BRAC University

Design And Optimization of An UWB Microstrip Patch Antenna Using Dielectric Substrates Duroid 5880 And FR4

A Thesis Submitted to the
Department of Electrical And Electronic
Of
BRAC University

Supervised by
Dr. Pran Kanai Saha
Professor And Head, Department of EEE, BUET

In Partial Fulfillment of the Requirement for the Degree of
Bachelor of Science in
Electronics And Communication Engineering

Submitted by
Nusrat Tasnufa Chowdhury (08110026)
Dilruba Chowdhury (08110063)

Program: Electronics And Communication Engineering
Department: Electrical And Electronic Engineering

January 2014

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Declaration

This is to certify that this thesis paper has been done by us and it has not been submitted anywhere else for an award of any degree or diploma.

Nusrat Tasnufa Chowdhury

Dilruba Chowdhury

Signature of the Supervisor

Dr. Pran Kanai Saha

Professor And Head, Department of EEE, BUET

Acknowledgement and Dedication

It is with immense gratitude that we acknowledge,

First and foremost, our Supervisor, **Dr. Pran Kanai Saha** (Prof. and Head, Department of EEE, BUET) for his support of all possible kind, comment, suggestion and feedback without which this Thesis along with this paper would not have been completed.

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Finally, we sincerely thank our parents and friends who have given us hope and encouragement during the thesis whenever we needed to overcome any hurdle.

We want to dedicate this project work to our

Parents and Freedom Fighters of 1971

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Abstract

No longer new in wireless technology; the ultra wide band (UWB) radio transmits large amounts of digital data over a wide spectrum of frequency bands (>500MHz) at distance up to 230 ft at very low power (< 0.5 mW), As well as can carry signals through doors or obstacles; that tend to reflect signals at limited bandwidths and at higher power. The low power spectral density limits the interference potential with conventional radio systems. High bandwidth can allow very high data throughput for communication, or high precision for location and imaging devices. The Shannon's Theorem given by, Channel capacity; C= B. ln(1+ SNR); Where, B is bandwidth shows us that the channel capacity increases with the channel bandwidth.

Design and development of a rectangular micro strip slot patch antenna for short distance ultra wideband communication has been demonstrated in this project. Different antenna family for wide band communication has been studied. Suitable antenna architecture is to be proposed for ultra wide band application analyzed using HFSS 15. Result required 1 GHz bandwidth for the applied substrate thickness 5 mm and resonance frequency 5 GHz, the impedance matched and voltage standing wave ratio (VSWR) closest to 1. However, using different sizes, shapes, allocation and number of slots on patch to obtain the foremost required bandwidth for UWB application was the challenging part. The architecture has been developed to transmit over a bandwidth of 0.96 GHz which is close to required 1 GHz, having VSWR of 1.2202. Further modifications of the design can optimize the antenna for best result.

Chapter 1

Introduction

1.1 Ultra Wideband Technology

The concept of Ultra-Wideband was formulated in the early 1960s through research in time-domain electromagnetic and receiver design, both performed primarily by Gerald F. Ross. Through his work, the first UWB communications patent was awarded for the short-pulse receiver which he developed while working for Sperry Rand Corporation. Throughout that time, UWB was referred in broad terms as “carrier-less” or impulse technology. The term UWB was coined in the late 1980s to describe the development, transmission, and reception of ultra-short pulses of radio frequency energy. Even though the knowledge has been in existence for over thirty years, UWB technology is an emerging research topic in the wireless communications field for a variety of reasons. For communication applications, high data rates are possible due to the large number of pulses that can be created in short time duration. Due to its low power spectral density, UWB can be used in military applications that require low probability of detection. Other common uses of UWB are in radar and imaging technologies, where the ability to resolve multi path delay is in the nanosecond range, allowing for finer resolution, whether it be from a target or for an image.

UWB is a wireless technology for transmitting large amounts of digital data over a wide spectrum of frequency bands (>500MHz) with very low power density for a short distance. 3.1-10.6 GHz spectrum is allocated for UWB communications. Currently, UWB is also defined in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 500 MHz or 20% of the center frequency.

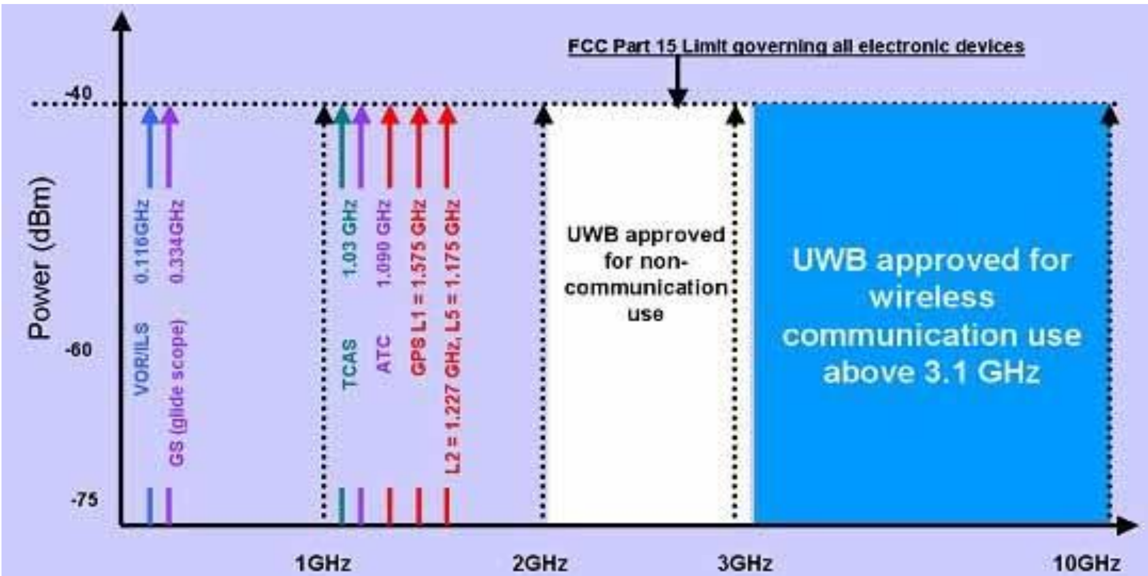


Figure: 1.1 (UWB Spectrum)

UWB radio not only can carry a huge amount of data over a distance up to 230 ft at very low power (< 0.5 mW), but has the ability to carry signals through doors and other obstacles; that tend to reflect signals at more limited bandwidths and a higher power. The low power spectral density limits the interference potential with conventional radio systems, and the high bandwidth can allow very high data throughput for communications devices, or high precision for location devices and imaging devices.

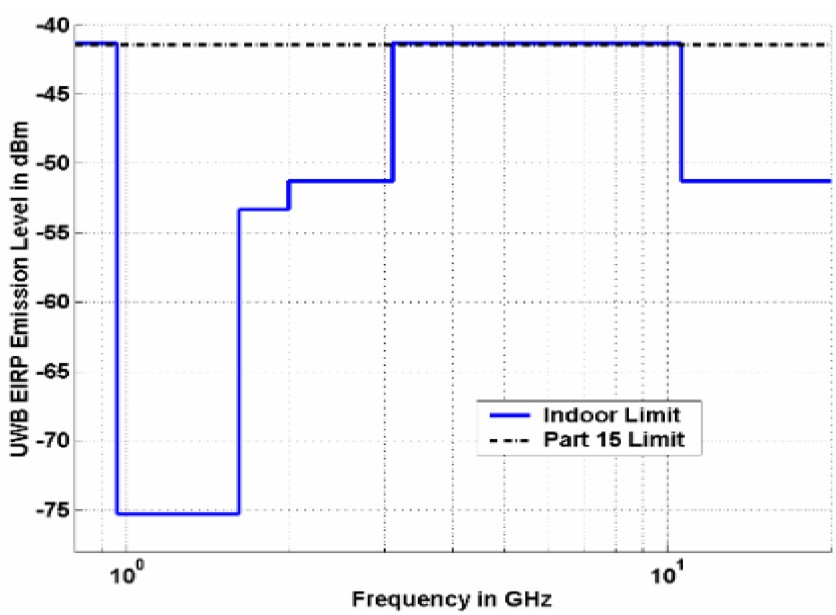


Figure: 1.2 (FCC Spectral mask for UWB Indoor Communication System)

1.2 History of UWB

Although UWB seems a new technology for its latest applications with; high data rates, lower powered devices and so on, sinusoidal electromagnetic waves is a dominant method of wireless communication these days and has been so universal that many people are not aware of that the first communication systems were in fact pulse based.

In 1893, Heinrich Hertz used a spark discharge to produce electromagnetic waves for his. These waves would be called colored noise today. Spark gaps and arc discharges between Carbon electrodes were the dominant wave generators for 20 years after Hertz's first experiment. However, the dominant form of wireless communications became sinusoidal, and it was not until the 1960's that work began again in earnest for time domain electromagnetic. The development of the sampling oscilloscope in the early 1960's and the Corresponding techniques for generating sub-nanosecond base band pulses sped up the development of UWB. Impulse response technique was used to characterize the transient behavior of certain microwave networks. From measurement techniques the main focus moved much attention because of accurate results that could be obtained. The low frequency components were useful in penetrating objects, and ground penetrating radar was developed.

In 1973 the first US patent was awarded for UWB communication. The field of UWB had moved in a new direction. Other applications, such as automobile collision avoidance, positioning systems, liquid level sensing, and altimetry were developed.

Most of the application and development occurred in the military or in work funded by the US Government under classified programs. For the military, accurate radar and low probability of intercept communications were the driving forces behind research and development.

The late 1990's saw the move to commercialize UWB communication devices and systems. Companies such as time domain and in particular startups like XtremeSpectrum were formed around the idea of consumer communication using UWB.

1.3 Applications of UWB

Low Data Rate:

UWB systems are usually short-range indoor applications. The power spectral density of UWB signals is extremely low, which enables system to operate in the same spectrum with narrowband technology without causing undue interference. The solution on the market for today's indoor application is infrared or ultrasonic approaches. UWB technology is less affected by shadows and allows the transmission through objects. The innovative communication method of UWB at low data rate gives numerous benefits to government and private sectors. For instance, the wireless connection of computer peripherals such as mouse, monitor, keyboard, joystick and printer can utilize UWB technology.

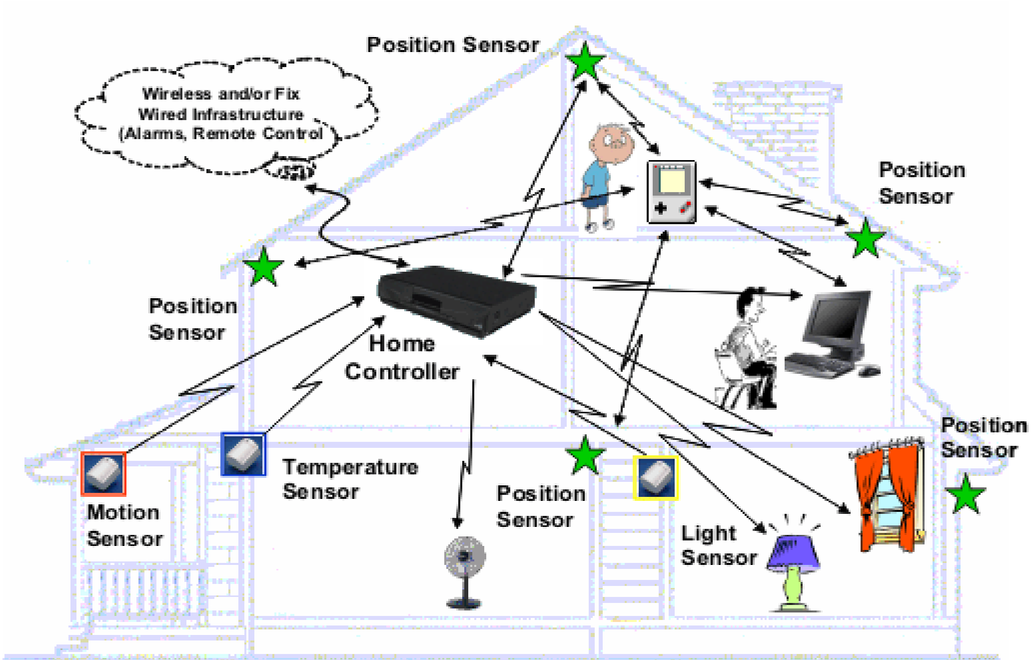


Figure: 1.3 (UWB application for low data rate)

UWB allows the operation of multiples devices without interference at the same time in the same space. It can be used as a communication link in a sensor network. It can also create a security bubble around a specific area to ensure security. It is the best candidate to support a variety of WBAN applications. A network of UWB sensors such as electrocardiogram (ECG), oxygen saturation sensor (SpO_2) and electromyography (EMG) can be used to develop a proactive and a smart healthcare system. This can benefit the patient in chronic condition and provides long term health monitoring. In UWB system, the transmitter is often kept simpler and most of the complexity is shifted towards receiver, which permits extremely low energy consumption and thus extends battery life.

High Data Rate:

High data rate UWB may enable wireless monitors, data transfer from digital camcorders, wireless printing of digital pictures directly from a camera, and file transfers between mobile handsets and handheld devices such as portable media players. The unique applications of UWB systems in different scenarios have initially drawn much attention, since many applications of UWB spans around existing market needs for high data rata applications.

Figure: 1.4 (High data rate applications of UWB)

Demand for high density multimedia applications is increasing, which needs innovative methods to better utilize the available bandwidth. UWB system has the property to fill the available bandwidth as demand increases. The problem of designing receiver and robustness against jamming are main challenges for high-rate applications. The large high-resolution video screens can benefit from UWB. These devices stream video content wirelessly from video source to a wall-mounted screen. Various high data rate applications include internet access and multimedia services, wireless peripheral interfaces and location based services. Regardless of the environment, very high data rate applications (>1 Gb/s) have to be provided. The use of very large bandwidth at lower spectral efficiency has designated UWB system as a suitable candidate for high internet access and multimedia applications.

Position location and tracking:

For active RF tracking and positioning applications, the short-pulse UWB techniques offer distinct advantages in precision time-of-flight measurement, multi path immunity for leading edge detection, and low prime power requirements for extended-operation RF identification.

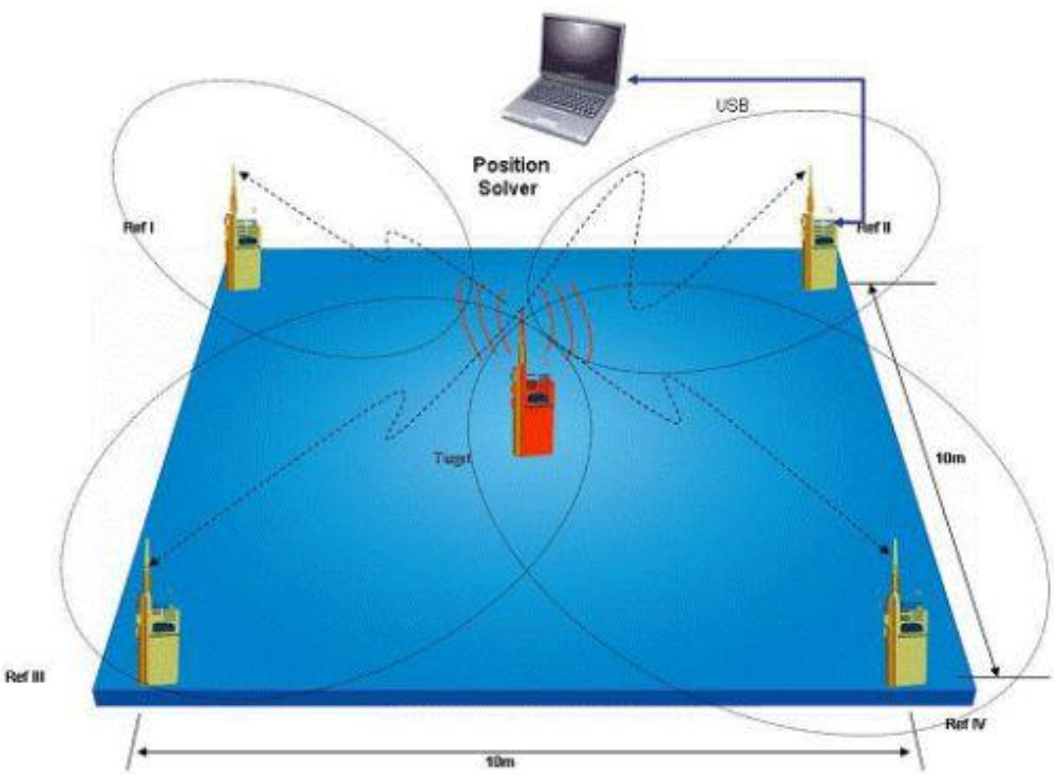


Figure: 1.5 (UWB geo positioning system for emergency service)

'See through wall' precision RADAR Imaging:

UWB is also used in ‘see-through-the-wall’ precision radar imaging technology. A short-pulse UWB technique have several radar applications such as higher range measurement accuracy and range resolution, enhanced target recognition, increased immunity to co-located radar transmissions, increased detection probability for certain classes of targets and ability to detect very slowly moving or stationary target. UWB is a leading technology candidate for micro air vehicles (MAV) applications.

