A COMPACT DUAL PORT MIMO ANTENNA WITH HIGH ISOLATION FOR UWB APPLICATIONS

A Project report submitted in partial fulfillment of the requirements for

the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCE

(Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A 'Grade)

Sangivalasa, Bheemili mandal, Visakhapatnam dist.(A.P)

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CERTIFICATE

This is to certify that the project report entitled **"A COMPACT DUAL PORT MIMO ANTENNA WITH HIGH ISOLATION FOR UWB APPLICATIONS"** submitted by **G.Sarvani (317126512133), L.Sumanth (317126512143) ,M.JayaPrakash(317126512144), S.YuvaRaju(317126512169), O.ChandrasekarRaju (316126512101)** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics and Communication Engineering** of **Andhra University,** Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

The project proposes two element compact monopole MIMO antenna for UWB Applications. This antenna configuration has two identical microstrip line fed elements with a comb-line structure on the ground plane to improve impedance matching and enhance isolation. It has better bandwidth, isolation and simulated peak gain. The applications of these antennas are WLAN, WiMAX and LTE Applications. It has well improved isolation characteristics for the operational bandwidth of the antenna. Simulation and measurement of the designed prototype have been analysed in terms of reflection coefficient, mutual coupling, radiation pattern, peak gain, efficiency and envelope correlation coefficient. These are achieved without too much trade-off with the foot print of the antenna. Results show that the antenna has an impedance bandwidth larger than 3.1–10.6 GHz, mutual coupling between the two ports lower than −25 dB and envelope correlation coefficient less than 0.003 across the UWB band. The proposed antenna has a compact size of 26 × 31 mm2. All the measured and calculated results show that the proposed UWB MIMO antenna is a good candidate for UWB MIMO systems.

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LIST OF ABBREVATIONS

MIMO	Multiple Input Multiple Output
SISO	Single Input Single Output
SIMO	Single Input Multiple output
MISO	Multiple Input Single Output
UWB	Ultra Wide Band
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
VSWR	Voltage Standing Wave Ratio

CHAPTER-1

Introduction to Microstrip Patch Antenna

1.1Introduction:

The Microstrip Patch Antenna is a single-layer design which consists generally of four parts (patch, ground plane, substrate, and the feeding part). Patch antenna can be classified as single – element resonant antenna. Once the frequency is given, everything (such as radiation pattern input impedance, etc.) is fixed. The patch is a very thin ($t<<\lambda 0$, where $\lambda 0$ is the free space wavelength) radiating metal strip (or array of strips) located on one side of a thin no conducting substrate, the ground plane is the same metal located on the other side of the substrate. The metallic patch is normally made of thin copper foil plated with a corrosion resistive metal, such as gold, tin, or nickel. Many shapes of patches are designed some are shown in figure and the most popular shape is the rectangular and circular patch. The substrate layer thickness is 0.01–0.05 of free-space wavelength ($\lambda 0$). It is used primarily to pro-vide proper spacing and mechanical support between the patch and its ground plane. It is also of-ten used with high dielectric-constant material to load the patch and reduce its size. The substrate material should be low in insertion loss with a loss tangent of less than 0.005. In this work we have used Arlon AD 410 with dielectric constant of 4.1 and tangent loss of 0.003. Generally, substrate materials can be separated into three categories according to the dielectric constant εr.

1.Having a relative dielectric constant in the (εr) range of 1.0–2.0. This type of material can be air, polystyrene foam, or dielectric honeycomb.

2. Having εr in the range of 2.0–4.0 with material consisting mostly of fiber glass reinforced Teflon.

3. With an εr between 4 and 10. The material can consist of ceramic, quartz, or alumina.

The advantages of the microstrip antennas are small size, low profile, and lightweight, conformable to planar and non planar surfaces. It demands a very little volume of the structure when mounting. They are simple and cheap to manufacture using modern printed- circuit technology. However, patch antennas have disadvantages. The main disadvantages of the microstrip antennas are: low efficiency, narrow bandwidth of less than 5%, low RF power due to the small separation between the radiation patch and the ground plane(not suitable for high-power applications).

1.1.1 Types of Patch Antennas :

There are a large number of shapes of microstrip patch antennas; they have been designed to match specific characteristics. Some of the common types are shown in figure for milli-meter wave frequencies, the most common types are rectangular, square, and circular patches.

Choose of substrate is also important, we have to consider the temperature, humanity, and other environmental ranges of operating. Thickness of the substrate h has a big effect on the resonant frequency fr and bandwidth BW of the antenna. Bandwidth of the microstrip antenna will increase with increasing of substrate thickness h but with limits, otherwise the antenna will stop resonating. The most common shapes of patch antenna

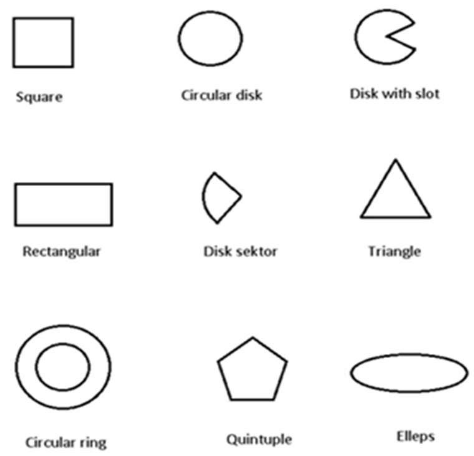


Fig: 1.1 (a) The most common shapes of patch antenna

Applications:

- Used in mobile satellite communication system.
- Direct broadcast television.
- Wireless LAN'S.
- Feed element of coaxial system .
- Global positioning system.
- Missiles , aircraft, spacecraft and telementry.
- UHF patch antenna for space.
- Radar system, surveillance system, remote sensing etc.
- MIMO(multi input multi output).

1.2 Microstrip Patch Antenna Elements:

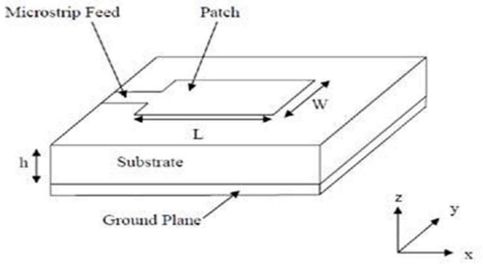


Fig 1.2(a) Microstrip patch antenna elements

Microstrip patch antenna has four structural components.

They are:

1. Ground plane
2. Dielectric substrate
3. Metal patch
4. Feed line

The top view and side view are shown below:

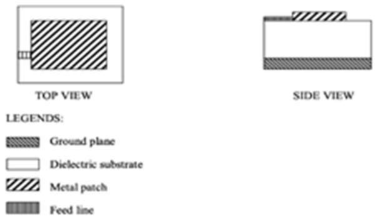


Fig 1.2(b) Top and side view of microstrip patch antenna

Thus, the microstrip patch antenna is a metal deposition on a dielectric material mounted on an electrical ground plane. A feed-line is used to feed the input power to the radiating element i.e., patch.

1.2.1 Different components:

There are four components as already mentioned. Of these four three is to the designers to choose. These three components are 1. Patch geometry 2. Dielectric material 3. Different feeding techniques.

