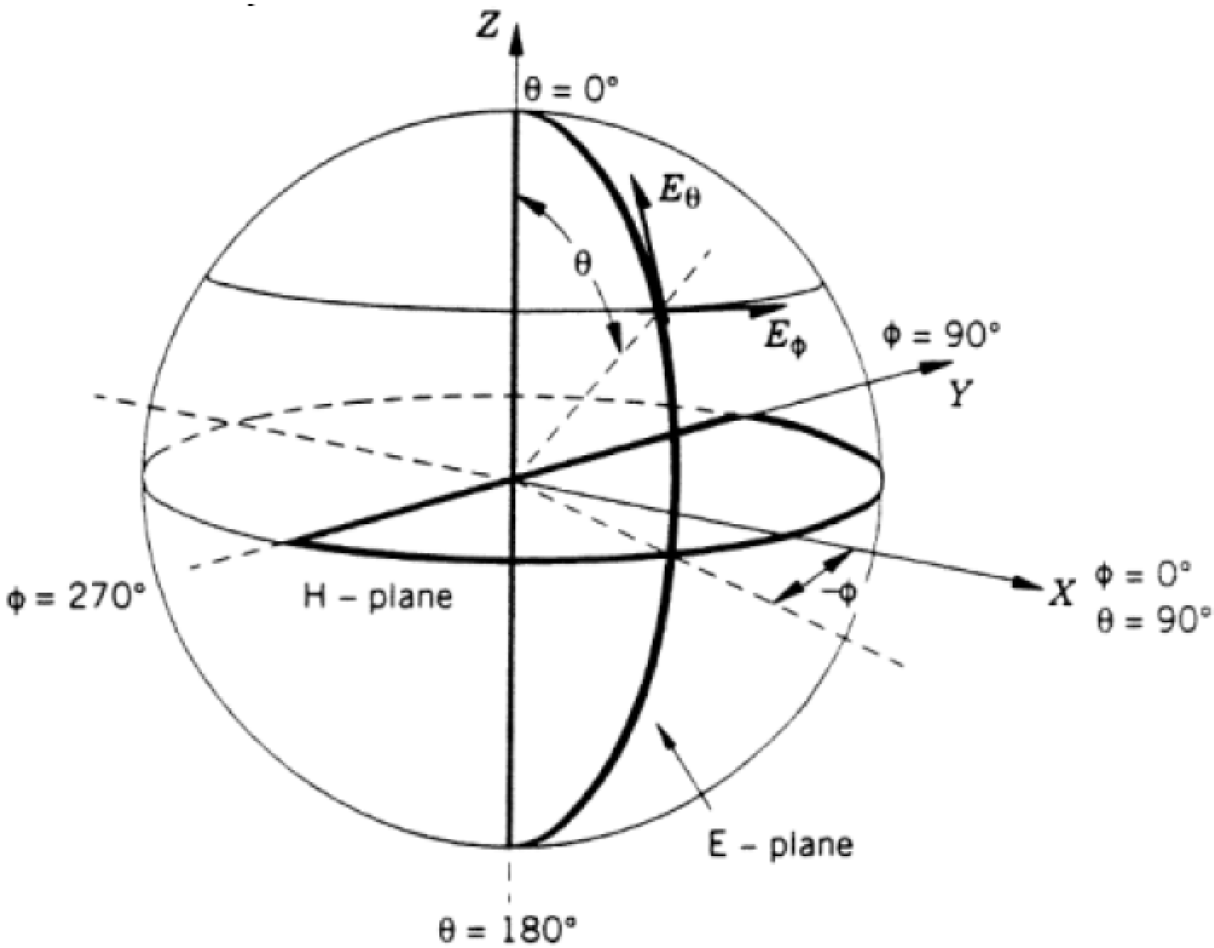

Figure 16 Representation of E-plane and H-plane

It is very important characteristic of any antenna. With the help of this plane we can measure radiation in any direction. E-plane and H-plane radiation pattern for our designed antenna is given below:

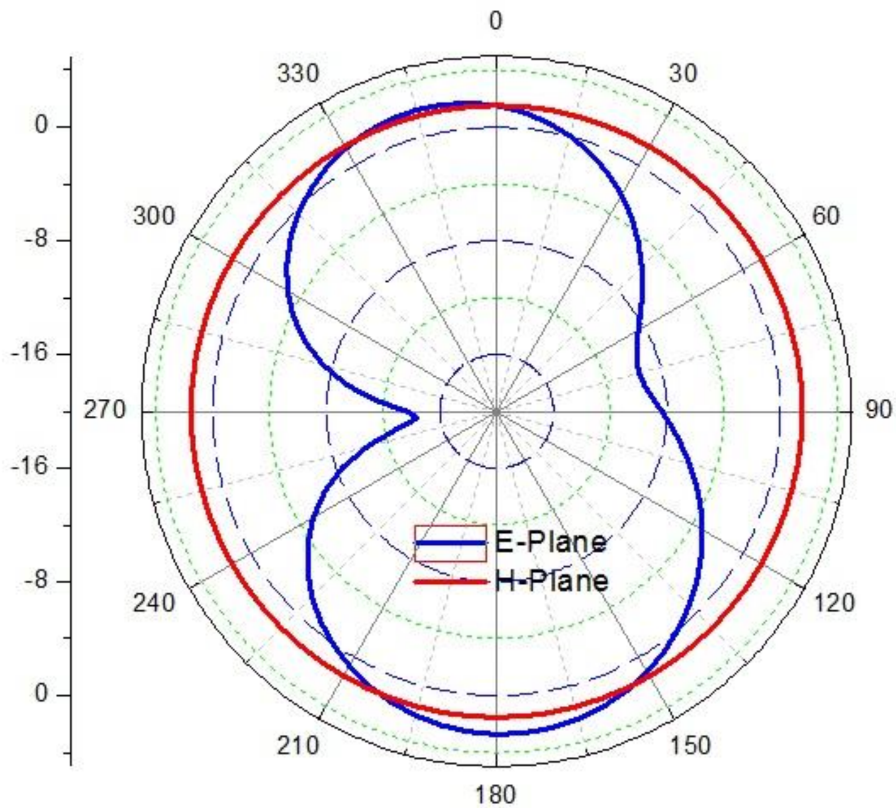

Figure 17 E-plane and H-plane Graph at Resonant Frequency

3.7 Bandwidth Calculation for Designed Antenna

To calculate bandwidth of any antenna we consider first and last frequencies at which antenna has -10 dB return loss.

Here,

$$f_1 = 6.7995 \text{ GHz}$$

$$f_2 = 10.933 \text{ GHz}$$

Hence,

$$\% \text{ Band-width} = \frac{f2 - f1}{\sqrt{f2.f1}} * 100$$

$$= \frac{10.933 - 6.7995}{\sqrt{10.933 * 6.7995}} * 100$$

$$= 47.94 \%$$

This is very large bandwidth compared to other regular antennas. This frequency range comes mostly in C-band and X-band.

Chapter 4

Conclusion

After a lot of modifications in the dimensions of ground plane and microstrip feed line we get the best results for this design. Even with full ground plane, we didn't get as good results as with this design. Here we have got bandwidth from 6.7995 GHz-10.933 GHz, which is the best that we have got for a DR of dielectric constant 2.1 i.e. for Teflon. This design has resonant frequency at 7.6818 GHz. It has VSWR from 1 to 2 in the operating frequency range which is very important for an antenna.

Finally after calculation of bandwidth we get its value and it is 47.94%. This range mostly comes in C and X-band; this is why we can use this antenna for short range tracking, missile guidance, mapping, marine radar etc.

So these are the good results in terms of bandwidth, VSWR, return loss and E and H-plane. But definitely there is a lot of scope for improvement and further works can be done to improve the results.

References

[1] C. A. Balanis, “Antenna Theory, Analysis and Design,” John Wiley & Sons, New York, Third ed., 2011,p.727-730.

[2] Aldo Petosa, “Dielectric Resonator Antenna Handbook”, Artech House, Boston, London.

[3] Kwai-Man Luk and Kwok-Wa Leung, “Dielectric Resonator Antenna”, City University of Hong-Kong, RESEARCH STUDIES PRESS LTD. Baldock, Hertfordshire, England.

[4] Young Man Kim, “Ultra Wide Band (UWB) Technology and Applications”,NEST group, The Ohio State University, July 10, 2003.

[5] M.F.Ain, S.I.S.Hassan, M.N. Ismail, M.A.Othman, M.R. Jaffar, A. Othman, A. A.Sulaiman, M.A. Zakariyya, S.Sreekantan, S.D.Hutagalung, Z.A.Ahmad, “3.5 GHz Rectangular Dielectric Resonator Antenna”, 2008 IEEE INTERNATIONAL RF AND MICROWAVE CONFERENCE PROCEEDINGS December 2-4, 2008, Kuala Lumpur, MALAYSIA.

[6] Richtinger, R.D., “Dielectric Resonators,” Journal of Applied physics, Vol. 10, June 1939, pp. 391-398.

[7] Okaya, A., and L.F. Barash, “The Dielectric Microwave Resonator,” Proceedings of the IRE, Vol. 50, Oct. 1962, pp. 2,081-2,092.

[8] Kajfez, D., and P. Guillon, (eds.), Dielectric Resonators, Dedham, MA: Artech House, 1986.

[9] McAllister, M.W., and S.A. Long, “Rectangular Dielectric-Resonator Antenna,” IEE Electronics Letters, Vol. 19, March 1983, pp. 218-219.