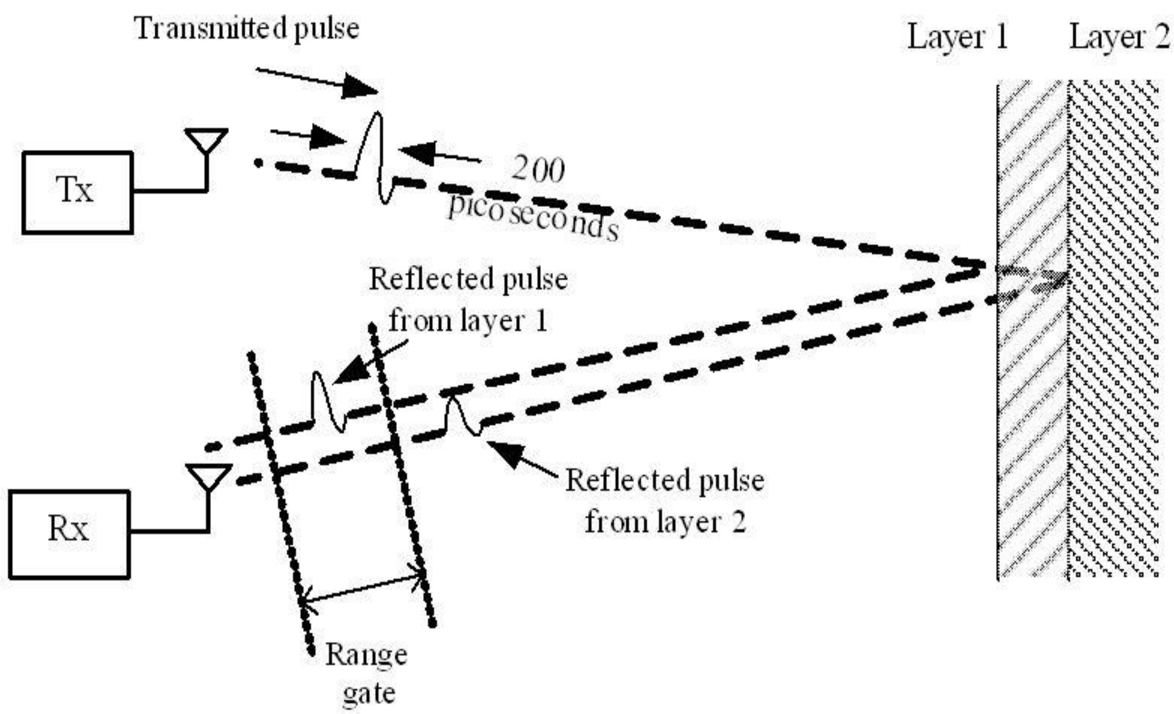


Figure: 1.6 (RADAR sensing using UWB)

Surveillance/navigation systems now use TV, infrared, and other LOS surveillance hardware extensively including both military and civil applications.

The nature of creating millions of ultra-wideband pulses per second has the capability of high penetration in a wide range of materials such as building materials, concrete block, plastic and wood.

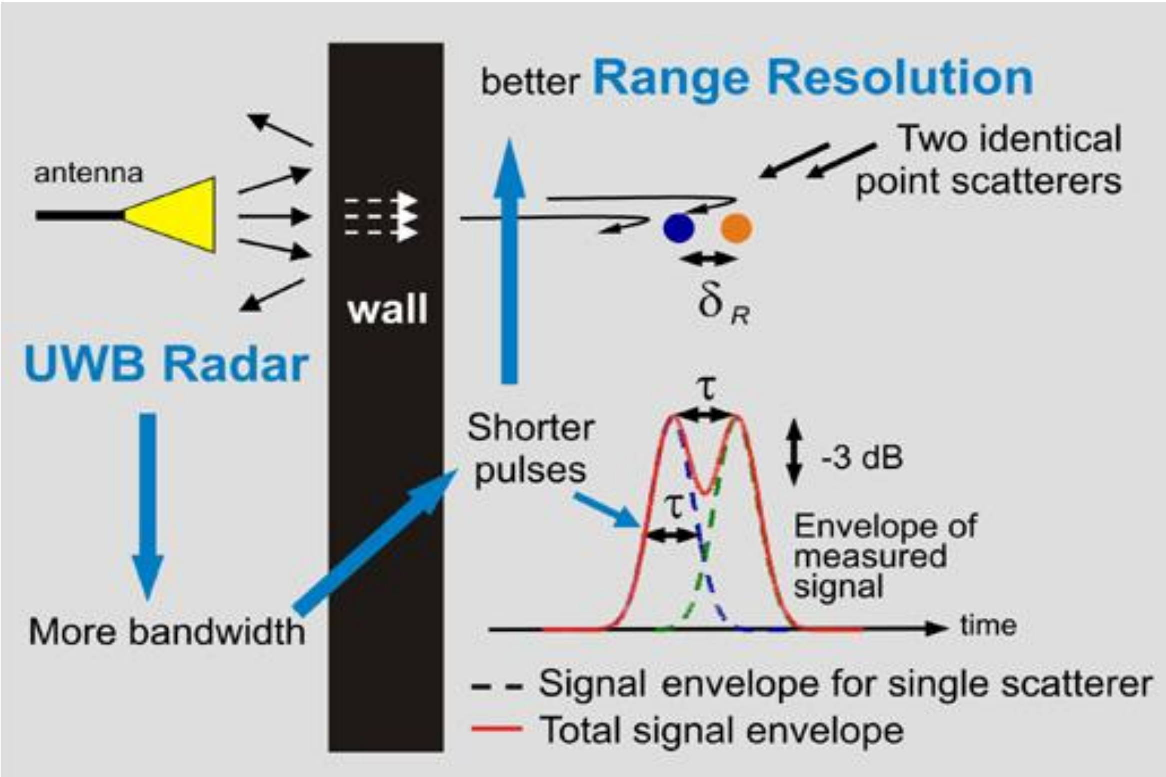


Figure: 1.7 (RADAR sensing through Wall)

UWB in WBAN technology:

A WBAN or wireless body area network consists of miniaturized, low power, and non- Invasive / Invasive wireless biosensors, which are seamlessly placed on or implanted in human body in order to provide a smart and adaptable healthcare system.

A WBAN requires the resolution of many technical issues and challenges such as interoperability, QoS, scalability, design of low power RF data paths, privacy and security, low power communication protocol, information infrastructure and data integrity of the patient’s medical records. The average power consumption of a radio interface in a WBAN must be reduced below 100W. Moreover, a WBAN is a one-hop star topology where power budget of the miniaturized sensor nodes is limited while network coordinator has enough power budgets. In addition, most of the complexity is shifted to the network coordinator due to its capability of having abundant power budget.

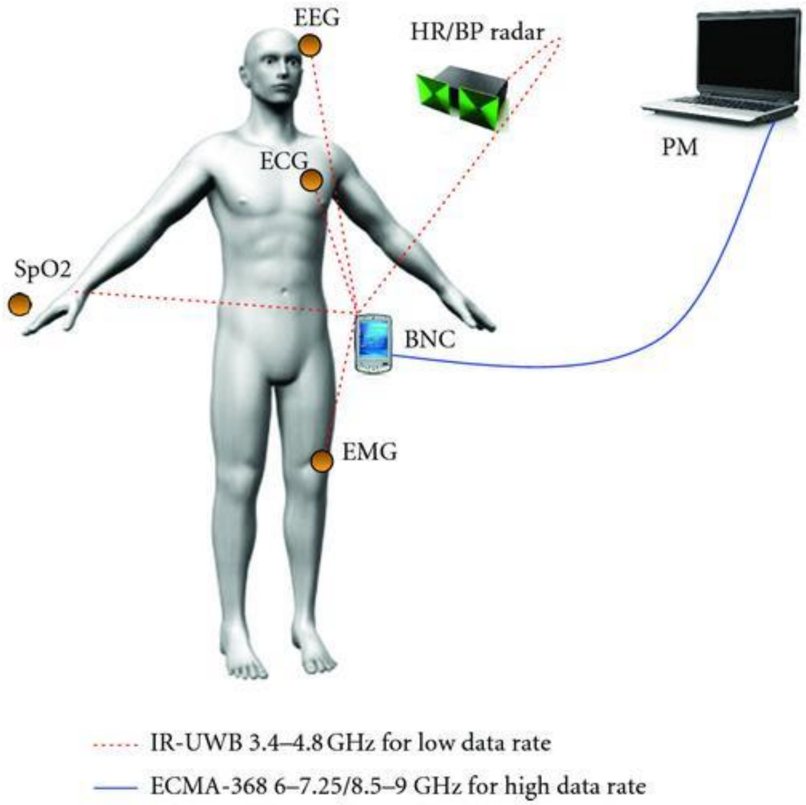


Figure: 1.8 (UWB in Medical Science)

The emerging UWB technology promises to satisfy the average power consumption requirement of the radio interface (100 W), and increases the operating period of sensors. In the UWB system, considerable complexity on the receiver side enables the development of ultra-low-power and low-complex UWB transmitters for uplink communication, thereby making UWB a perfect candidate for a WBAN. The difficulty in detecting noise-like behavior and robustness of UWB signals offer high security and reliability for medical applications.

1.4 Basic Definitions, Rules and Theorem

UWB bandwidth: The frequency band bounded by the points that are 10dB below the highest radiated emission, as based on the complete transmission system including the antenna. Upper boundary and lower boundary is designated as f_H and f_L .

Center frequency: average of f_H and f_L .

$$f_c = (f_H + f_L)/2$$ **…[1.1]**

Fractional Bandwidth: BW= $2(f_H - f_L) / (f_H + f_L)$**…[1.2]**

In order to regulate the use of UWB systems, FCC has allocated frequency spectrum from 3.1GHz to 10.6GHz, and the average output power has been limited to 41.3dBm/MHz.

Shannon's Theory: Channel capacity (in bit/s); C= B. ln(1+ SNR) **…[1.3]**
Where, B is Band Width (in Hz) and SNR is Signal-to-Noise Power Ratio.

Clearly, from the equation it can be determined that capacity increases with increasing bandwidth. UWB channel has an abundance of bandwidth and in fact can trade off some of the bandwidth for reduced signal power and interference from other sources. Thus, from Shannon's equation it can be seen that UWB systems have a great potential for high capacity wireless communication.

1.5 Benefits and Challenges of UWB

Key benefits of UWB

a) High data rates
b) Low equipment cost
c) Multi path immunity
d) Ranging and communication at the same time

Using UWB high speed personal area networks can be created. They connect e.g. many high speed office or home entertainment devices, like PC's peripherals, digital cameras, digital camcorders, video-player, TV screens, etc.. In other words: UWB puts an end to "all those cables". Currently, the first volume products are close to market, since UWB (Relying upon the multi band OFDM approach) is the radio platform of Wireless USB, which is a true "killer application".

UWB can also support ultra low power data communication. Such a feature will be required by e.g. wireless sensors (measuring temperature, humidity, movement, etc.) or RF-tags (i.e. electronic identifiers, RF-ID) which demand for battery lifetime in the order of a year or more.

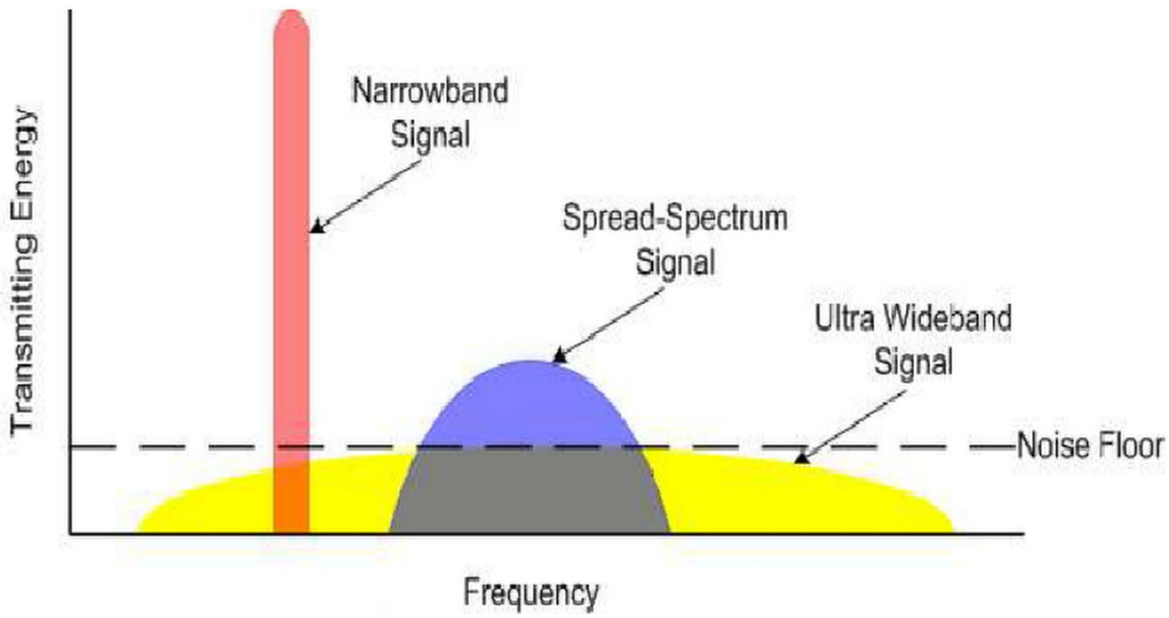


Figure: 1.9 (UWB communications spread transmitting energy across a wide spectrum of frequency)

Furthermore, UWB supports data communication combined with a high precision ranging/ location capability. That is, UWB can be used for tags or mobile sensors which additionally provide information about their location. If required, such devices can be tracked as well. Ad-hoc networks may also benefit from the ranging/location capability, since the information to be transmitted can be routed via intermediate stations (with known positions) over highly extended rages.

The ability to directly modulate a pulse onto an antenna is perhaps as simple a transmitter as can be made, leading many manufacturers to get excited by the possibilities for extremely cheap transceivers. This is possible by eliminating many of the components required for conventional sinusoidal transmitters and receivers. The narrow pulses used by UWB, which also give the extremely wide bandwidth, if separated out provide a fine resolution of reflected pulses at the receiver. This is important in any wireless communication, as pulses (or sinusoids) interfering with each other is the major obstacle to error-free communication.

<u>Challenges of UWB</u>

In spite of all the advantages, Ultra Wideband has several fundamental and practical issues that need to be carefully addressed to ensure the success of this technology in the wireless communication market.

Multi access code design, multiple access interference (MAI) cancellation, narrowband interference (NBI) detection and cancellation, synchronization of the receiver to extremely narrow pulses, accurate modeling of Ultra Wideband channels, estimation of multi path channel delays and coefficients, and adaptive transceiver design are some of the issues that still require a great deal of investigation.

In addition to the above physical layer issues, the fundamental role of Ultra Wideband technology in wireless networks is still open, and a wide range of research questions continue to present challenges, such as the particular role of Ultra Wideband in wireless ad-hoc and sensors network.

Among the challenges of UWB, a limited list can be given as follows:

- Coexistence with other services and handling strong narrowband interference;
- Shaping (adapting) spectrum of transmitted signals (multi band, OFDM based UWB etc.);
- Practical, simple, and low-power transceiver design;
- Accurate synchronization and channel parameter estimation;
- High sampling rate for digital implementations;
- Powerful processing capabilities for high performance and coherent digital receiver structure;
- Wideband RF component design (such as antennas, low noise amplifiers etc.);
- Multiple accessing, multiple access code design, and multi user interference;
- Accurate modeling of the ultra wideband channel in various environments;
- Adaptive system design and cross-layer adaptation for UWB;
- UWB tailored network design.

1.6 Thesis Layout

In chapter 1, we presented a general background to UWB and explained the reasons UWB is considered to be an exciting and breakthrough technology, particularly from the viewpoint of Shannon's famous capacity equation. We placed UWB in its historical background and showed the development of UWB from RADAR to communication applications. We briefly explained the basic definitions and rules of UWB signal systems.