1. Patch Geometry:

The geometry of the patch can be of many types for example square, rectangle, circle, dipole etc. The parameters to choose from these geometries are

a. Ease of Fabrication: this determines the cost of the device

b. Ease of Analysis: Different shapes lead to analysis in different co- ordinate systems leading to several levels of numerical complexity

c. Space occupation: This factor determines the packing density of the designs.

2. Dielectric material:

The dielectric substance can have relative permittivity of the range . But lower means lower dielectric loss, higher power radiated to the space hence better power gain and efficiency which are important performance metric of any antenna. Whereas higher value of means higher loss and hence lower efficiency but due to higher capacitance electric field lines are tightly coupled to the substrate, hence extremely useful for MIC (Microwave Integrated circuit) operations where inter- device coupling is a important metric. But when we use any microstrip antenna it cannot be done without integrating with some other integrated circuits, hence we need to reach a trade of between antenna performance and the inter device coupling property and use that optimised value. A value is normally used.

1.3 Feeding Methods:

Because of the antenna is radiating from one side of the substrate, so it is easy to feed it from the other side (the ground plane), or from the side of the element. The most important thing to be considered is the maximum transfer of power (matching of the feed line with the input impedance of the antenna), this will be discussed later in the section of Impedance Matching. Many good designs have been discarded because of their bad feeding. The designer can build an antenna with good characteristics and good radiation parameter and high efficiency but when feeding is bad, the total efficiency could be reduced to a low level which makes the whole system to be rejected.

1. Microstrip Line.
2. Coaxial Probe (coplanar feed).
3. Proximity Coupling.
4. Aperture Coupling.

1.3.1 Microstrip Line Feed.

This method of feeding is very widely used because it is very simple to design and analyze and very easy to manufacture. Figure shows a patch with microstrip line feed from the side of the patch.

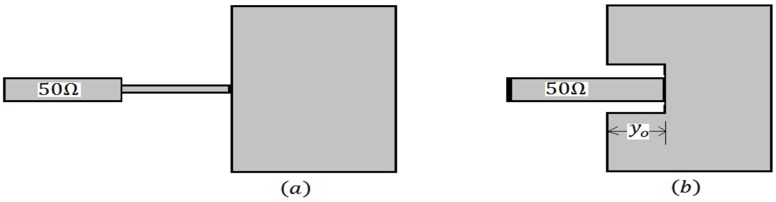


Fig 1.3 (a) Microstrip patch antenna with feed from side

The position of the feed point (y0) of the patch in figure (1.3.1b) has been discussed in details in the section of Impedance Matching. Feeding technique of the patch in figure (1.3.1a) and figure (1.3.2) is discussed .

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

It is widely used in both one patch antenna and multi-patches (array) antennas.

The impedance of the patch is given by:

$$Z_T = \sqrt{50 + Z_a} \quad (1.1)$$

The characteristic impedance of the transition section should be

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}} ln(\frac{8d}{W_T} + \frac{W_T}{4d}) \quad (1.3)$$

The width of the 50Ω microstrip feed can be found using the equation (1.4) below:

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon reff}\left(1.393+\frac{W}{h}+\frac{2}{3}\ln\left(\frac{W}{h}+1.444\right)\right)} \quad (1.4)$$

Where Z0 = 50Ω

$$R_{in(x=0)} = cos^2(\frac{\pi}{L}x_o) \quad (1.5)$$

The length of the transition line is quarter wavelength.

$$l = \frac{\lambda}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon_{reff}}} \quad (1.6)$$

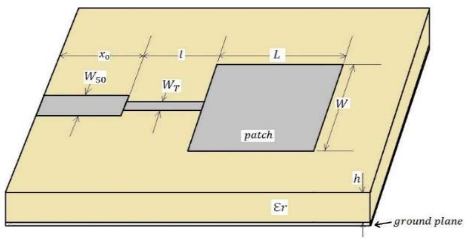


Fig 1.3. (b)Rectangular microstrip patch antenna

1.3.2.Coaxial Feed (Coplanar Feed) :

Coupling of power to the patch antenna through a probe is very simple, cheap, and effective way. If the designer adjusts the feed point to50Ω, so he just needs to use a 50Ω coaxial cable with N-type coaxial connector. The N-coaxial connector is coupled to the back side of the microstrip antenna (the ground plane) and the centre connector of the coaxial will be passed through the substrate and soldered to the patch, as shown in the figure.

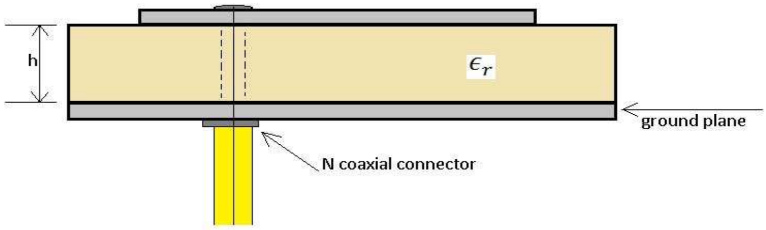


Fig 1.3 (c)Coaxial linefeed

1.3.3 Proximity coupling

Proximity coupling is use two substrate εr1 and εr2. The patch will be on the top, the ground plane in the bottom and a microstrip line is connected to the power source and lying between the two substrates as shown in the figure. This type is known also as "electromagnetically coupled microstrip feed".

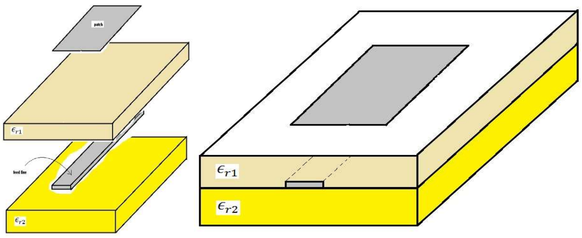


Fig 1.3 (d) Proximity coupling feed method

The principle of this mechanism is that the behavior between the patch and the feed strip line is capacitive. Analysis and design of such an antenna is little more complicated than the other ones discussed in the previous sections because the designer has to take into account the effect of the coupling capacitor between the strip feed line and the patch as well as the equivalent R- L-C resonant circuit representing the patch and the calculating of two substrates (εr1and εr2). The coupling capacitor of this antenna can be designed for impedance matching of the antenna.

1.3.4 Aperture Coupling :

Figure shows the layers of the microstrip patch antenna using the aperture mechanism. The ground plane has an aperture in a shape of a circle or rectangular, and separates two substrates:

the upper substrate Er2 with the patch on it, and the lower substrate Er1 with the microstrip feed line under it. This type of coupling gives wider bandwidth. Another property of this type is the radiating of the feeding strip line is reduced by the shielding effect of the ground plane. This feature improves the polarization purity.

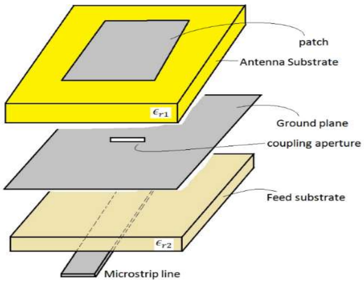


Fig 1.3 (e) Aperture coupling feed method

1.4 Methods of Analysis :

There are many methods of microstrip antenna analysis; the most popular are transmission line (in which we assume that the patch is a transmission line or a part of a transmission line) .The second method is the cavity mode (here we assume that the patch is a dielectric – loaded cavity). The transmission line method is the easiest way of studying the microstrip patch antennas we will discuss briefly each one of these ways.

Transmission Line Model :

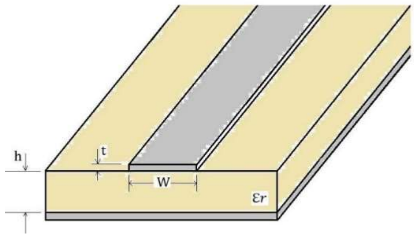


Fig 1.4(a)Microstrip line

The transmission line method is the easiest way to study the microstrip antenna. In this method the transmission line model represents the microstrip patch antenna by two slots separated by a low-impedance transmission line of length L. Results we get are not the best accurate compared with other methods but it is good enough to design the antenna.

To study the theory of microstrip transmission line we have two different cases: W/h < 1 (narrow strip line) and this is not what we are interesting with.

The second case w/h >>1 and ε_r>1 (wider transmission line) this will help us to build a good picture to study the antenna figure.

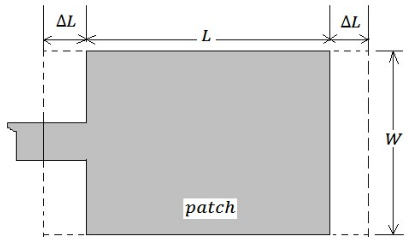


Fig 1.4. (b) physical and effective length of a microstrip patch

The first approximation we make is to assume that the thickness of the conductor t that forms the line has no effect on our calculations, because it is very thin comparing with the substrate h, (h >> t); so we use here empirical formulas that depend only on the line dimensions:

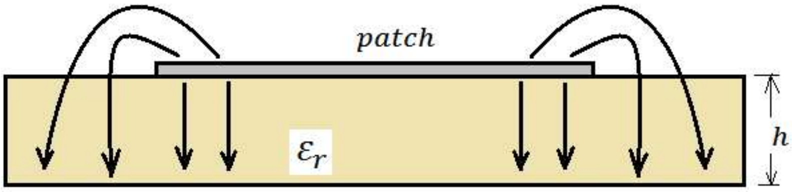


Fig 1.4 (c) Electric field lines

It is important to note that the characteristic impedance given by equation are approximate value. To estimate the effective dielectric constant let us consider the radiating patch is embedded into the dielectric as shown in the figure.Assuming the same dimensions of W, h , and t, the effective dielectric constant **ε**reff can be defined as: "the dielectric constant of the uniform dielectric material so that the line of figure has identical electrical characteristics, particularly propagation constant, as the actual line of figure[1].

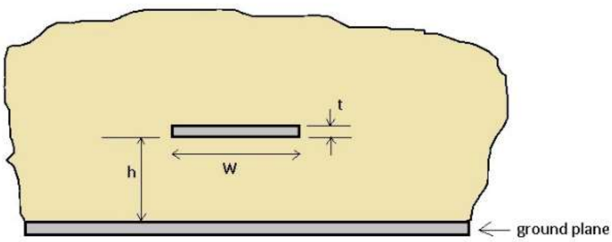


Fig 1.4 (d)Microstrip line embedded into the dielectric

For patch antennas air is above the substrate, this will lead to 1 < **ε**reff < **ε**r . For **ε**r >> 1, **ε**reff is closer to the actual value of the dielectric constant **ε**r of the substrate.The affective dielectric constant is also a function of frequency fr equation. Working in high frequencies makes the microstrip line behave more homogeneous line as it is only one dielectric (one substrate under and above the transmission line), and the effective dielectric constant is closer to the actual dielectric constant.

We can generalize the effective dielectric constant shown in figure (into the one shown in figure)

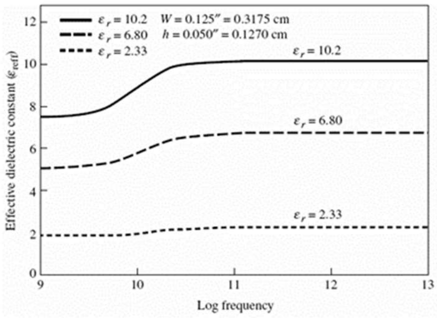


Fig 1.4(e)Effective dielectric constant versus frequency

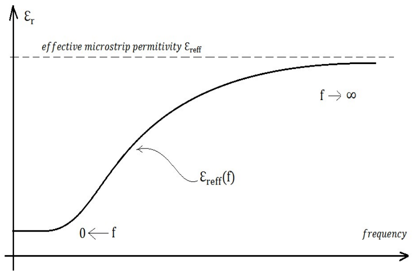


Fig 1.4 (f) Effective dielectric constant versus frequency

1.4.1 Cavity Model :

The cavity model in analyzing the microstrip antennas is based on the assumption that the region between the microstrip patch and ground plane is a resonance cavity bounded by ceiling and floor of electric conductorsmagnetic walls along the edge of the conductor as shown in figure

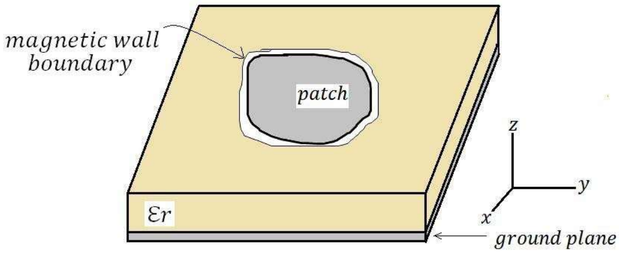


Fig 1.4 (g) Magnetic wall model of a microstrip patch antenna

The assumption above is based on the observation of: There are only three field components in the region enclosed by the cavity: E component in the z axis (Ez) and two components of H along the x and y axis (Hx , Hy). Because h (height of the substrate) is very thin (h<<λ), field in the interior region do not vary with z-coordinates for all frequencies. The electric current in the microstrip patch has no component normal to the edge of the patch at any point. This model is fair good in studying the microstrip resonators with the edge extending slightly to account for the fringing field. Before going further with calculation of the field in the cavity let's take a look on the mechanism of the cavity. Consider the microstrip antenna in the figure.

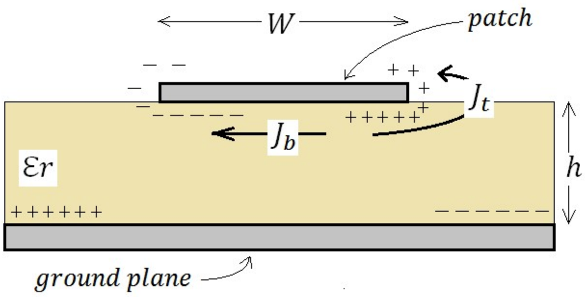


Fig 1.4 (h) Charge distribution and current density on a microstrip antenna

When the microstrip antenna is connected to a microwave source, the charge distribution will be established on the upper and the lower planes of the antenna as shown in figure (ca2). The charge distribution is controlled by two mechanisms; attractive and repulsive. The attractive force is between the opposite charges on the patch and on the ground plane, it creates a current density inside the dielectric Jb at the bottom of the patch.The repulsive force is between the like charges tends to push the charges from the bottom of the patch around the edge of the patch to the top of the patch, this will create the current density J.We have mentioned before that the field inside the cavity has three field components Ez , Hx and Hy ; the wave equation can be re-written as equation

$$\nabla \times \nabla \times \vec{E} - k^2 \vec{E} = -j\omega\mu_o \vec{J}$$

$$\nabla^2 E_Z + k^2 E_Z = j\omega\mu_o \hat{z} \cdot \vec{J}$$

Where $k^2 = \omega^2 \mu_o \varepsilon_o \varepsilon_r$ is the wave number.