In chapter 2, we briefly discussed different UWB antennas and antenna parameters. With figures and usage we described UWB micro strip patch antenna.

In chapter 3, we introduced the software we used to theoretically design and analyze the targeted antenna; that is High Frequency Structural Simulator or HFSS version 15. We also have discussed the advantages and challenges of using HFSS from our thesis work experience.

In chapter 4, the used dielectric substrates and the necessary calculation for antenna geometry applied in the design has been included with their substrate properties those affects the antenna behavior. Setting the allocation of ground plane, dielectric substrate, patch, strip line, feed along with their coordinates convenient to their calculated measurements. Steps and screenshots of HFSS setting and property windows have been showed as well.

In chapter 5, we included the obtained results and figures of the various plots extracted to analyze the design. And finally concludes the thesis showing scope for future work on this topic giving some suggestions.

Chapter 2

UWB Antenna

2.1 UWB Antenna overview

UWB antennas are specifically designed to transmit and receive very short time durations of electromagnetic energy. Typically, narrow-band antennas and propagation are described in the frequency domain. Usually the characteristic parameters are assumed to be constant over a few percent bandwidth. For ultra-wide-band (UWB) systems, the frequency-dependent characteristics of the antennas and the frequency-dependent behavior of the channel have to be considered. On the other hand, UWB systems are often realized in an impulse-based technology, and therefore the time-domain effects and properties have to be known as well. Hence there is a demand for both a frequency-domain representation and a time-domain representation of the system description.

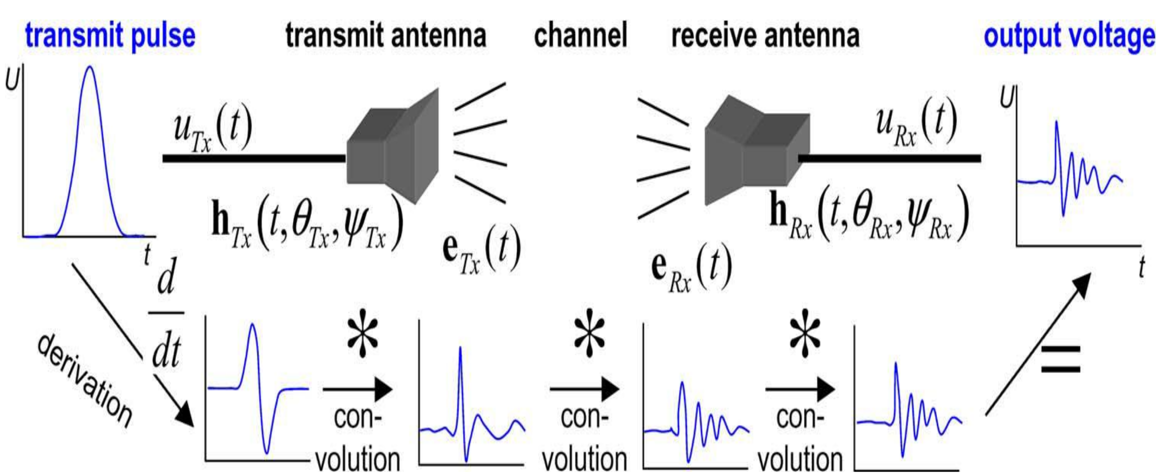


Figure: 2.1 (UWB system link level characterization in time domain)

The key mechanism for radiation is charge acceleration. The question to answer for Ultra Wideband is: what kind of structures facilitates the charge acceleration over a very wide bandwidth?

The ultra wide bandwidth radiation is based on a few principles:

- traveling-wave structures;
- frequency-independent antennas (angular constant structures);
- self-complementary antennas;
- multiple resonance antennas;
- Electrically small antennas.

In most cases the radiation starts where the electric field connects 180 degree out-of-phase currents with half wavelength spacing. Many antennas radiate by a combination of two or more of the above principles and can therefore not be simply classified.

2.2 Different Types of Antenna

A wide variety of antennas are suitable for use in ultra-wideband applications. Some of these are described elsewhere in a historical survey. UWB antennas may be classified as directional or non-directional. They may further be classified as either electric or magnetic antennas. These classifications as well as the various types of UWB antennas will be considered in turn.

Directionality of antenna

High gain or directional antennas concentrate energy into a narrower solid angle than an omni-directional antenna. An isotropic antenna has a gain of 0 dBi by definition where, “dBi” means dB relative to an ideal isotropic antenna. A typical dipole antenna has a gain of about 2.2 dBi. High gain horn or reflector antennas may have gains of +10 dBi, +20 dBi, or even more. Antenna efficiency is included in the definition of antenna gain, so a 50% efficient (-3 dB) dipole will have a gain of about –1.8 dBi.

A directional antenna will have high gain, a narrow field of view, and will be relatively large in size. An omni-directional antenna has relatively low gain, a wide field of view and will tend to be relatively small. The fundamental trade-offs with directional antennas are shown below,

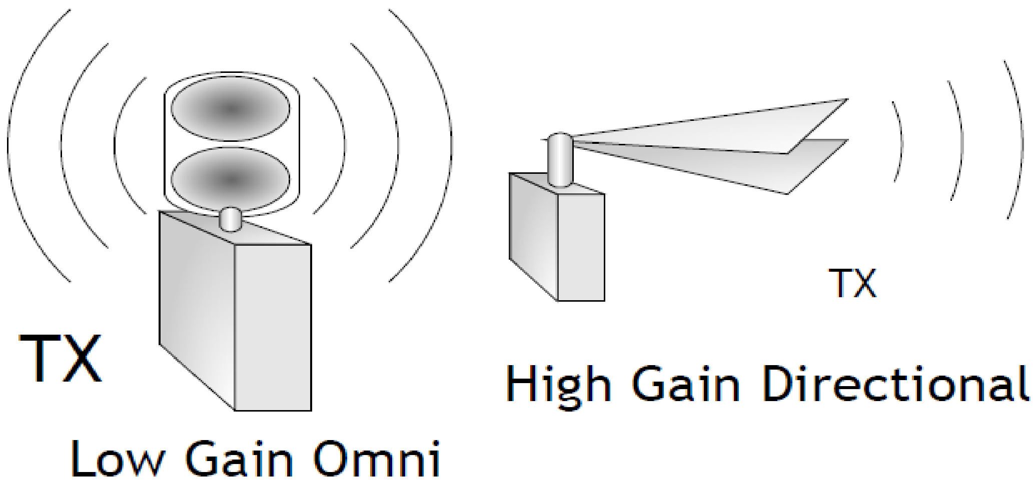


Figure: 2.2 (Antenna gain vs. directionality)

	Directional	Omni-Directional
Gain:	High	Low
Field of View:	Narrow	Wide
Antenna Size:	Large	Small

Table 2.1: (Trades off between directional and omni directional antennas)

1. Electric antennas include dipoles and most horns.

2. Magnetic antennas include loops and slots.

3. Magnetic antennas are characterized by intense magnetic fields close to the antenna.

Electric or magnetic antenna

Antennas may also be classified as either electric or magnetic. Electric antennas include dipoles and most horns. These antennas are characterized by intense electric fields close to the antenna. Magnetic antennas include loops and slots. These antennas are characterized by intense magnetic fields close to the antenna.

Dipole antenna

The dipole antenna is made of two poles into which radio frequency current flows. It is usually an antenna that uses a resonant length of conductor. This conductor is cut so it can be connected to what is sending the signal. Dipole antennas are used for television. A UWB dipole antenna with circular shows good characteristics on the UWB band.

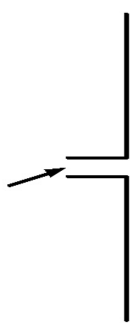


Figure 2.2.1 (*Loop antenna*)

A loop antenna is a radio antenna consisting of loop/loops of wire, tubing, or other electrical conductor with its ends connected to a balanced transmission line. The impedance bandwidth of those antennas is seen to be insufficient for UWB applications. However some proposed design loop antenna as a low cost option for high speed point-to-point UWB links.

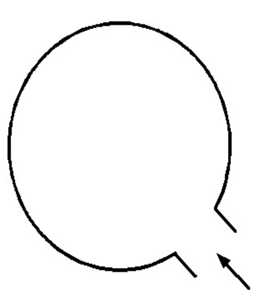


Figure 2.2.2 (*Micro Strip antenna*)

Micro strip antennas are frequently used in today's communication systems. Good for their low profile, they can be mounted to the walls of buildings, to the fuselages of airplanes or to the reverse sides of the mobile phones. Moreover, micro strip antennas are fabricated using the same technology as producing printed circuit boards. Therefore, the fabrication is relatively simple and well reproducible.

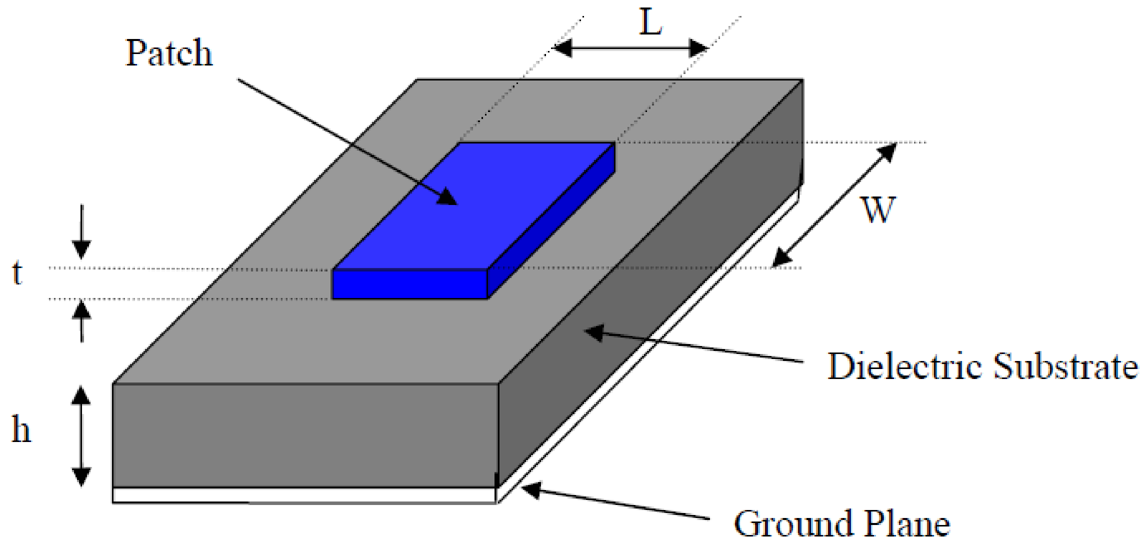


Figure: 2.3 (Micro strip antenna)

2.3 Parameters of micro strip patch Antenna

All of the parameters in a rectangular patch antenna design (Length and Width of patch, height of substrate, permittivity) control the properties of the antenna. The length of the patch **L** controls the resonant frequency; the width **W** controls the input impedance and the radiation pattern; the height of the substrate **h** also controls the bandwidth - increasing the height increases the bandwidth. The permittivity of the substrate ε_r controls the fringing fields - lower permittivity have wider fringes and therefore better radiation.

Decreasing the permittivity also increases the antenna's bandwidth. The efficiency is also increased with a lower value for the permittivity. The impedance of the antenna increases with higher permittivity.

Resonance frequency: $f = (1/2L)*(c/\sqrt{\varepsilon_r})$…**[2.1]**

Radiation efficiency: $e_r = P_{rad}/P_{input}$…**[2.2]**

Directivity: The directivity is fairly insensitive to the substrate thickness. The directivity is higher for lower permittivity, because the patch is larger.

Permittivity: determined with the dielectric constant of the dielectric substrate. A micro strip antenna in its simplest configuration consists of a radiating patch on one side of a dielectric substrate ($\varepsilon_r \leq 10$), which has a ground plane on the other side.

Width and length of the patch is necessarily calculated from the formulas below having dielectric constant; [8]

W = $C / [2 * f_o * \sqrt{\{(\varepsilon_r + 1)/2\}}]$**…[2.3]**

$\boldsymbol{\varepsilon}_{\mathbf{reff}} = (\varepsilon_r + 1)/2 + (\varepsilon_r - 1)/2 * [1 + 12*(h/W)]^{-1/2}$**…[2.4]**

ΔL = $0.412*h *\{[(\varepsilon_{reff} + 0.3)*(W/h + 0.264)]/ [(\varepsilon_{reff} - 0.258)*(W/h + 0.8)]\}$ **…[2.5]**

L = $(\lambda_o/2) - 2*\Delta L$**…[2.6]**

Effective dielectric constant ε_{reff} *:* The dielectric constant of the substrate is much greater than the unity; the effective value of ε_{reff} will be closer to the value of the actual dielectric constant ε_r of the substrate. The effective dielectric constant is also a function of frequency. As the frequency of operation increases the effective dielectric constant approaches the value of the dielectric constant of the substrate.

2.4 UWB rectangular micro strip patch antenna

There are numerous and well-known methods to increase the bandwidth of antennas, including increase of the substrate thickness, the use of a low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonators, and the use of slot patch geometry.

Micro strip patch antenna has a ground plane on the one side of a dielectric substrate which other side has a radiating patch. A rectangular patch is used as the main radiator. The patch is generally made of conducting metal such as Copper or Aluminium or theoretically Perfect Electric Conductor (PEC) and can take any possible shape. Dielectric constant of the substrate is typically in the range of 2.2 to 12.

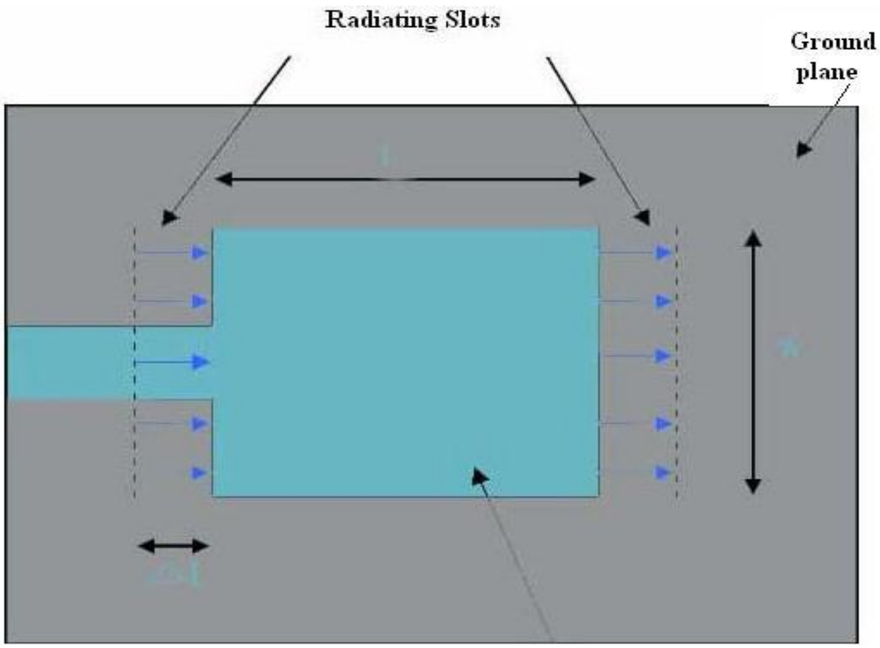


Figure: 2.4 (rectangular micro strip)

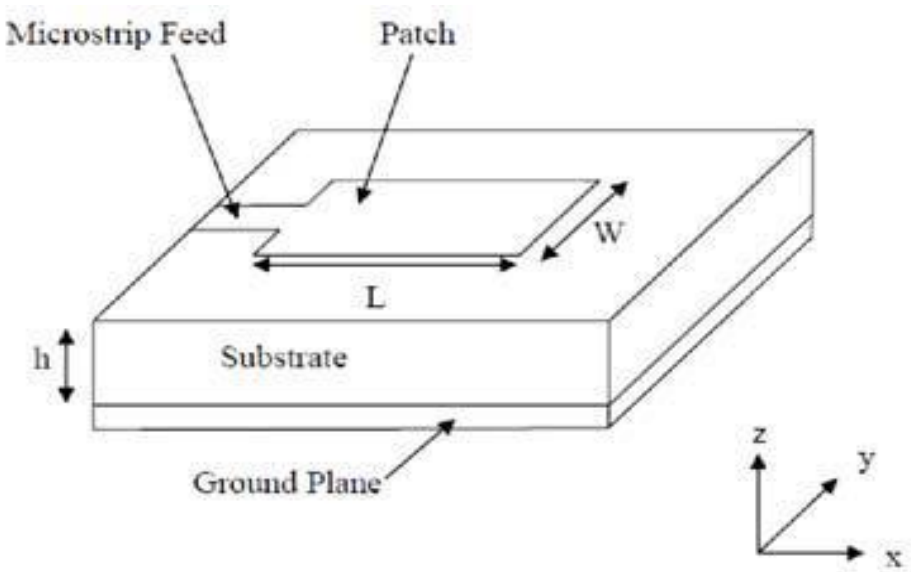


Figure: 2.5 (Micro strip patch antenna)

The patch may be in a variety of shapes, but rectangular and circular are the most common. Feed along the centerline is the most common (minimizes higher -order modes and cross - pole)

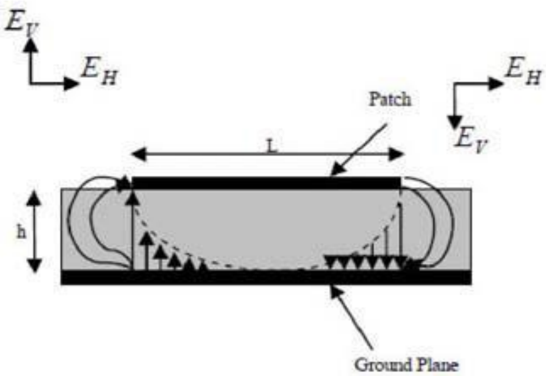


Figure: 2.6 (E field from side view)

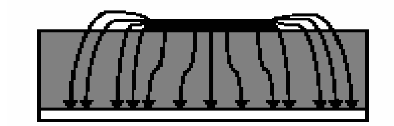


Figure: 2.7 (E field lines)

2.5 Usage of UWB micro strip patch antenna

Advantages of Micro strip antennas;

- Low profile (can even be “conformal”)
- Easy to fabricate (use etching and photolithography).
- Easy to feed (coaxial cable, micro strip line, etc.).
- Easy to use in an array or incorporate with other micro strip circuit elements.
- Patterns are somewhat hemispherical, with a moderate directivity (about 6-8 dB is typical).
- Micro strip antennas are fabricated using the same technology as producing printed circuit boards.
- The fabrication is relatively simple and well reproducible.
- Good for their low profile, they can be mounted to the walls of buildings, to the fuselages of airplanes or to the reverse sides of the mobile phones.