$\overrightarrow{J =}$ Electric current density fed by the feed line to the patch.

$\hat{z}$ Is the unit vector normal to the plane of the patch.

In addition we have on the top and the bottom conductors:

$$\hat{n} \times \vec{E} = 0$$

And on the walls:

$$\hat{n} \times \vec{H} = 0$$

1.4.2 The Ground plane :

As a part of the antenna, the ground plane should be infinite in size as for a monopole antenna [7] but in reality this is not easy to apply besides a small size of ground plane is desired. Length of ground plane should be at least one wavelength, it means as the length of the patch is equal or less than half wavelength ($L \leq \lambda 0/2$) so ground plane will extend $\lambda/4$ from the edge of the patch.

$$\lambda_o = \frac{\upsilon_o}{f_r}$$

Where:

λ0 is wavelength in free space.

υ0 is speed of light in free space (3 00000000 m/s).

fr is resonance frequency (1.57542 GHz).

λeff is effective wavelength in the substrate.

εreff is effective dielectric constant in the substrate.

λeff = 96.5857mm

λeff/4 = 24.146mm

The width W of the patch must be less than the wavelength in the dielectric substrate material so that higher – order modes will not be excited.

1.5 Antenna Design parameters and configuration

1.5.1 Antenna Design parameters:

Design parameters are calculated by using the following equations.

- Patch width (wp):

wp=c/(2f_0 √(((Ɛ_r+1))/2))

The effective dielectric constant (Ɛ_reff) of an antenna

Ɛ_reff=((Ɛ_r+1)/2)+((Ɛ_r-1)/2) (1+12 h/w)^((-1)/2)

Where Ɛreff = effective dielectric constant

Ɛr= dielectric constant of the substrate

h = height of the dielectric substrate

W = the patch width

- Extension of the length (ΔL)

ΔL=h*0.412 (Ɛ_reff+0.3)(w/h+0.264)/(Ɛ_reff-0.258)(w/h+0.8)

The fringing effect is used to enhance the effective electrical length of the patch longer than its physical length. Thus, the resonance condition depends on Leff.

Therefore, the effective length of the patch:

$$\mathbf{L = L + 2\Delta L}$$

The actual length of the patch (Lp):

$$\mathbf{Lp = c/(2f\_0\ \sqrt{(Ɛ\_reff)})-2\Delta L}$$

Substrate length (Lsb):

$$\mathbf{Lsb = 12h + Lp}$$

Width of the substrate

$$\mathbf{Wsb = 12h + W}$$

Length of slot (Lsl):

$$\mathbf{Lsl = Lp/Ɛreff}$$

Width of slot (Wsl):

$$\mathbf{Wsl = w/2}$$

Example: f0, h, Ɛr

$$\mathbf{\lambda = c/f}$$

$$\mathbf{w = c/f\ \sqrt{(2/(Ɛr+1))}}$$

$$\mathbf{L = Leff - 2\Delta L}$$

Where, w = width of the patch

C = velocity of the light (3x1011mm)

f = Resonant frequency

L = Length of the patch

Ɛr = Dielectric constant of substrate

Leff = Effective length, and it is given by

$$\mathbf{Leff = c/(2f\sqrt{(Ɛreff\ )})}$$

The normalized extension is length is given by,

$$\mathbf{\Delta L = 0.412h\ (Ɛreff+0.3)(w/h+0.264)/(Ɛreff-0.258)(w/h+0.8)}$$

Where Ɛreff = effective dielectric constant, and the equation for it is given below

$$\mathbf{Ɛreff = (\ (Ɛr+1)/2)+(\ (Ɛr-1)/2)\ (1+12\ h/w)\text{^}((-1)/2)}$$

Substrate length and width are calculated using the below formulae,

$$Lg = L+6h$$

$$Wg = W+6h$$

Where Lg and Wg are length and width of the substrate and h is given by

$$h=0.0606\lambda/\sqrt{\varepsilon r}$$

Feed line length is calculated using the below equation,

Feed length:

$$(Lf)= \lambda g/4$$

Where $\lambda g = \lambda/\sqrt{\varepsilon reff}$

And finally, efficiency of the antenna is calculated by

$$\eta = gain/directivity \times 100\%$$

Where η = efficiency

Radiation box

Axis position:

$$(-\lambda g)/6+(-\lambda g)/6+(-\lambda g)/6$$

Length:

$$\lambda/6+\lambda/6+Lg$$

Width:

$$\lambda/6+\lambda/6+Wg$$

Height:

$$\lambda/6+\lambda/6+h$$

1.6 Parameters of Antenna:

1.6.1 Gain of an Antenna:

The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Antenna gain is more commonly quoted than directivity in an antenna's specification sheet because it takes into account the actual losses that occur.A transmitting antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power. Note that a lossless antenna would be an antenna with an antenna efficiency of 0 dB (or 100%). Similarly, a receive antenna with a gain of 3 dB in a particular direction would receive 3 dB more power than a lossless isotropic antenna.

$$G = \varepsilon_R D$$

Antenna Gain is sometimes discussed as a function of angle. In this case, we are essentially plotting the radiation pattern, where the units (or magnitude of the pattern) are measured in antenna gain.However, more often a single number is quoted the gain is the 'peak gain' over all directions. Antenna Gain (G) can be related to directivity (D) and antenna efficiency by:

1.6.2 Return Loss:

Return loss is a quantity often used within RF circuits where impedance matching is important. The return loss is the proportion of a signal that is reflected as a result of an impedance mismatch.The return loss approach is akin to VSWR, voltage standing wave ratio, but it is widely used in applications where feeders are not used, or they are very short in comparison with a wavelength and hence the concept of standing waves is not applicable.

Typically return loss is used in circuit applications, whereas VSWR is used in association with feeders / transmission lines.The definition of return loss is that it is the loss of power in the signal returned / reflected by a discontinuity in a transmission line or optical fibre. This is normally expressed in decibels.In other words if all the power was transferred to the load, then there would be an infinite return loss. Conversely if there is an open or short circuit termination, then all the power will be returned and there will be no return loss.

The return loss is normally calculated as follows:

$$R = 10\log10(Pi/Pr)$$

Then as the reflection coefficient Γ is the ratio of the forward and reflected voltages, and power is proportional $R = 20\log(\Gamma)$

Return loss is a figure which is widely used for assessing items like the input characteristics of an RF component, or when measuring the characteristics of a network using a vector network analyser. As such the return loss is an important characteristic.

1.6.3 Reflection Co-efficient:

The reflection coefficient is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium.The reflection coefficient is a very useful quality when determining VSWR or investigating the match between, for example, a feeder and a load.