With the ever-increasing need for mobile communication and the emergence of many systems, it is important to design antennas to cover a wide frequency range. The design of an efficient wide band small size antenna, for recent wireless applications, is a major challenge. Micro strip patch antennas have found extensive application in wireless communication system owing to their advantages such as low profile, conformability, low-cost fabrication and ease of integration with feed networks.

Chapter 3

Design with HFSS

Introduction to Software

HFSS stands for **H**igh **F**requency **S**tructural **S**imulator a commercial finite element method solver for electro-magnetic structures from Ansys. It was originally developed by Professor Zoltan Cendes and his students at Carnegie Mellon University. Prof. Cendes and his brother Nicholas Csendes founded Ansoft and sold HFSS stand-alone under a 1989 marketing relationship with Hewlett-Packard, and bundled into Ansoft products.

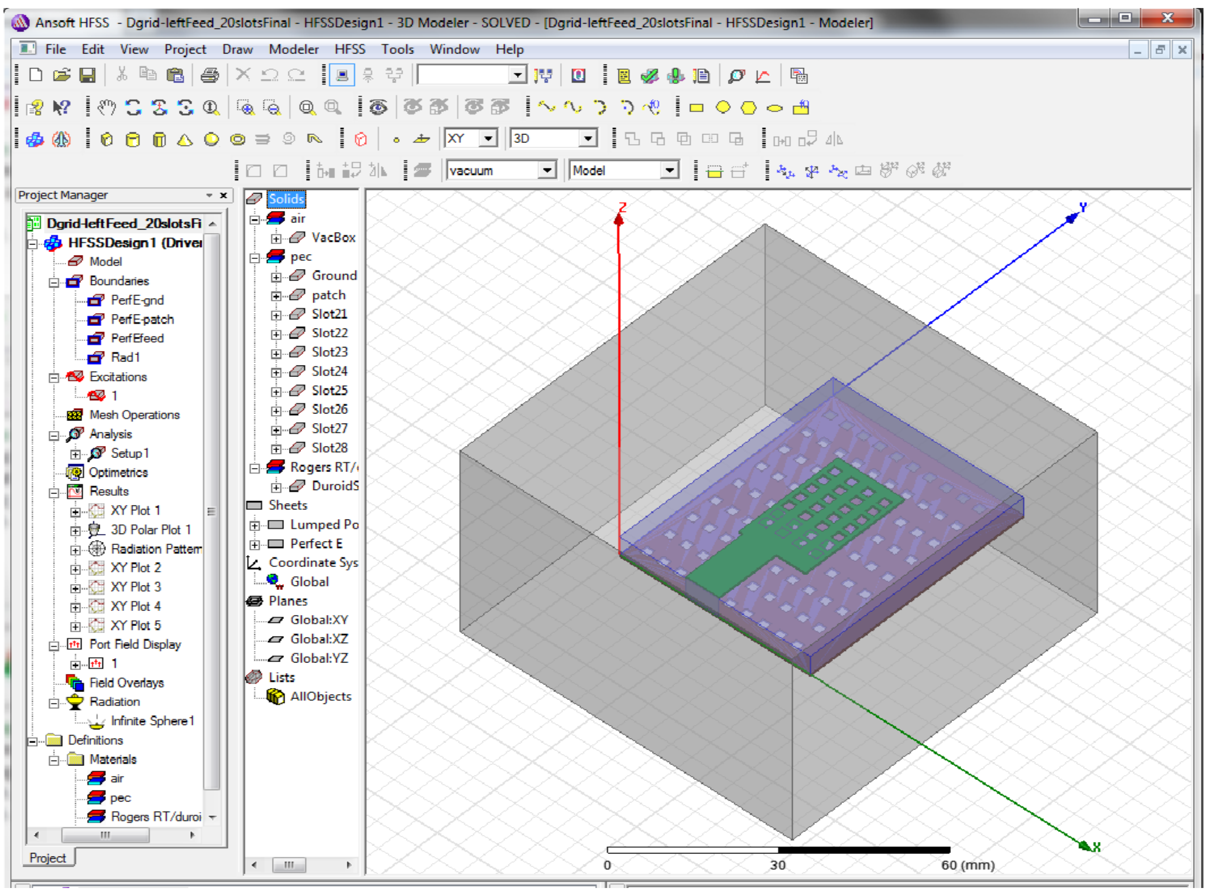


Figure: 3.1 (HFSS version 15 Interface)

Challenges of access to HFSS

Commercial software like HFSS is not very available at market. Although downloadable it requires installation key perfectly matched with its version.

Advantage of using HFSS

- HFSS offers multiple state-of the-art solver technologies based on finite element
- Integral equation or advanced hybrid methods to solve a wide range of applications
- Each HFSS solver incorporates a powerful, automated solution process
- you need only to specify geometry material properties and the desired output
- HFSS automatically generates an appropriate, efficient and accurate mesh for solving the problem using the selected solution technology

Chapter 4

Calculation for Rectangular Micro Strip Patch

4.1 Materials used in the Design

Perfect electric conductor PEC for ground plane, Duroid 5880 and FR4 for Dielectric Substrate, PEC for patch, and Air for vacuum box have been used.

4.2 Necessary calculations for antenna geometry

The basic structure of the proposed antenna, shown in Fig 4.1, consists of 3 layers. The lower layer, which constitutes the ground plane, covers the partial rectangular shaped substrate with a side of $W_{Gnd} \times L_{Gnd}$ mm. The middle substrate, which is made of Roger RT Duroid 5880 and again FR4 epoxy resin, having relative dielectric constants 2.2 and 4.47, with height of 5 mm. The upper layer, which is the patch, covers the rectangular top surface. The rectangular patch has sides $W_{patch} \times L_{patch}$ mm that covers the middle portion of the substrate. Two rectangular slots are cut out from the patch near the feeding Microstrip line for impedance matching the patch is fed by a Microstrip line with 50Ω port impedance.

Dielectric constant; for Duroid 5880; $\boldsymbol{\varepsilon}_{\mathbf{rd}} = 2.20$
For FR4; $\boldsymbol{\varepsilon}_{\mathbf{fr}} = 4.47$

We know, $C = C_o/(\sqrt{\varepsilon_r})$; **…[4.1]**
Where, speed of light in free space; $C_o = 3*10^8$ m/s

Therefore; from equation [4.1]
For Duroid 5880; $\mathbf{C_{du}} = C_o/(\sqrt{\varepsilon_{rd}}) = 202.26*10^6$ m/s
For FR4; $\mathbf{C_{fr}} = C_o/(\sqrt{\varepsilon_{fr}}) = 141.895*10^6$ m/s

From equation [2.3] the width of the antenna patch for Duroid 5880;
$\mathbf{W_{du}} = C_{du}/\mathbf{[}2*f_o * \sqrt{\{(\varepsilon_{rd} + 1)/2\}}\mathbf{]} = 15.99*10^{-3}$ m
Similarly, the width of the antenna patch for FR4;
$\mathbf{W_{fr}} = C_{fr}/\mathbf{[}2*f_o * \sqrt{\{(\varepsilon_{fr} + 1)/2\}}\mathbf{]} = 8.58*10^{-3}$ m

From equation [2.4] Effective Dielectric constant for Duroid 5880;
$\boldsymbol{\varepsilon}_{\mathbf{reffD}} = (\varepsilon_{rd} + 1)/2 + (\varepsilon_{rd} - 1)/2 * [1+12*(h/W_{du})]^{-1/2} = 1.89277$
Effective Dielectric constant for FR4;
$\boldsymbol{\varepsilon}_{\mathbf{reffF}} = (\varepsilon_{fr} + 1)/2 + (\varepsilon_{fr} - 1)/2 * [1+12*(h/W_{fr})]\text{^}(-1/2) = 3.41063$

From equation [2.5] the dimensions of the patch along its length are to be extended on each end by a distance for Duroid 5880 and FR4;

$\mathbf{\Delta L_d} = 0.412*h*\{[(\varepsilon_{reffD}+0.3)*(W_{du}/h+0.264)] /[(\varepsilon_{reffD}–0.258)*(W_{du}/h+0.8)]\}$
$= 1.96344*10^{-3}$ m
$\mathbf{\Delta L_f =} 0.412*h *\{[(\varepsilon_{reffD} +0.3)*(W_{rd}/h + 0.264)] / [(\varepsilon_{reffD} – 0.258)*(W_{rd}/h + 0.8)]\} = 1.6019 *10^{-3}$ m

From equation [2.6] the actual length L of the patch is given for Duroid 5880 and FR4;
$\mathbf{L_{du}} = (\lambda_o/2) – 2*\Delta L_d = 26.07312*10^{-3}$ m

$\mathbf{L_{fr}} = (\lambda_o/2) – 2*\Delta L_f = 26.7962*10^{-3}$ m

Rather than arbitrary width and length for ground plane, a finite ground plane needs to be calculated for practical consideration. Width and length for ground plane have been taken greater than patch width and length; approximately 6 time the substrate thickness.[8]

$$\mathbf{L_{Gnd}} = 6*h_{substrate} + L_{patch}\ldots\mathbf{[4.1]}$$
$$\mathbf{W_{Gnd}} = 6*h_{substrate} + W_{Patch}\ldots\mathbf{[4.2]}$$

From equation [4.1] length of ground for Duroid 5880 and FR4,

$\mathbf{L_{GndD}} = 6*h_{substrate} + L_{du} = 6*(5*10^{-3}) + 26.07312*10^{-3}$
$= 56.07312*10^{-3}$ m $= 56.07312$ mm
$\mathbf{L_{GndF}} = 6*h_{substrate} + L_{fr}$
$= 6*(5*10^{-3}) + 26.7962*10^{-3} = 56.7962$ mm

From equation [4.2] width of ground for Duroid 5880 and FR4,

$\mathbf{W_{GndD}} = 6*h_{substrate} + W_{du}$
$= 6*(5*10^{-3}) + 15.99*10^{-3} = 45.99$ mm
$\mathbf{W_{GndF}} = 6*h_{substrate} + W_{fr}$
$= 6*(5*10^{-3}) + 8.58*10^{-3} = 38.58$ mm

4.3 Patch with and without Slots and Feed Allocation

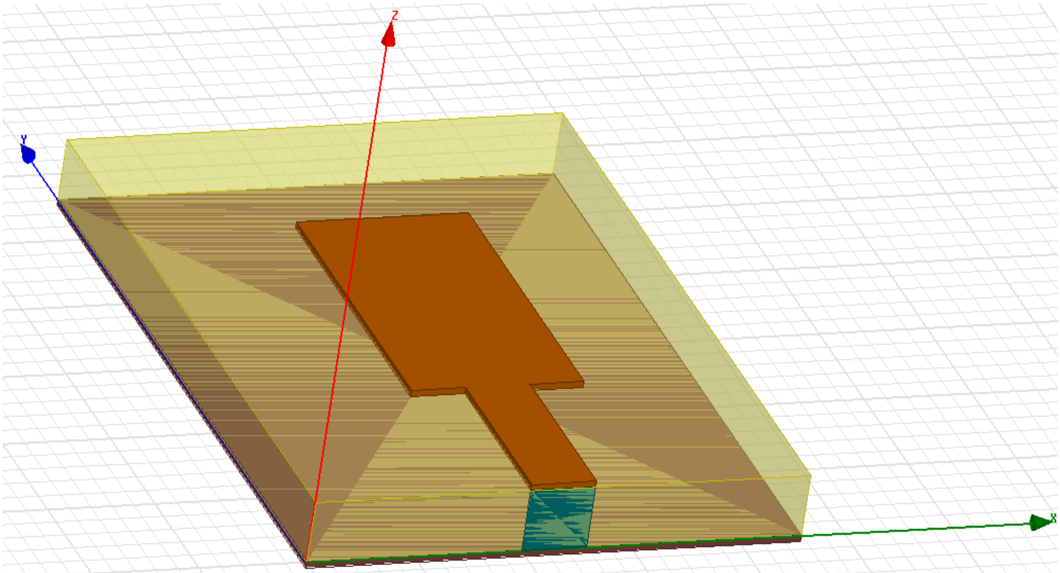


Figure: 4.1 (Antenna architecture with solid ground and Patch)

- Grid ground has been taken with 2mm by 2mm square holes.
- It does not affect the results
- Reduces the material weight as well as the cost

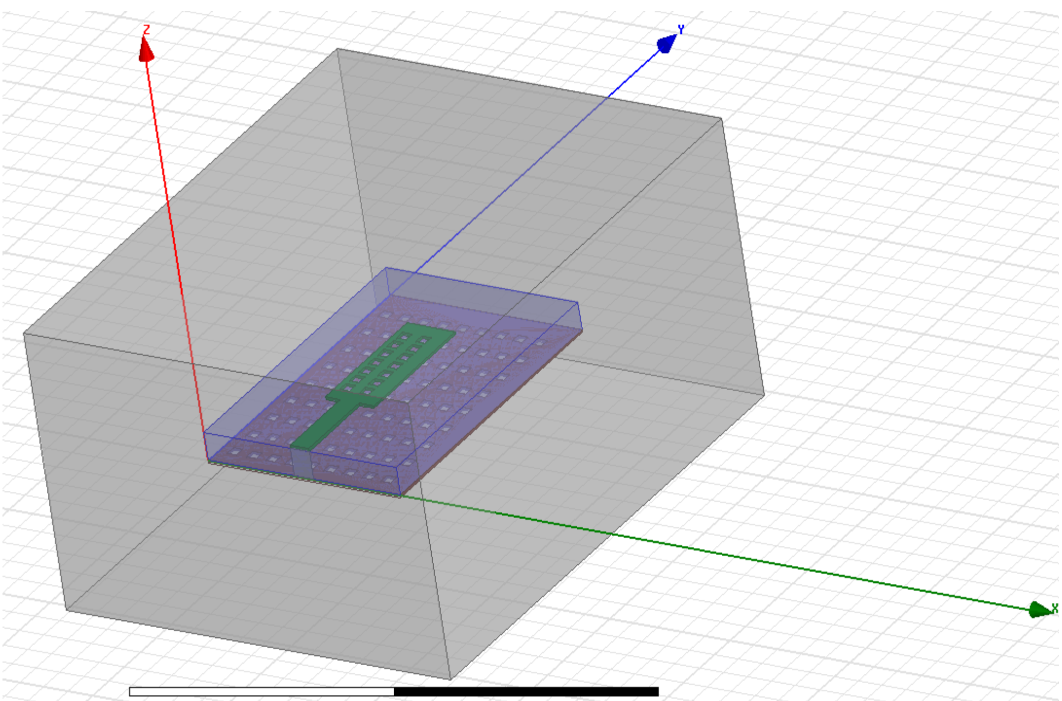


Figure: 4.2 (Antenna architecture with grid ground and Slot Patch)

4.4 Initial Setting

On the Project menu, click Insert HFSS Design. The new design is listed in the project tree. The 3D Modeler window appears to the right of the Project Manager.