The return loss is normally calculated as follows:

$$R = 10\log10(Pi/Pr)$$

Then as the reflection coefficient Γ is the ratio of the forward and reflected voltages, and power is proportional

$$R = 20\log10(\Gamma)$$

$$\Gamma = Vref/Vfwd$$

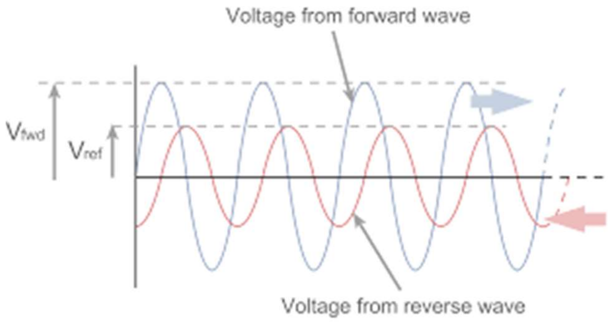


Fig 1.6 (a)reflection coefficient waves

Where:

Γ = reflection coefficient

Vref = reflected voltage

Vfwd = forward voltage

It is also possible to express the reflection coefficient in terms of the load and line or feeder impedances:

$$\Gamma = |(ZL-Z0)/ (ZL+Z0)|$$

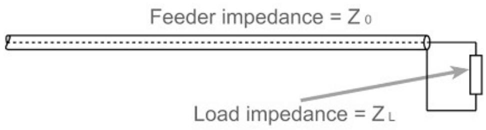


Fig 1.6 (b)impedance

Where:

Γ=reflectioncoefficient

ZL =load impedance

Z0 = feeder characteristic impedance

It is also useful to be able to calculate the refelction coefficient in terms of the forward and reverse power levels. As the power is proportional to V2 [watts = V2 / R], we can deduce that:

$\Gamma=\sqrt{Pref/Pfwd}$

Γ = reflection coefficient

Pref = reflected power

Pfwd = forward power

1.6.4 VSWR:

For a radio (transmitter or receiver) to deliver power to an antenna, the impedance of the radio and transmission line must be well matched to the antenna's impedance. The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to.

VSWR stands for Voltage Standing Wave Ratio, and is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. If the reflection coefficient is given by , then the VSWR is defined by the following formula:

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

The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is ideal.Often antennas must satisfy a bandwidth requirement that is given in terms of VSWR. For instance, an antenna might claim to operate from 100-200 MHz with VSWR<3. This implies that the VSWR is less than 3.0 over the specified frequency range. This VSWR specifications also implies that the reflection coefficient is less than 0.5 (i.e., <0.5) over the quoted frequency range.VSWR is determined from the voltage measured along a transmission line leading to an antenna. VSWR is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave, as seen in the following Figure.

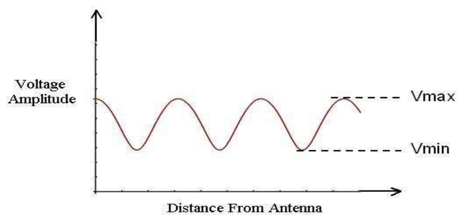


Fig 1.6 (c) Voltage amplitude

1.6.5 Bandwidth of Antenna:

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1.

$$BW = 100 \times \frac{F_H - F_L}{F_C}$$

The bandwidth can also be described in terms of percentage of the centre frequency of the band. where FH is the highest frequency in the band, FL is the lowest frequency in the band, and FC is the centre frequency in the band. Bandwidth is typically quoted in terms of VSWR. For instance, an antenna may be described as operating at 100-400 MHz with a VSWR<1.5. This statement implies that the reflection coefficient is less than 0.2 across the quoted frequency range. Hence, of the power delivered to the antenna, only 4% of the power is reflected back to the transmitter. Alternatively, the return loss S11=20*log10(0.2) = -13.98 dB.
Also, the radiation pattern will vary with frequency. In general, the shape of the radiation pattern does not change radically.There are also other criteria which may be used to characterize bandwidth. This may be the polarization over a certain range, for instance, an antenna may be described as having circular polarization with an axial ratio < 3dB (less than 3 dB) from 1.4-1.6 GHz. This polarization bandwidth sets the range over which the antenna's operation is approximately circularly polarized.The bandwidth is often specified in terms of its Fractional Bandwidth (FBW). The FBW is the ratio of the frequency range (highest frequency minus lowest frequency) divided by the centre frequency. The antenna Q also relates to bandwidth (higher Q is lower bandwidth, and vice versa).

CHAPTER – 2

High Frequency Structure Simulator

2.1 Introduction to HFSS

HFSS is a high-performance full-wave electromagnetic(EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. HFSS employs the Finite Element Method(FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. HFSS can be used to calculate parameters such as S-Parameters, Resonant Frequency, and Fields. Typical uses include: Package Modeling – BGA, QFP, Flip-Chip PCB Board Modeling – Power/Ground planes, Mesh Grid Grounds, Backplanes Silicon/GaAs - Spiral Inductors, Transformers EMC/EMI – Shield Enclosures, Coupling, Near- or Far-Field Radiation Antennas/Mobile Communications – Patches, Dipoles, Horns, Conformal Cell Phone Antennas, Quadrafilar Helix, Specific Absorption Rate(SAR), Infinite Arrays, Radar Cross Section(RCS), Frequency Selective Surfaces(FSS) Connectors – Coax, SFP/XFP, Backplane, Transitions Waveguide – Filters, Resonators, Transitions, Couplers Filters – Cavity Filters, Microstrip, Dielectric HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques. The name HFSS stands for High Frequency Structure Simulator. Pioneered the use of the Finite Element Method(FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep(ALPS). Today, HFSS continues to lead the industry with innovations such as Modes-to-Nodes and full wave Spice. HFSS has evolved over a period of years with input from many users and industries. In industry, HFSS is the tool of choice for high-productivity research, development, and virtual prototyping.

2.2 Icons Used in HFSS:

Ground: To create ground plane by using the rectangle which is 2-Dimensional.Double click on this rectangle name it as ground. Click on create rectangle to change the dimensions according to our project. Ground plane of size and position (x,y,z).

Substrate: For dielectric substrate draw the same size of box and extend in the Z- direction. Click on Box and change the name with "Substrate"(FR4-Epoxy).Click on create box to change positions of X size,Y size, Z size.

Patch: Over this substrate we need to place a patch. The length and width of patch are calculated according to design equations. Double click on the rectangular box to change the name as "Patch". Click on create rectangle to change the dimensions according to design equations.

Feed Line: we need to provide a feed line so that, create a rectangle along the x-axis. Double click on the rectangle and name it as feed. Click on create rectangle to change the dimensions. Now at this point impedance is matching and this feed has to be in contact with the patch. For that click on the patch and feed to get "Unite" a inset feed antenna has designed.

Port: Create a port in YZ plane so that it is designed in order to provide the excitation. We can create the port by drawing a rectangle and by clicking on rectangle we can change the name as "Port" and by clicking create rectangle we can change the dimensions of x-axis, Y-size , Z-size.

Excitation: If we want to see the excitation so that click on the "project manager", excitation on the port has been assigned with the excitation in the similar manner.