4.5 Box for Ground Plane

For Duroid 5880	For FR4
Ground (material PEC):	**Ground (material PEC):**
X=0, Y=0, Z= -0.5;	X=0, Y=0, Z= -0.5;
d_X= W_{GndD}= 45.99mm ;(approximately 46 mm)	d_X= W_{GndF}= 38.58mm ;(taken 40 mm)
d_Y= L_{GndD} = 56.07312 mm ;(approximately 56 mm)	d_Y= L_{GndD} = 56.79 mm ;(taken 58 mm)
d_Z= 0.5 mm ;(arbitrary)	d_Z= 0.5 mm ;(arbitrary)

Table 4.1: (coordinates for ground plane in case of Duroid 5880 and FR4)

4.6 Box for Dielectric Substrate

Substrate (Duroid 5880)	Substrate (FR4)
X=0, Y=0, Z= 0;	X=0, Y=0, Z= 0;
d_X= (Same as W_{GndD})= 45.99mm ;(approximately 46 mm)	d_X= (Same as W_{GndF}) 38.58mm = (approx.) 40mm
d_Y= (Same as L_{GndD}) = 56.07312 mm ;(approximately 56 mm)	d_Y= (Same as L_{GndF}) 56.79mm = (approx.) 58 mm
d_Z= h = 5 mm ;(arbitrary)	d_Z= h = 5 mm ;(arbitrary)

Table 4.2: (coordinates for substrate in case of Duroid 5880 and FR4)

4.7 Box for Patch

Duroid 5880	FR4
Patch (material PEC): X=15, Y=15, Z= 5; d_X= W_{du}= 15.99mm ;(approximately 16 mm) d_Y= L_{du} = 26.07312 mm ;(approximately 26 mm) d_Z= 0.5 mm ;(arbitrary)	**Patch (material PEC):** X=15, Y=16, Z= 5; d_X= W_{fr}= 8.58mm ;(taken 10 mm) d_Y= L_{fr} = 26.7962 mm ;(taken 28 mm) d_Z= 0.5 mm ;(arbitrary)

Table 4.3: (coordinates for patch in case of Duroid 5880 and FR4)

4.8 Box for Strip Line

Duroid 5880	FR4
Strip Line (material PEC): X=19, Y=0, Z= 5; (center feed) X=16, Y=0, Z= 5; (left side feed) d_X= W_{du}/2= 8mm d_Y= 15 mm d_Z= 0.5 mm ;(same as patch)	**Strip Line (material PEC):** X=18, Y=0, Z= 5; (center feed) X=16, Y=0, Z= 5; (left side feed) d_X= W_{fr}/2= 4.29mm d_Y= 15 mm d_Z= 0.5 mm ;(same as patch)

Table 4.4: (coordinates for strip line in case of Duroid 5880 and FR4)

Patch and Strip Line are united.

4.9 Rectangle for Feed

(Duroid 5880) Feed:	(FR4) Feed:
X=19, Y=0, Z= 5; (center feed) X=16, Y=0, Z= 5; (left side feed) d_X= W_{du}/2= 8mm d_Y= 15 mm d_Z= 0.5 mm ;(same as patch)	X=18, Y=0, Z= 5; (center feed) X=16, Y=0, Z= 5; (left side feed) d_X= W_{fr}/2= 4.29mm d_Y= 15 mm d_Z= 0.5 mm ;(same as patch)

Table 4.5: (coordinates for feed in case of Duroid 5880 and FR4)

4.10 Port assigning, excitations, radiation, E-Boundaries

(Duroid 5880 and FR4) Create Air:
X= -20, Y= -20, Z= -20;
d_X= 80mm ;(arbitrary) d_Y= 80mm ;(arbitrary) d_Z= 50mm ;(arbitrary)

Table 4.6: (coordinates for creating air)

Lumped Port set for feed at 5 ohm resistance and 0 reactance by default and port impedance 50 ohm. Perfect E boundaries for Ground, Patch, Feed are set. Assigned far field radiation boundary for Air box of infinite sphere.

Analysis setup and frequency sweep
Sweep type selected fast, frequency setup starts from 1 to 10 GHz with 50MHz at linear step. Validate the design and analyze all.

Chapter 5

Obtaining Results and Discussions

5.1 Without calculated geometry

From rectangular plot option, we get the S_{11} plots.

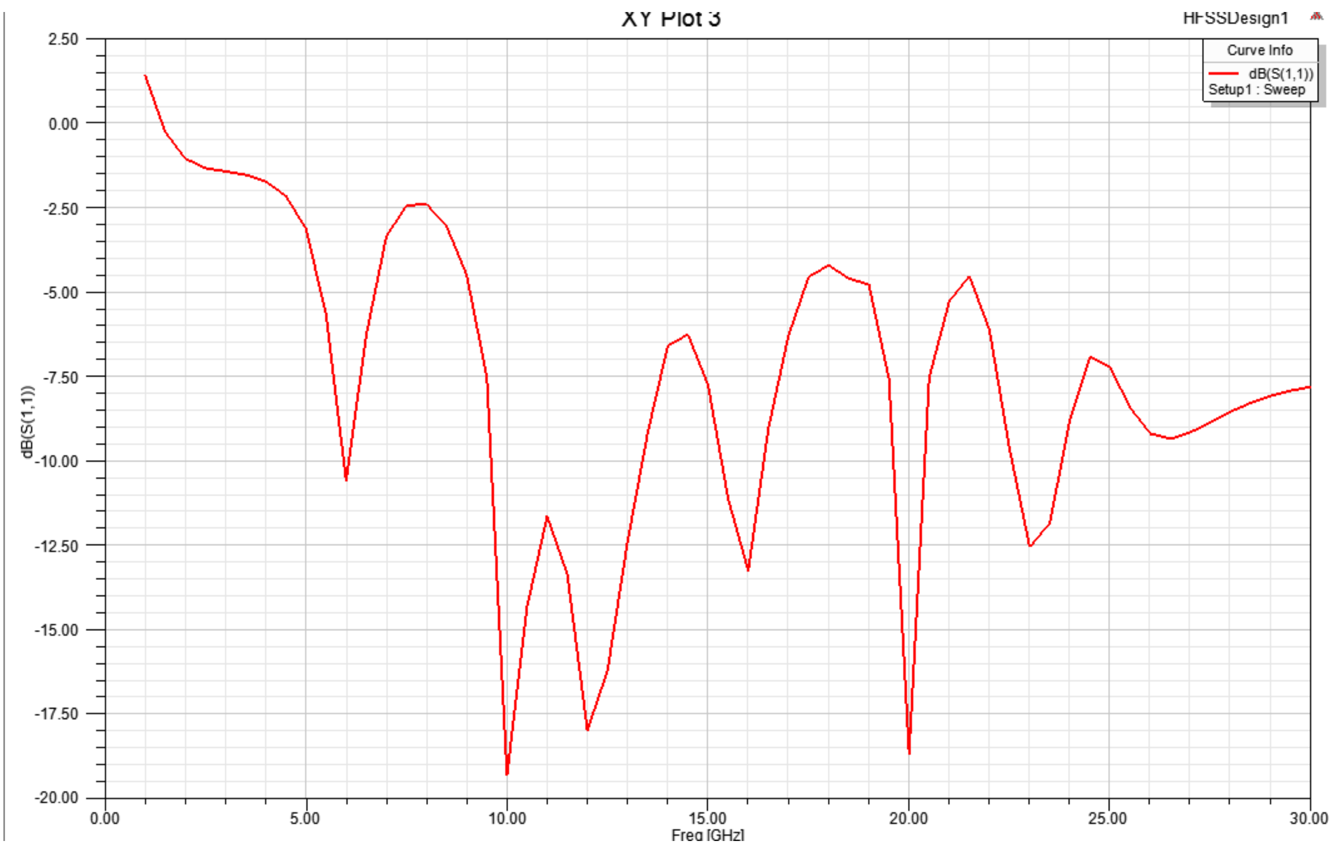


Figure: 5.1 (S_{11} plot for arbitrary geometry)

For arbitrary geometry of Patch Design with no slots (solution frequency is 10GHz, Duroid 5880) we get Multi band S_{11} plot for the very first design.

Report Analyzing Sequence

- Obtain Center Frequency and Impedance Bandwidth from the S_{11} plot by observing f_H and f_L at -10dB. As resonance frequency or solution frequency for the design has been taken **fo** =5 GHz ; <u>bandwidth</u> (fH - fL) is <u>required</u> to be minimum (20% of **fo**)= <u>1 GHz</u>

- Obtain Z_{11} plot
- Obtain 3D Polar plot
- Discuss the Slot Patch Antenna Radiation Properties with the obtained plots

5.2 With calculated geometry and arbitrary slots

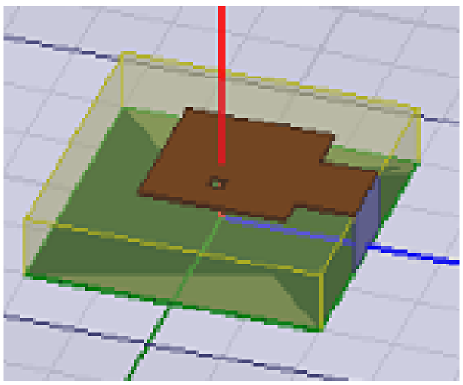


Figure: 5.2 (1 Slot for Duroid 5880)

f_c= 8.5GHz

BW= $f_H - f_L$= 8.9 – 8.1=0.8 GHz

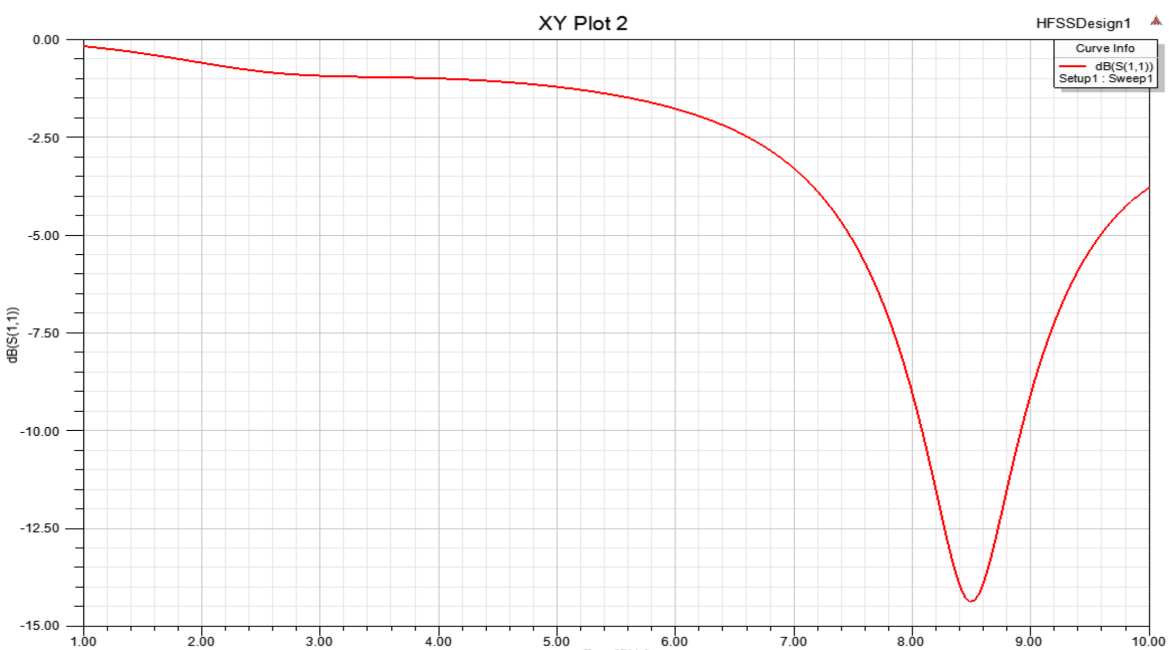


Figure: 5.3 (S_{11} plot: 1 Slot for Duroid 5880)

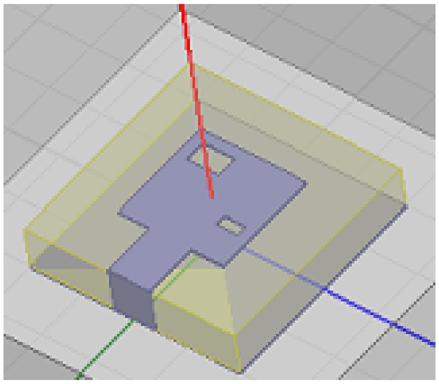


Figure: 5.4 (2 Slot for Duroid 5880)

f_c= 8.1GHz
BW= $f_H - f_L$
= 8.35 – 7.85 = 0.5 GHz

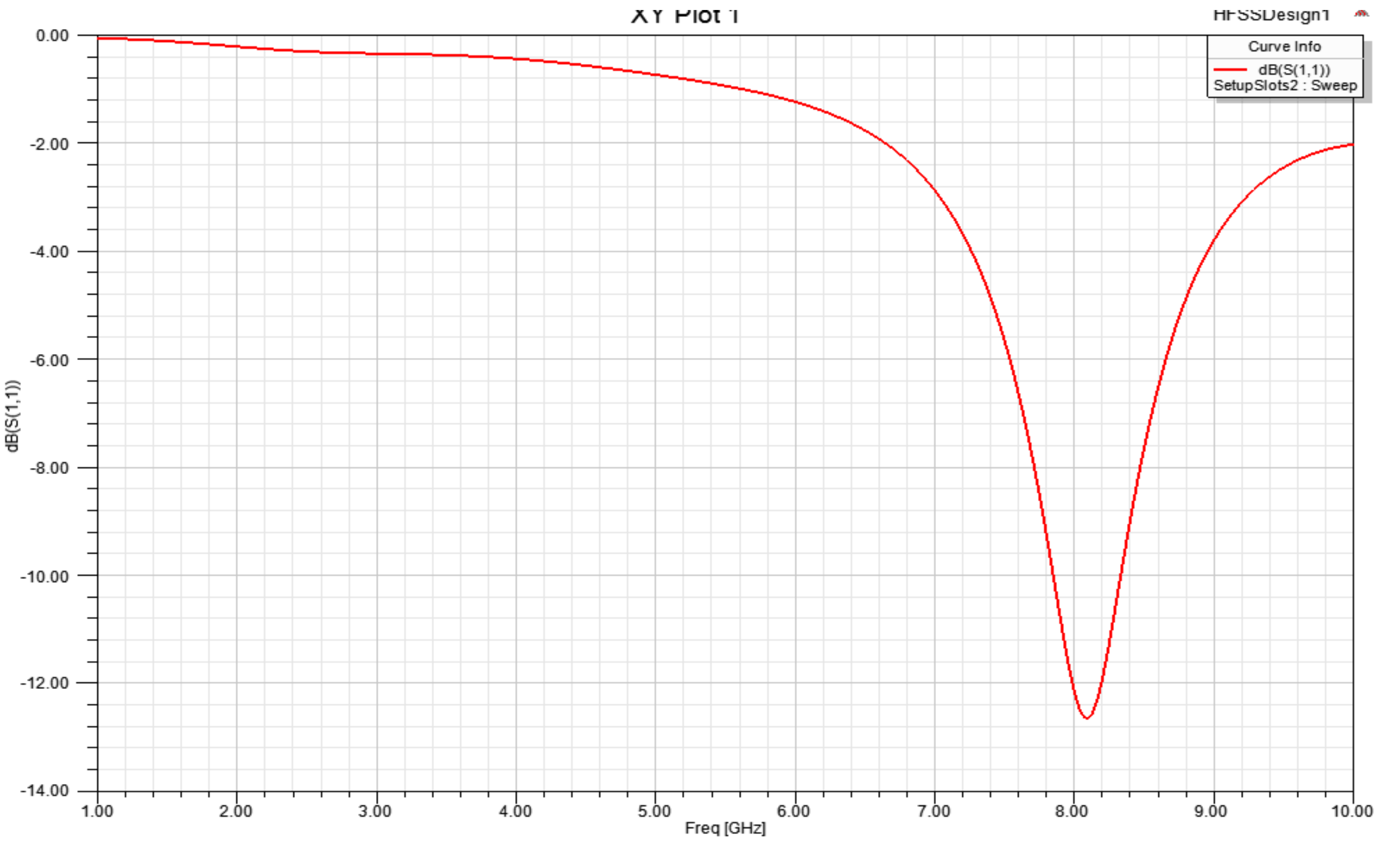


Figure: 5.5 (S_{11} plot: 2 Slots for Duroid 5880)