Radiation: This antenna design has to be radiated for the simulation environment has created by drawing a box i.e to create environment. For that create a "Box" and name it as "Radiation". If we want to radiate this to air radiation medium is selected as "Air". And click on color of "White" so that the transparency is one and we can view the antenna design. Click on create box and change the size of the radiation box of required position, X-size , Y-size, Z-size because we can provide sufficient space for this radiation of antenna. If we observe, the substrate is already provided with "FR4 Epoxy" but the ground and patch are not assigned with any material.

Boundaries: There are twelve boundaries available within HFSS. Boundaries are applied to specifically created 2D sheet objects, or surfaces of 3D objects. The twelve boundaries are:

1. Perfect Electric Conductor (PEC): default HFSS boundary fully encloses the solution space and creates a closed model
2. Radiation: used to create an open model
3. Perfectly Matched layer (PML): used to create an open model and preferred for antenna simulations
4. Finite Conductivity: allows creation of single layer conductors
5. Layered Impedance: allows creation of multilayer conductors and thin dielectrics

6. Impedance: allows creation of ohm per square material layers
7. Lumped RLC: allows creation of ideal lumped components
8. Symmetry: used to enforce a symmetry boundary
9. Master: used in conjunction with Slave Boundary to model infinitely large repeating array structures
10. Slave: used in conjunction with Master Boundary to model large infinitely repeating array structures
11. Screening Impedance: allows creation of large screens or grids
12. Perfect H: allows creation of a symmetry plane.

2.2.1 Overview of the 3D Modeler User Interface

When using the 3D Modeler interface you will also interact with two additional interfaces:

Property Window – The Property Window is used to view or Property Window modify the attributes and dimensions of structural objects

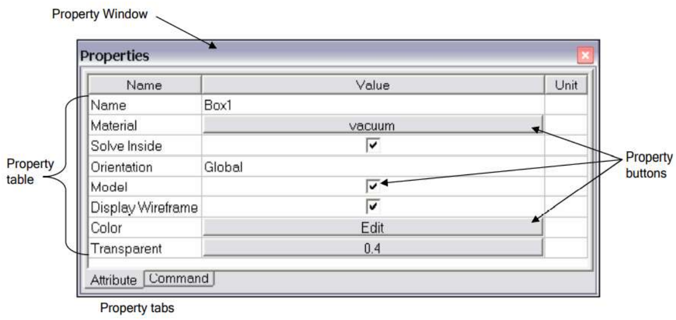


Fig 2.2(a) shows the Property window

Status Bar/Coordinate Entry-The Status Bar on the Ans Status Bar/Coordinate Entry HFSS Desktop Window displays the Coordinate Entry fields that can be used to define points or offsets during the creation of structural objects

Fig 2.2(b) shows Status Bar/Coordinate Entry

2.2.2 Toolbars

The toolbar buttons are shortcuts for frequently used commands. Most of the available toolbars are displayed in this illustration of the HFSS initial screen, but your HFSS window probably will not be arranged this way.

You can customize your toolbar display in a way that is convenient for you. Some toolbars are always displayed; other toolbars display automatically when you select a document of the related type. For example, when you select a 2D report from the project tree, the 2D report toolbar displays.

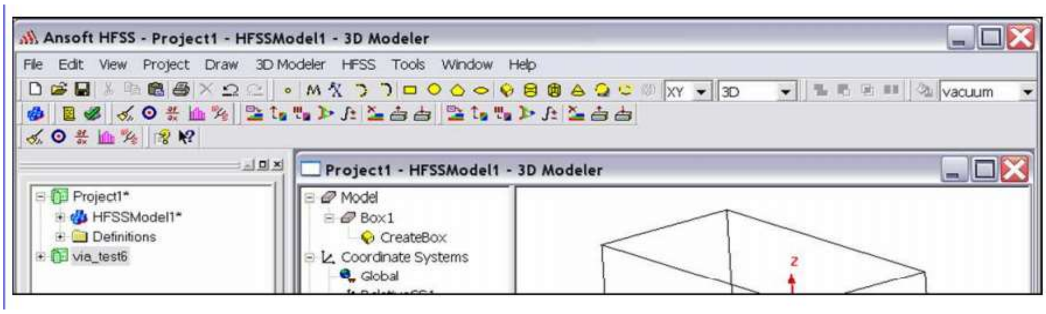
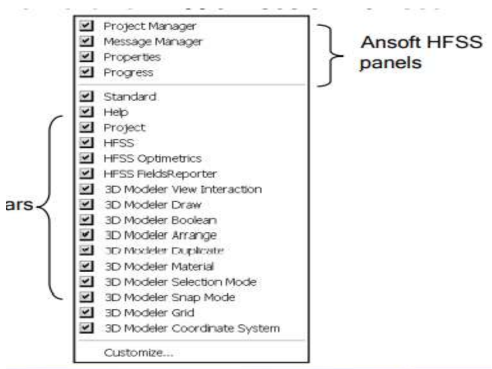


Fig2.2(c)shows in HFSS

To display or hide individual toolbars:

Right-click the HFSS window frame.

A list of all the toolbars is displayed. The toolbars with a check mark beside them are visible; the toolbars without a check mark are hidden. Click the toolbar name to turn its display on or off. To make changes to the toolbars, select the menu item Tools > Customize. See Customize and Arrange Toolbars on the Customize and Arrange Toolbars next page. Toolbar



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2.2.3 Set Solution Type

This section describes how to set the Solution Type. The Solution Type defines the type of results, how the excitations are defined, and the convergence. The following Solution Types are available:

1. Driven Modal - calculates the modal-based S-parameters. Driven Modal The S-matrix solutions will be expressed in terms of the incident and reflected powers of waveguide modes.
2. Driven Terminal - calculates the terminal-based S-parame Driven Terminal of multi conductor transmission line ports. The S-matrix solutions will be expressed in terms of terminal voltages and currents.
3. Eignemode – calculate the eigenmodes, or resonances, of Eignemode a structure. The Eigenmode solver finds the resonant frequencies of the structure and the fields at those resonant frequencies.

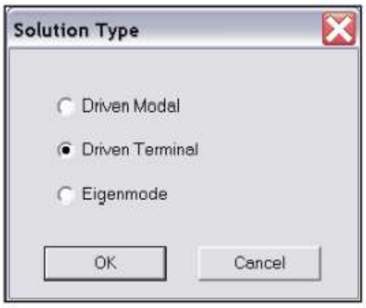


Fig 2.2(d) shows solution type box

Driven Modal – Delta S for modal S-Parameters. This wa Driven Modal s the only convergence method available for Driven Solutions in previous versions.

Driven Terminal – Delta S for the single-ended or diff Driven Terminal erential nodal SParameters.

Eigenmode - Delta F

To set the solution type:

1. Select the menu item HFSS > Solution Type
2. Solution Type Window:
   1. Choose one of the following:
      1. Driven Modal
      2. Driven Terminal

3. Eigenmode.

2. Click the OK button

2.2.4 Parametric Model Creation

The HFSS 3D Modeler is designed for ease of use and flexibility. The power of the 3D Modeler is in its unique ability to create fully parametric designs without editing complex macros/model history.

The purpose of this chapter is to provide an overview of the 3D Modeling capabilities. By understanding the basic concepts outlined here you will be able to quickly take advantage of the full feature set offered by the 3D Parametric Modeler.

Overview of the 3D Modeler User Interface

The following picture shows the 3D Modeler window.

3D Modeler Design Tree – The 3D Modeler Design Tree is a 3D Modeler Design Tree n essential part of the user interface. From here you may access the structural elements in addition to any object dependencies and attributes.

Context Menus – Context menus are a flexible way of accessing Context Menus frequently used menu commands for the current context. The contents of these menus change dynamically and are available throughout the interface by clicking the right mouse button.

Graphics Area – The graphics area is used to interact with Graphics Area the structural elements.

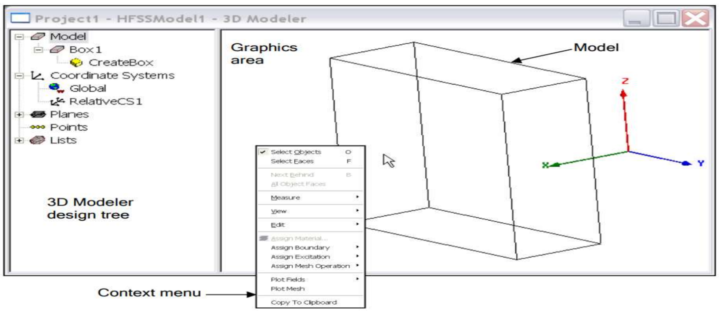


Fig 2.2(e)shows 3D Modeler Design Tree

Creating and Viewing a Simple Structure

Creating 3D structural objects is accomplished by performing the following steps:

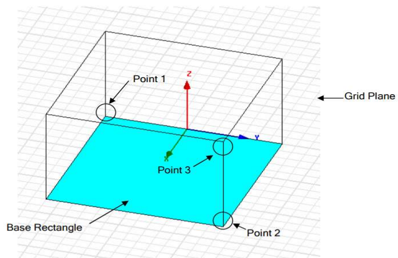
1. Set the grid plane.
2. Create the base shape of the object.
3. Set the Height.

Create a Box

We will investigate creating a box to demonstrate these steps. These steps assume that project and a HFSS design have already been created. Three points are required to create the box. The first two form the base rectangle and the third sets the height. Point 1: Defines the start point of the base rectangle.

Point 2: Defines the size of the base rectangle.

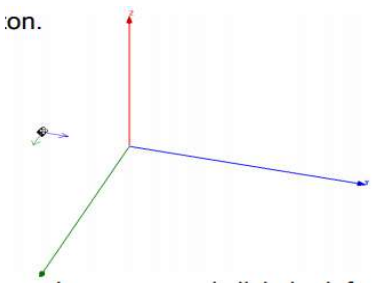
Point 3: Defines the height of the Box.



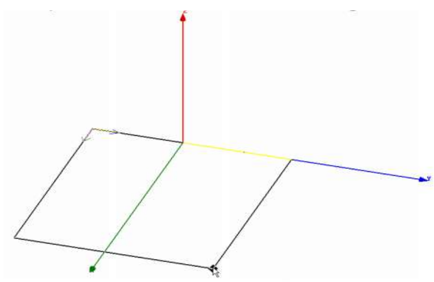
Create a Box (Continued)

1. Select the menu item 3D Modeler > Grid Plane > XY
2. Use the mouse to create the base shape

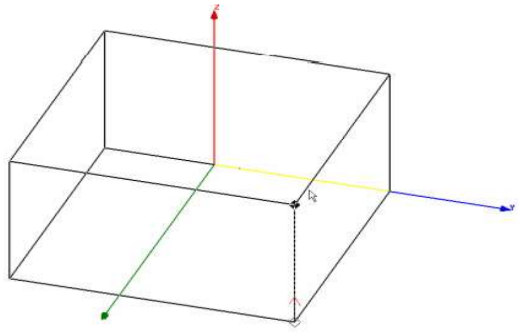
- Set the start point by positioning the active cursor and click the left mouse button



- Position the active cursor and click the left mouse button to set the second point that forms the base rectangle.



- Set the Height by positioning the active cursor and clicking left mouse button.



Object Properties

By default the Properties dialog will appear after you have finished sketching an object. The position and size of objects can be modified from the dialog. This method allows you to create objects by clicking the estimated values using the mouse and then correcting the values in the final dialog.

The Property dialog accepts equations, variables, and units. See the Overview of Entering Parameters for more detail.

Every object has two types of properties.

1. Command – Defines the structural primitive Command.
2. Attributes – Defines the material, display, and solve pr Attributes properties.

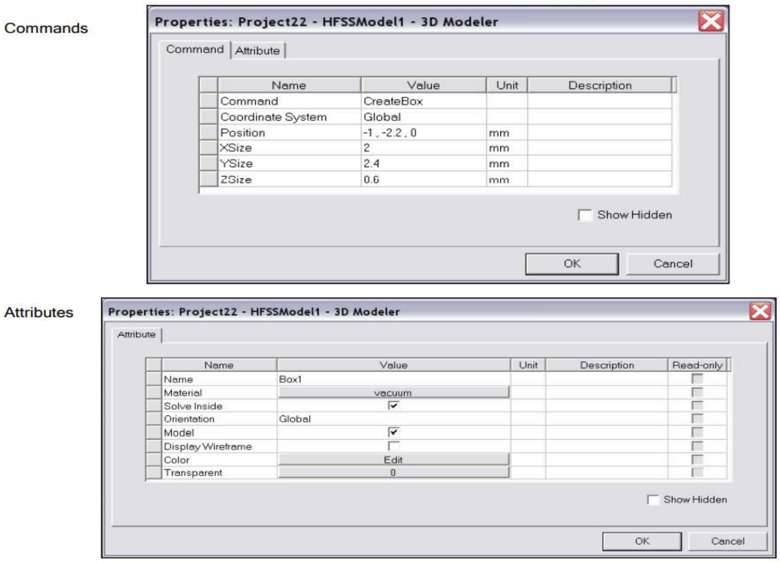


Fig 2.2 (f) shows that Commands and Attributes

Object Attributes:

An objects attributes set the following user defined properties:

Name– User defined name. Default names start with the Name e primitive type followed by an increasing number: Box1, Box2, etc.

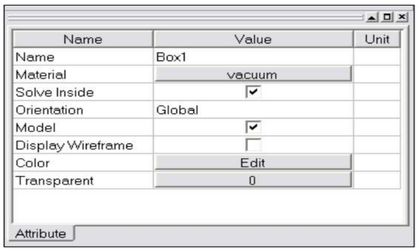
Material – User defined material property. The default Material property is vacuum. This can be changed by using the material toolbar.

Solve Inside – By default HFSS only solves for fields inside Solve Inside dielectrics. To force HFSS to solve inside conductors, check solve inside Orientation.

Model Object – Controls if the object is included in the Model Object solve.

Display Wireframe – Forces the object to always be displayed as wireframe Color – Set object color.

Transparency – Set the transparency of an object. 0–Solid, 1- Wireframe Note: Visibility is not an object property.



Materials

By clicking on the property button for the material name, the material definition window will appear. You can select from the existing database or define a custom project material.