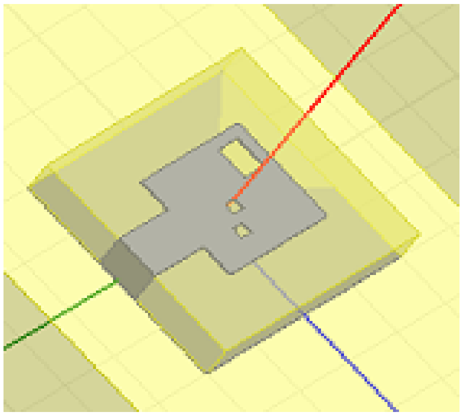


Figure: 5.6 (3 Slots for Duroid 5880)

f_c= 8.05GHz

BW= $f_H - f_L$

= 8.25 – 7.85

= 0.4 GHz

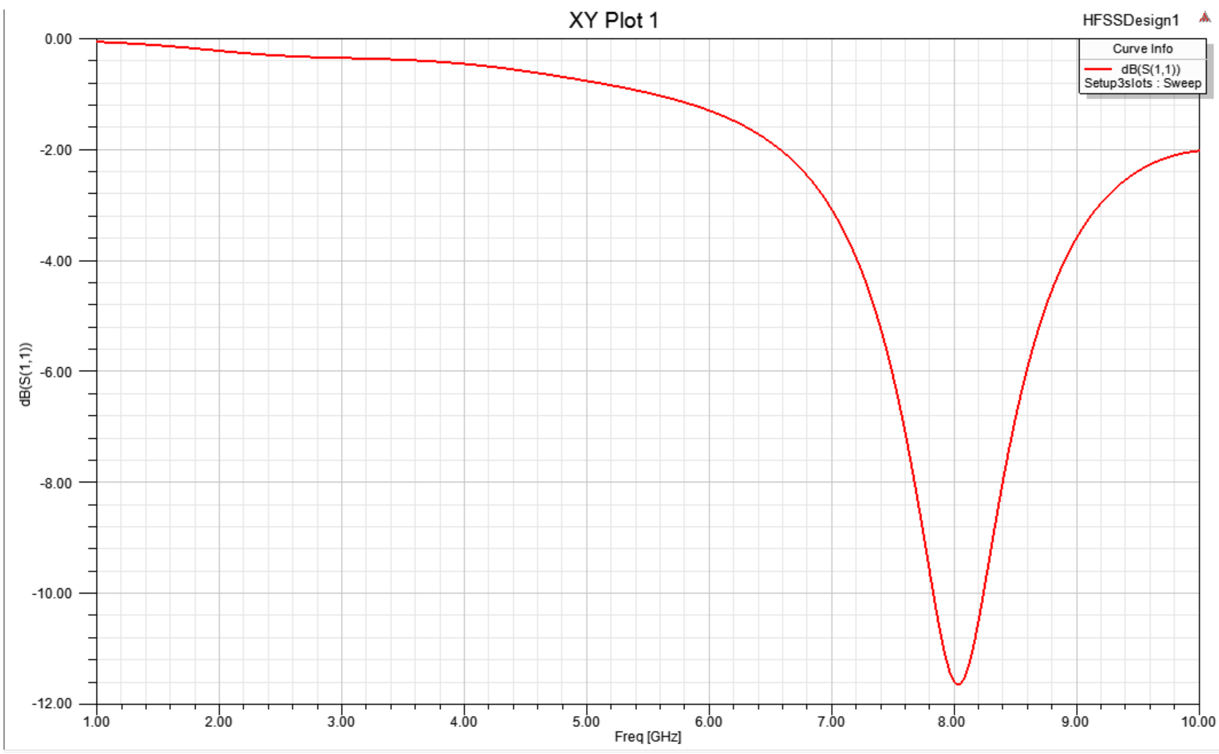


Figure: 5.7 (S_{11} plot: 3 Slots for Duroid 5880)

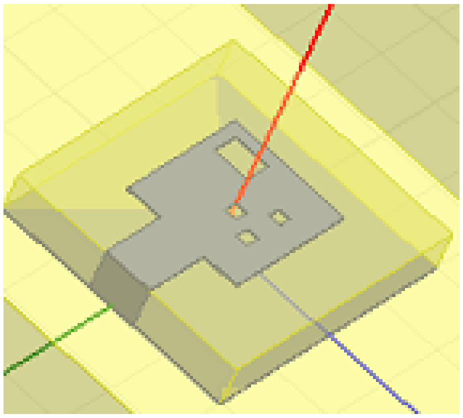


Figure: 5.8 (4 Slots for Duroid 5880)

fc= 8.05GHz
BW= fH – fL
= 8.3 – 7.8
= 0.5 GHz

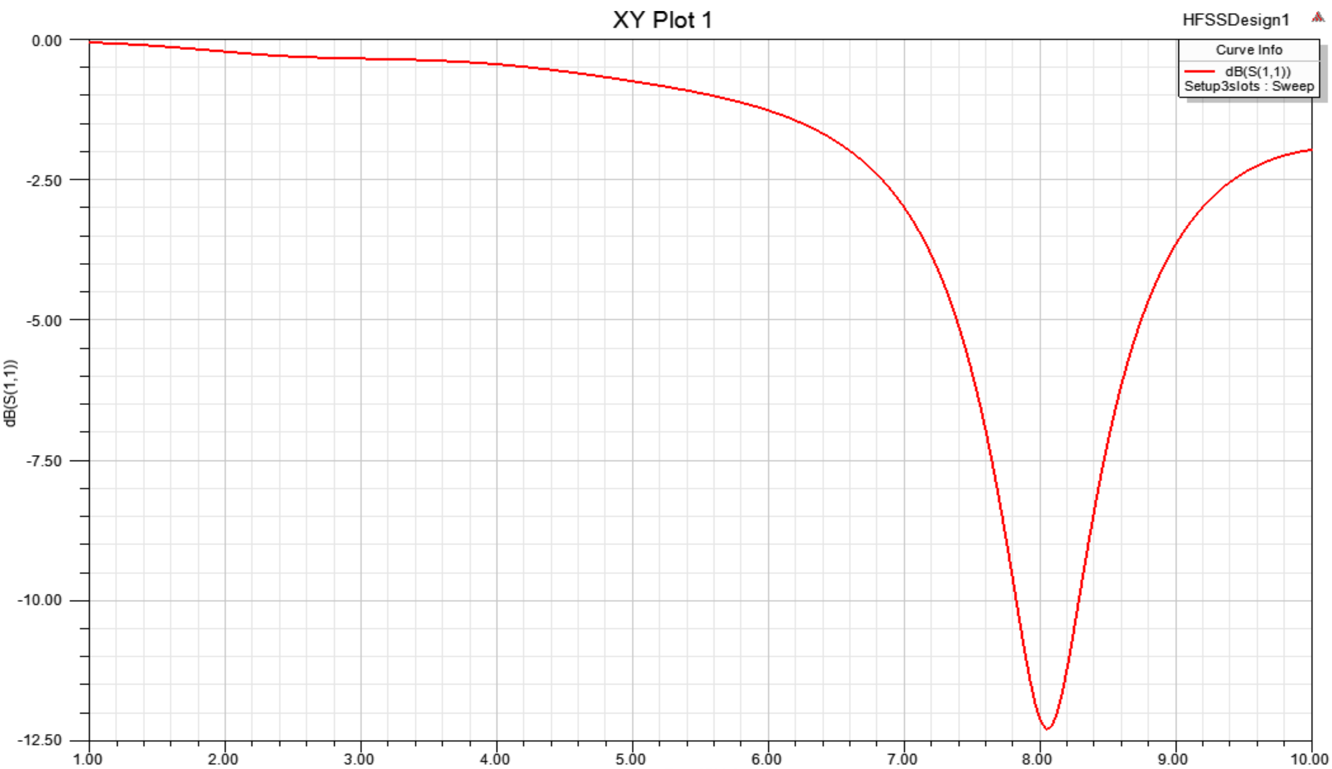


Figure: 5.9 (S_{11} plot: 4 Slots for Duroid 5880)

S11 plots for Patch without slot, 1,2,3,4 slots (FR4)

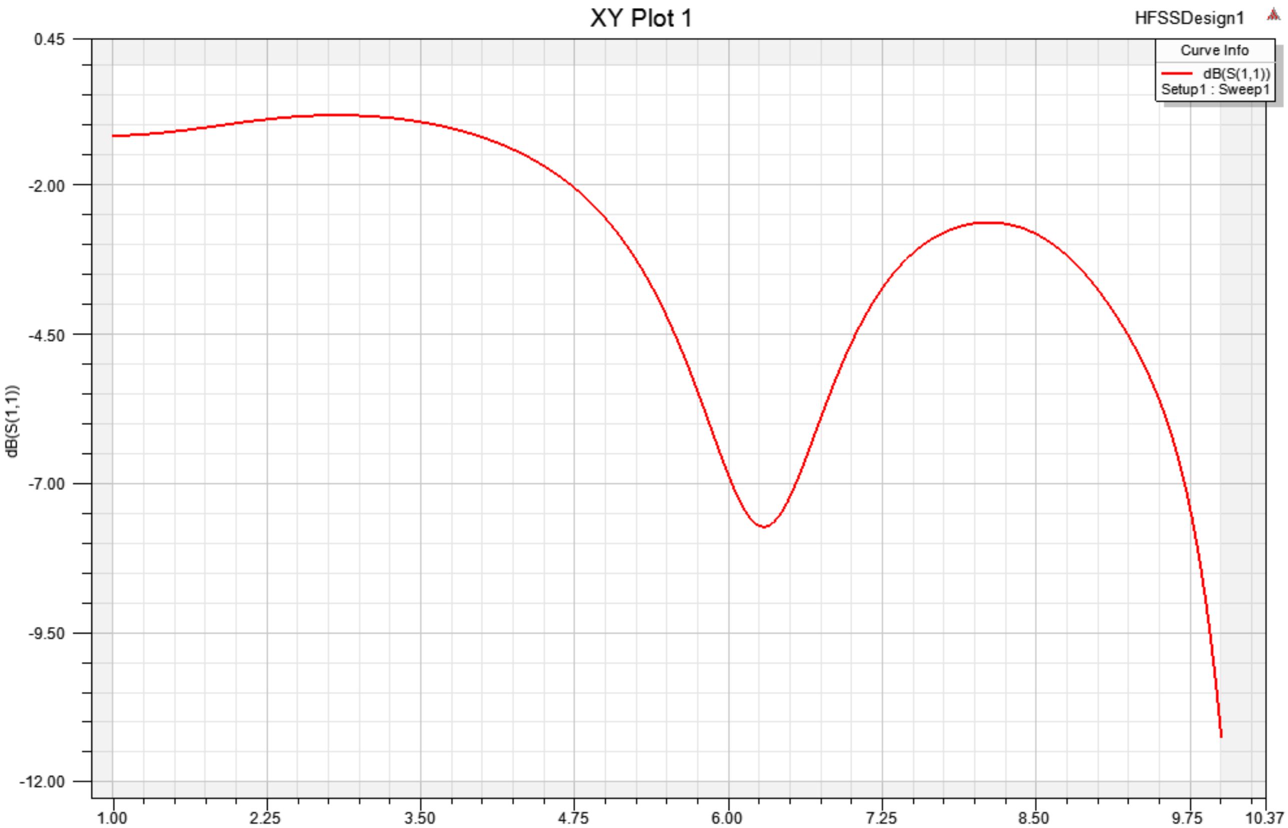


Figure: 5.10 (S_{11} plot: 0 Slots for FR4)

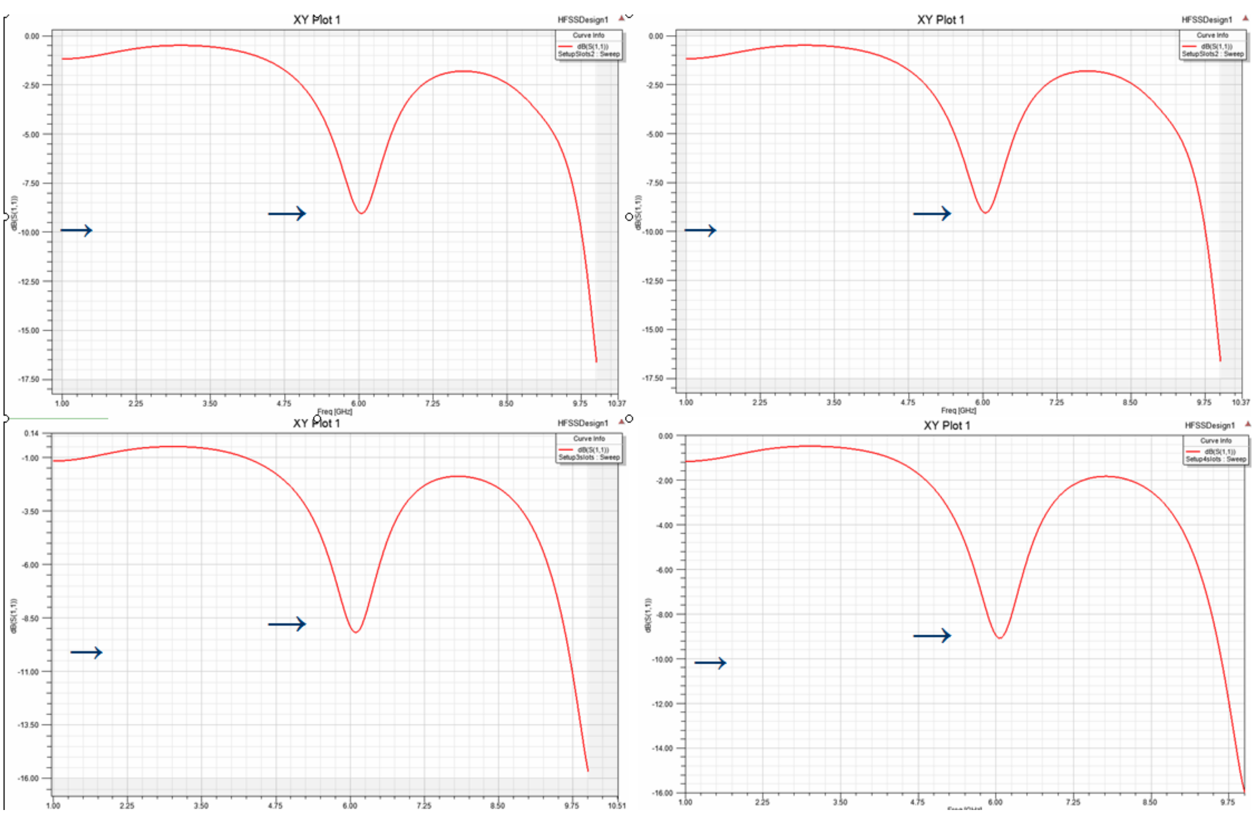


Figure: 5.11 (S_{11} plot: 1-4 Slots for FR4)

Neither of the FR4 designs could show a S_{11} plot that demonstrate frequency at -10dB.

5.3 With circular slots

Since slots with arbitrary size and position give results not even close to impedance Bandwidth required for UWB; we tried circular slots.

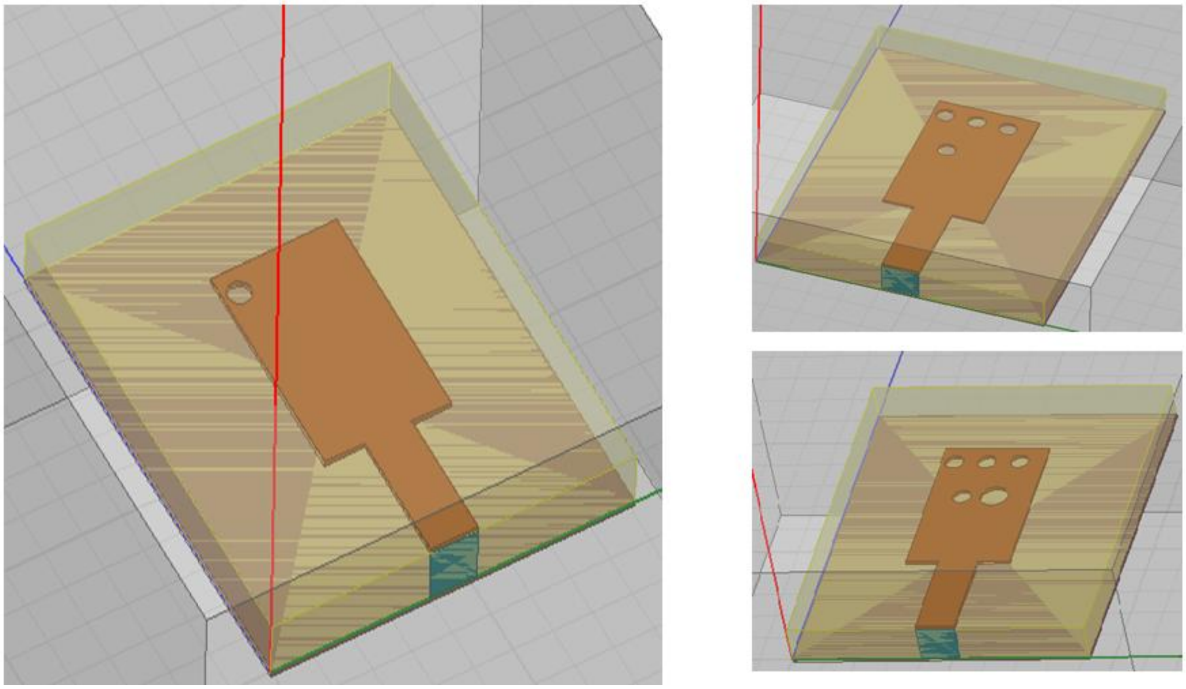
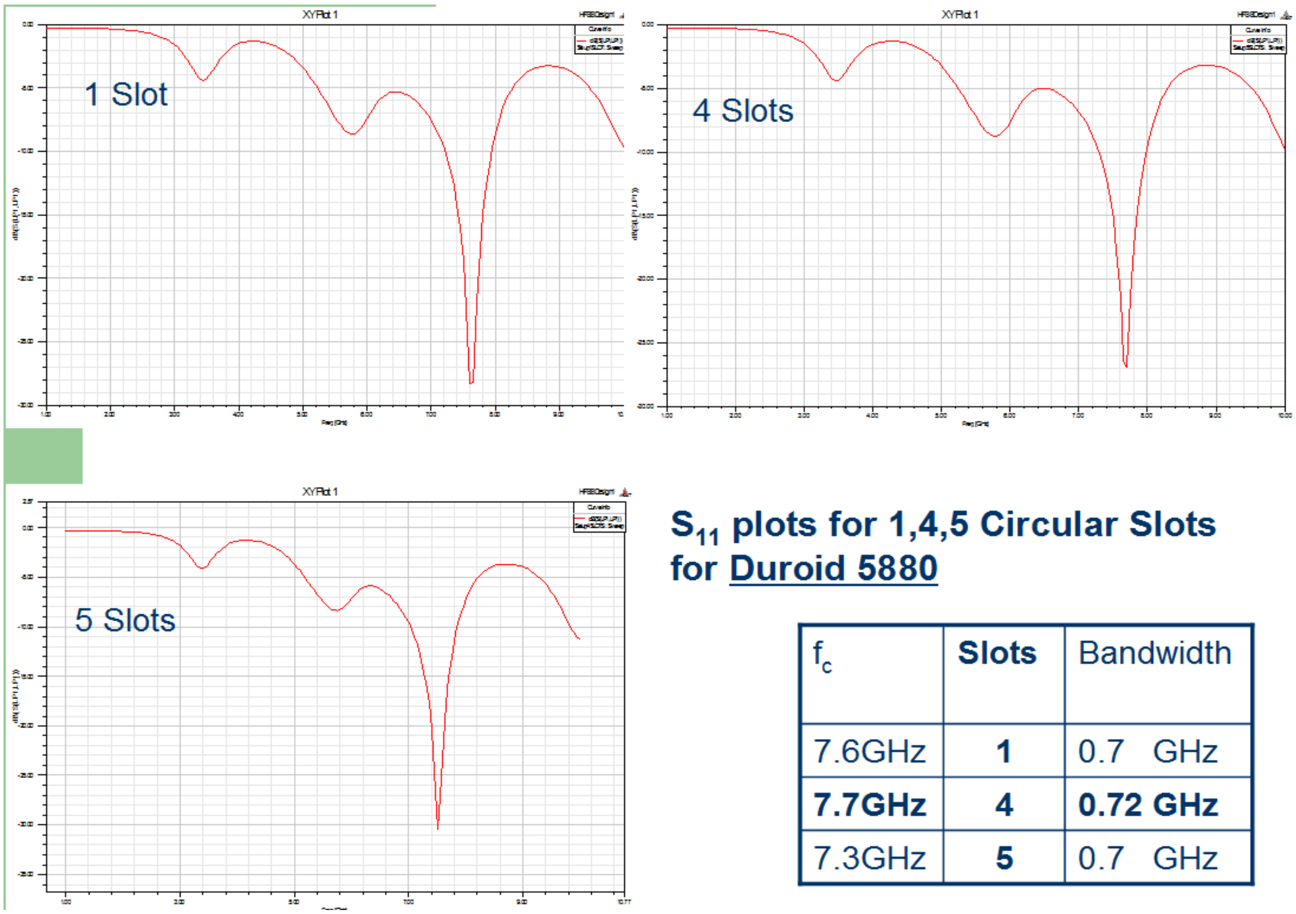


Figure: 5.12 (1,4,5 Slots for Duroid 5880)

Following plots are S_{11} plots for 1, 4 and 5 circular slots on the patch with dielectric substrate Duroid 5880. It shows the bandwidths and center frequencies according to the slots



f_c	Slots	Bandwidth
7.6GHz	**1**	0.7 GHz
7.7GHz	**4**	**0.72 GHz**
7.3GHz	**5**	0.7 GHz

Figure: 5.13 (S_{11} plot: 1, 4, 5 Slots for Duroid 5880)

5.4 With even square slots

Following diagrams and plots are for 2 x 2 mm Square slots evenly distributed on the patch as well as the feed shifted to left side.

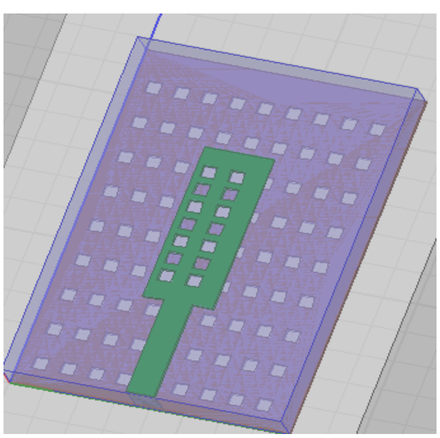


Figure: 5.14 (14 Slots for FR4)

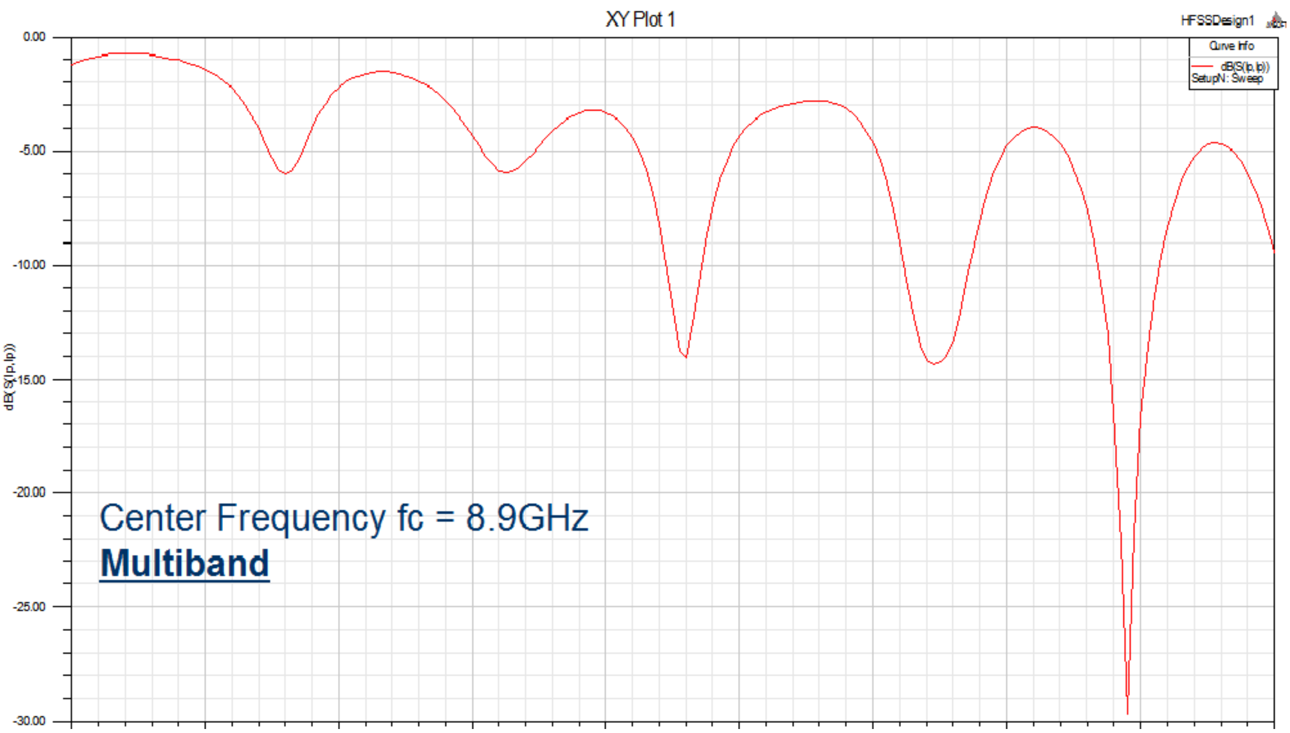


Figure: 5.15 (S_{11} plot: 14 Slots for FR4)

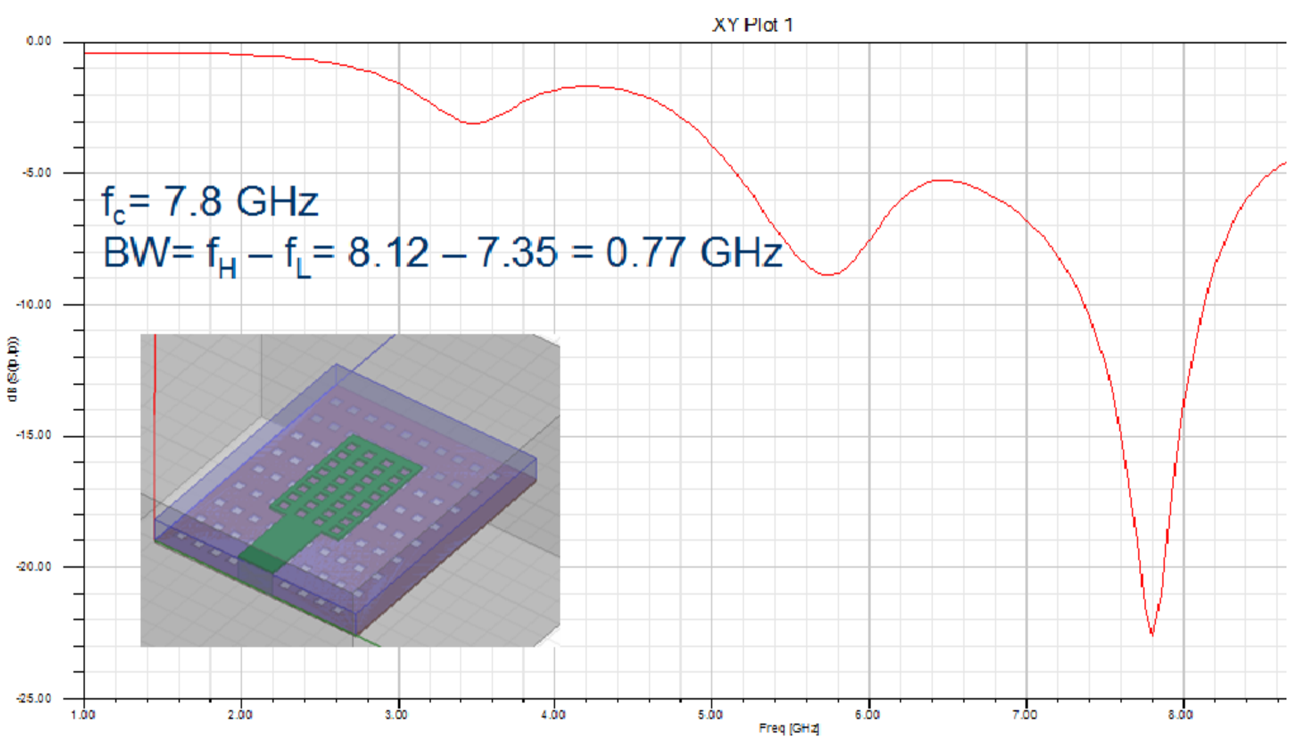


Figure: 5.16 (S_{11} plot: 32 Slots for Duroid)

5.5 With even square slots and feed shift

The strip line and feed shifted to left.

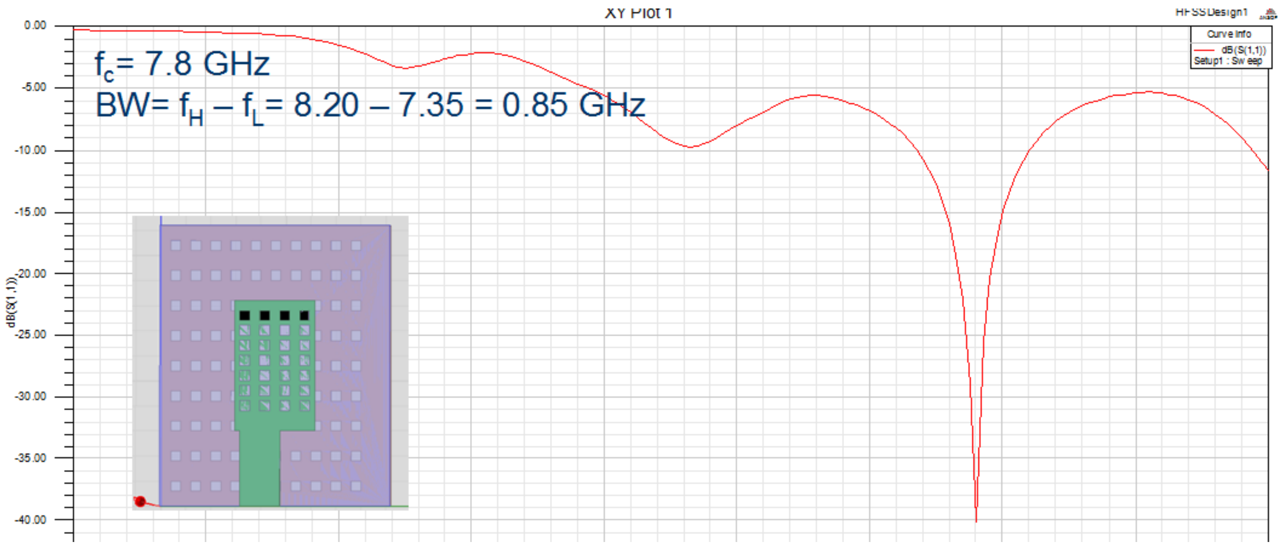


Figure: 5.17 (S_{11} plot: 4 Slots for Duroid 5880)

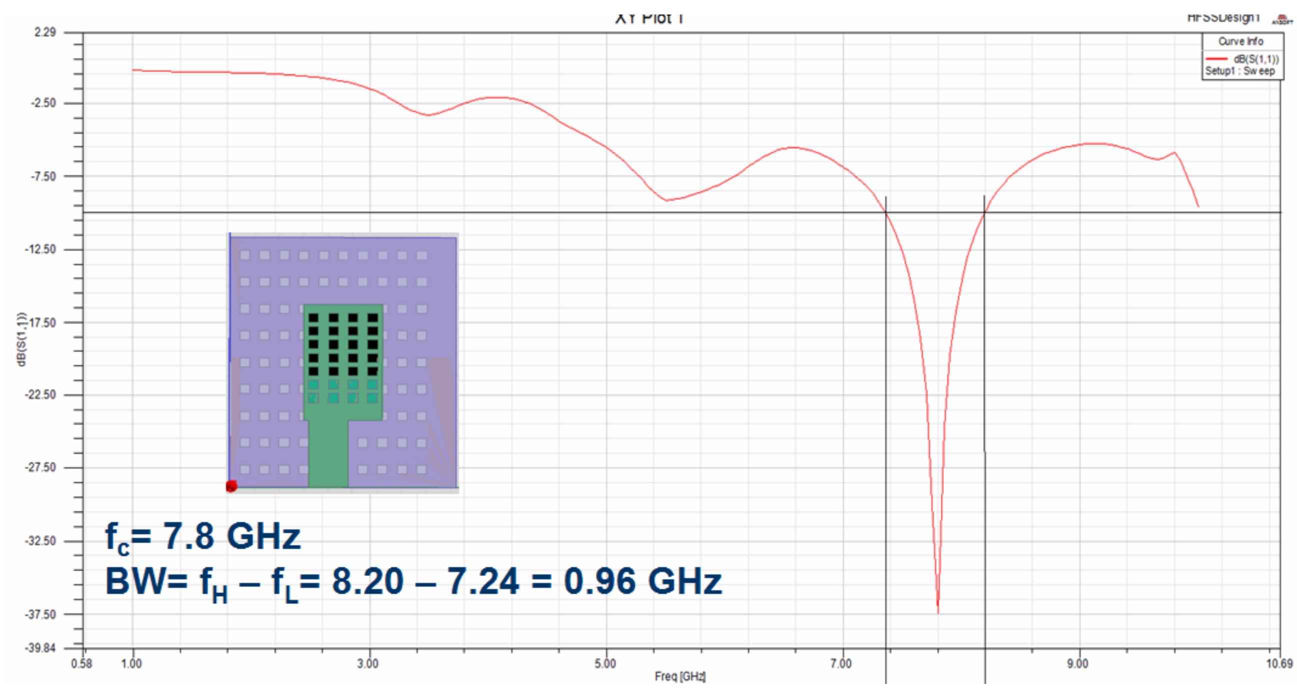


Figure: 5.18 (S_{11} plot: 20 Slots for Duroid 5880)

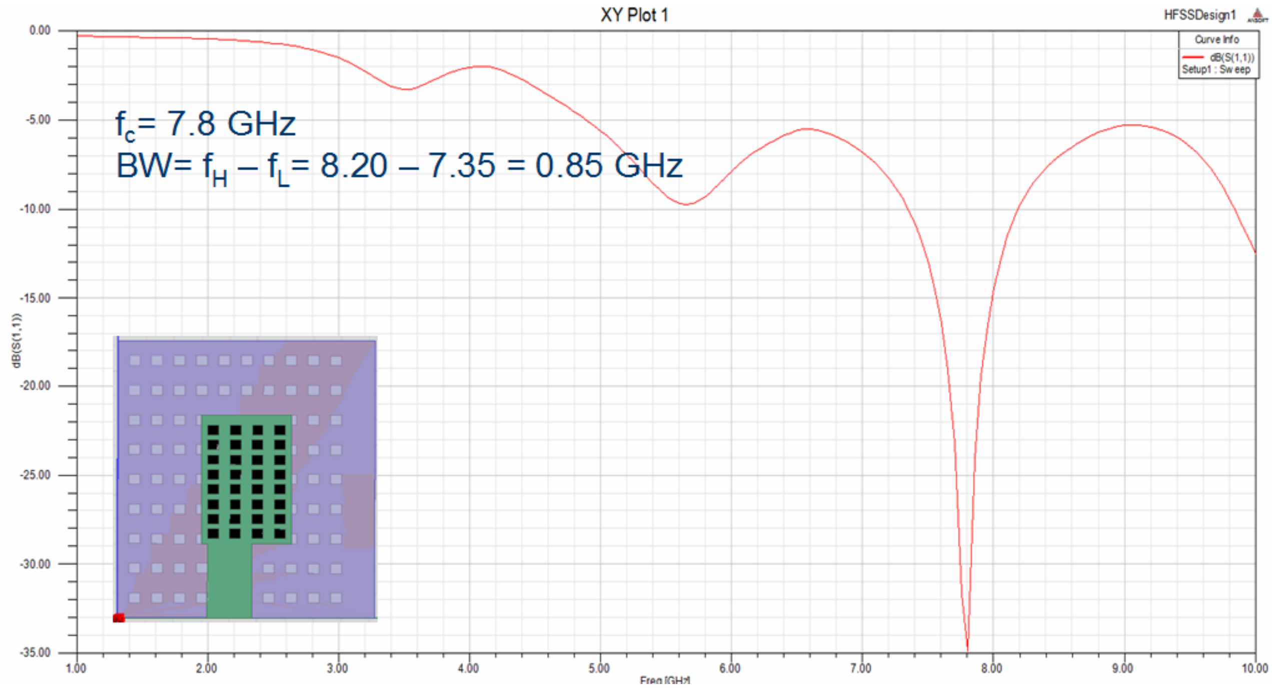


Figure: 5.19 (S_{11} plot: 32 Slots for Duroid 5880)

Best Result is obtained from 20 slots, up to 20 slots the bandwidth increases and then again decreases. The bandwidth 0.96 is the closest to the required Bandwidth 1 GHz.

f_c and BW Table (0-32 slots) for Duroid 5880 (Left shifted feed)

Slots	0	4	12	16	**20**	24	28	30	32
Center Frequency f_c	7.8 GHz	7.8 GHz	7.8 GHz	7.8 GHz	**7.8** GHz	7.75 GHz	7.75 GHz	7.7 GHz	7.7 GHz
Bandwidth = f_H - f_L	0.75 GHz	0.8 GHz	0.87 GHz	0.9 GHz	**0.96** GHz	0.9 GHz	0.9 GHz	0.85 GHz	0.85 GHz

Table 5.1: (*f_c and BW for Duroid 5880 Left shifted feed 0-32 slots*)

Below the plots of impedance and 3D Polar plot for the above design of 20 slots with best result have been shown with indicated values.

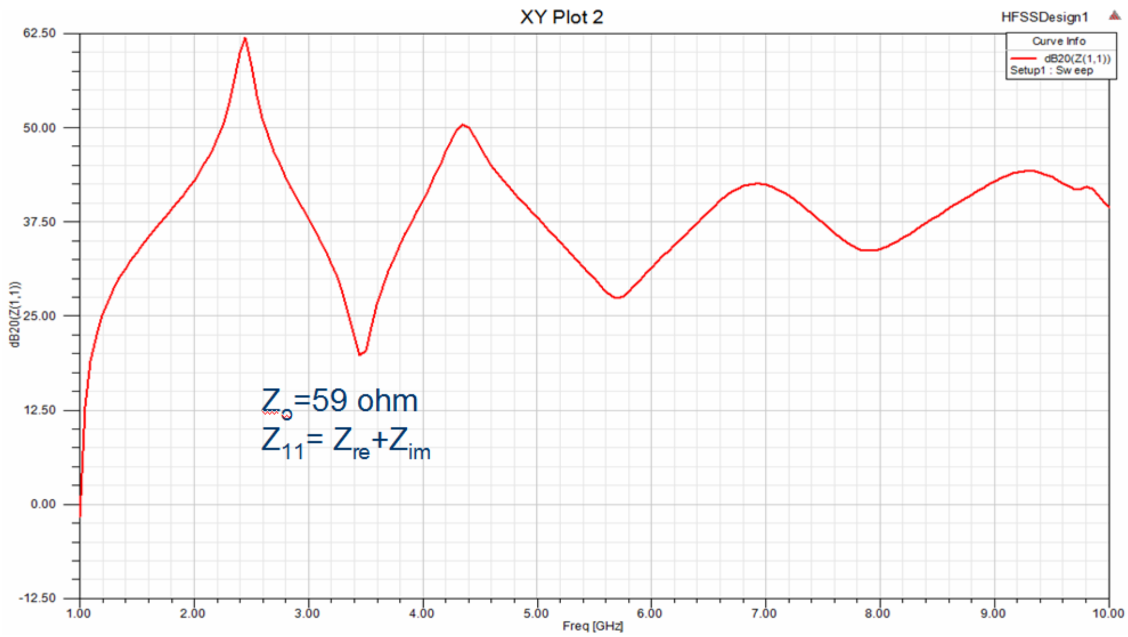


Figure: 5.20 (Z_{11} plot: 20 Slots for Duroid 5880)

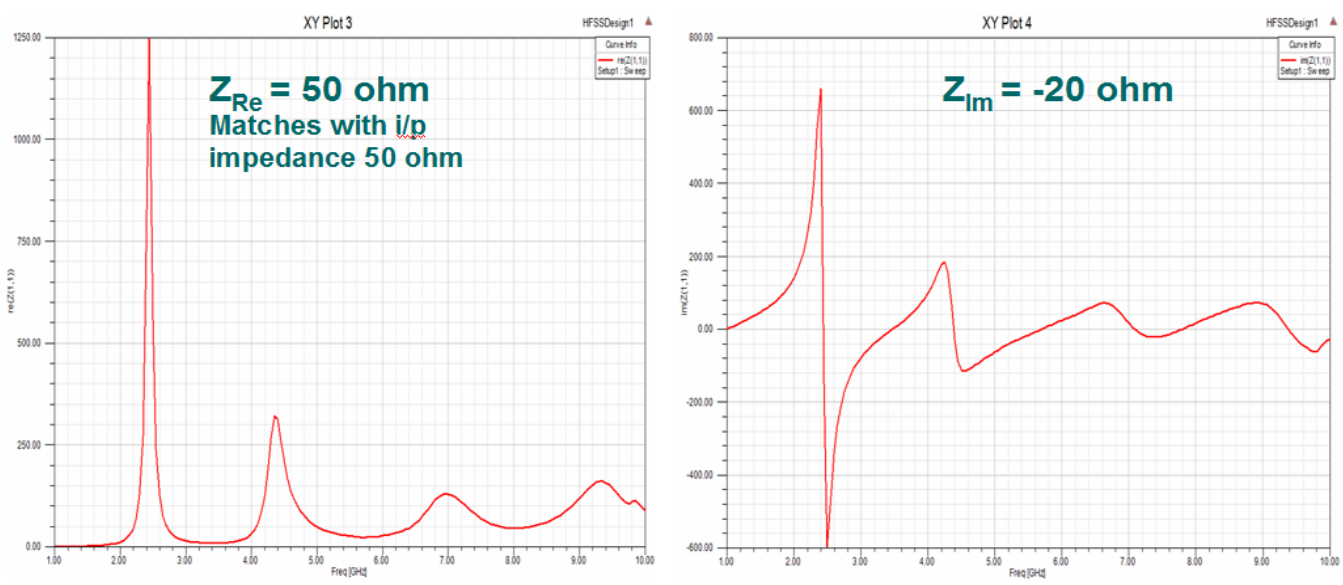


Figure: 5.21 (Z_{re} and Z_{im} plot: 20 Slots for Duroid 5880)

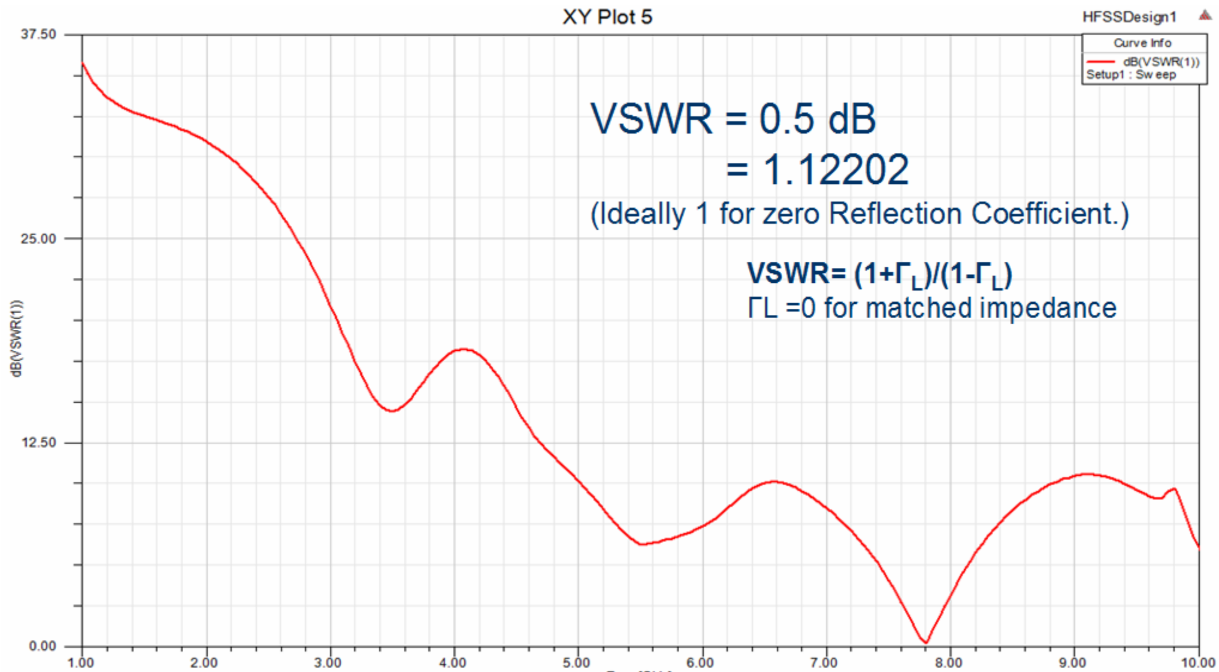


Figure: 5.22 (VSWR plot: 20 Slots for Duroid 5880)

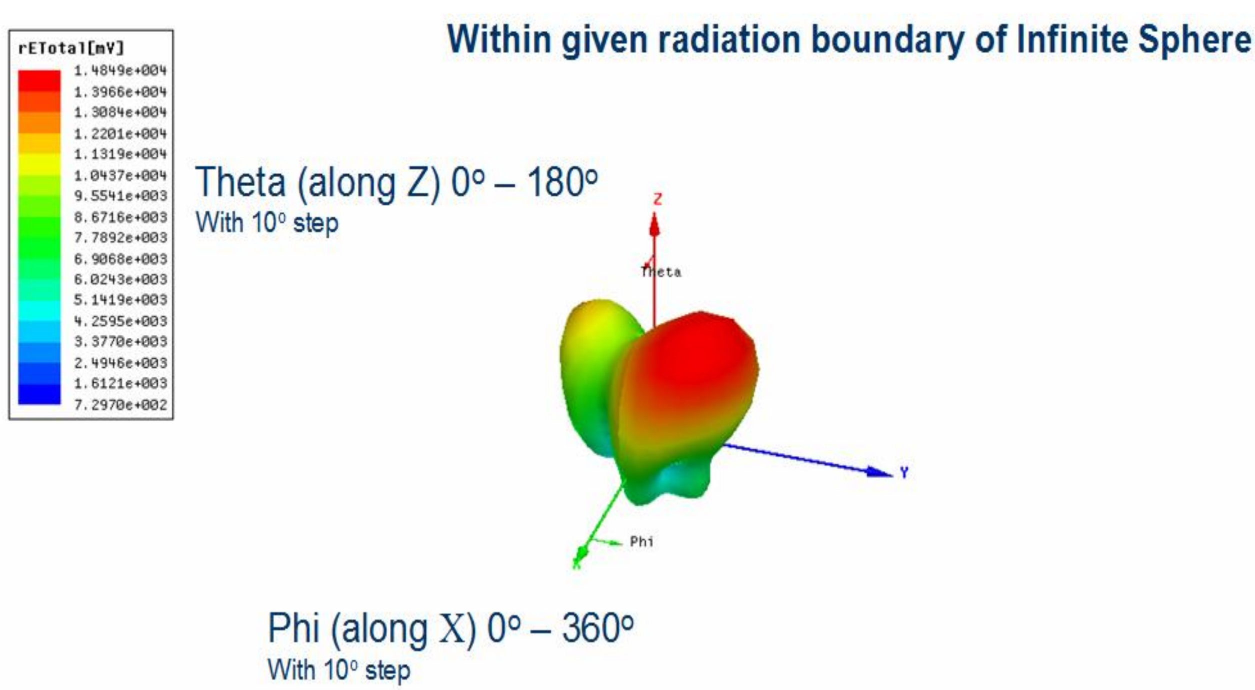


Figure: 5.23 (3D Polar plot: 20 Slots for Duroid 5880)

5.6 Conclusion

- The design of

1. Duroid 5880 substrate
2. 20 square slots
3. Shifted feed

Gives the closest result to our required result for UWB application

- The results show

    1. the Center frequency fc = 7.8GHz
    2. and Bandwidth = 0.96GHz

- 20% of (fc = 7.8GHz) is 1.56GHz is required as bandwidth but the obtained bandwidth 0.96GHz is 12.3077% of (fc = 7.8GHz)

- Grid ground lessens the weight and cost since it requires less of the material for ground and does not noticeably affect performance

5.7 Future work

- The desired bandwidth for the used dielectric substrates and required parameters can be obtained by changing the slot sizes and alignments.

- Dielectric substrate thickness can be increased or decreased for better results.

- Different resonant frequency can be used.

- The simulations are for theoretically perfect electric conductor PEC used for both ground plane and patch, for practical design other metals are to be taken as conductors.

- Fabrication of the optimized architecture for slot patch antenna design for Ultra Wideband application; is further to be done.

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