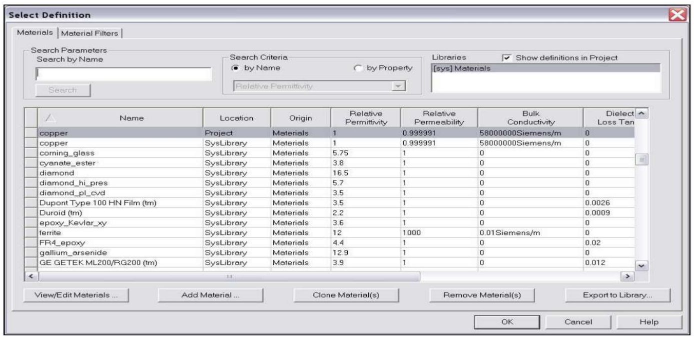


Fig 2.2(g) shows Different Types of Materials

User Defined Project Material

To define a custom material click the Add Material Add Material Add Material button from the material definition window. The following dialog will appear. Enter the material definitions and click the OK button.

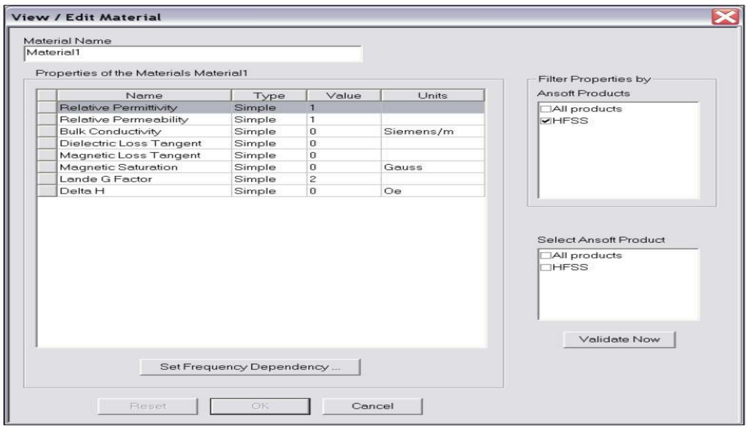


Fig 2.2(h) shows Di Electric Constants of Different Fields

2.2.5 Changing the View

You can change the view at any time (even during shape generation) by using the following commands:

Toolbar

Rotate – The structure will be rotated around the coordi Rotate nate system Pan – The structure will be translated in the graphical Pan area

Dynamic Zoom – Moving the mouse upwards will increase the Dynamic Zoom zoom factor while moving the mouse downwards will decrease the zoom factor

Zoom In/Out – In this mode a rubber band rectangle will Zoom In/Out be defined by dragging the mouse. After releasing the mouse button the zoom factor will be applied.

Context Menu

Right click in the graphics area and select the menu item View and choose from the options outlined in the Toolbar section. The context menu also offers the following:

Fit All – This will zoom the defined structure to a poin Fit All t where it fits in the drawing area

Fit Selection – This fits only the selected objects into th Fit Selection e drawing area.

Spin – Drag the mouse and release the mouse button to Spin start the object spinning. The speed of the dragging prior to releasing the mouse controls the speed of the spin.

Animate – Create or display the animation of parametric Animatic geometry

Shortcuts

Since changing the view is a frequently used operation, some useful shortcut keys exist. Press the appropriate keys and drag the mouse with the left button pressed:

ALT + Drag – Rotate

ALT + Drag In addition, there are 9 pre-defined view angles that can be selected by holding the

ALT key and double clicking on the locations shown on the next page.

Shift + Drag - Pan

ALT + Shift + Drag – Dynamic Zoom

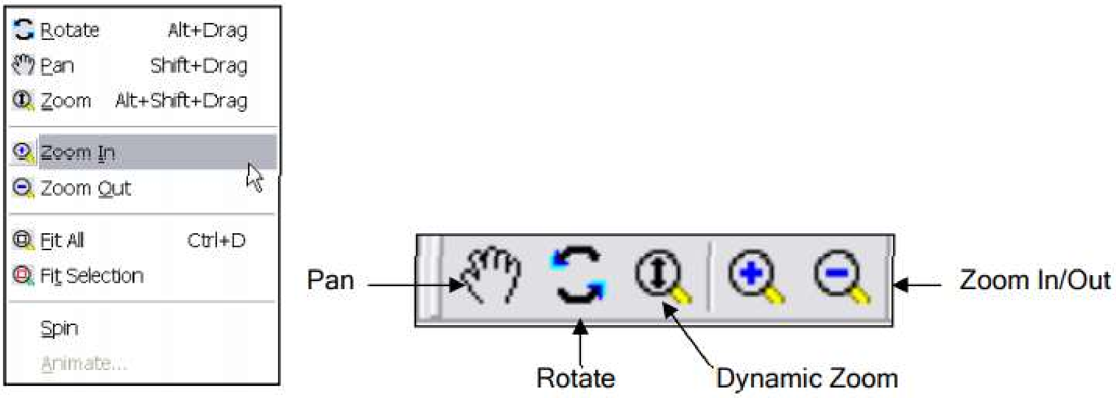


Fig 2.2(i) shows that ICONS used to Rotate and ZOOM

Combine Objects by Using Boolean Operations

Most complex structures can be reduced to combinations of simple primitives. Even the solid primitives can be reduced to simple 2D primitives that are swept along a vector or around an axis(Box is a square that is swept along a vector to give it thickness). The solid modeler supports the following Boolean operations:

Unite- combine multiple primitives

Unite disjoint objects

Separate Bodies to separate

Subtract – remove part of a primitive from another Subtract

Split – break primitives into multiple parts

Intersect– keep only the parts of primitives that overlap

Sweep – turn a 2D primitive into a solid by sweeping: Al Sweep ong a Vector, Around an Axis, Along a Path

Connect – connect 2D primitives. Use Cover Surfaces to turn Connect the connected object into a solid Section – generate 2D cross-sections of a 3D object

Most Boolean operations require a base primitive in which the Boolean operation is performed. Only the base object will be preserved. The Boolean functions provide the option to Clone objects.

Split Crossing Objects –

When a group of objects Split Crossing Objects are selected, a Boolean split is performed on ANY objects that overlap

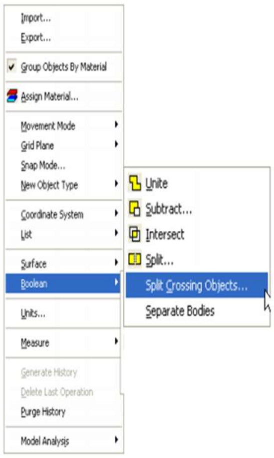


Fig 2.2(j) shows using of Boolean Operations

2.2.6 Parametric Geometry

The parametric modeler capability allows us to define variables in replace of a fixed position or size. Once this has been defined the variable can be changed by the user or by optimetrics. optimetrics can then be used to perform automatic Optimization, Parametric Sweeps, Statistical, or Sensitivity Analysis.

Defining Parameters

1)Select the command to parameterized

2) Choose the value to change

3)Enter a variable in replace of the fixed value

4)Define the variable using any combination of math functions or design variables.

5)The model will automatically be updated

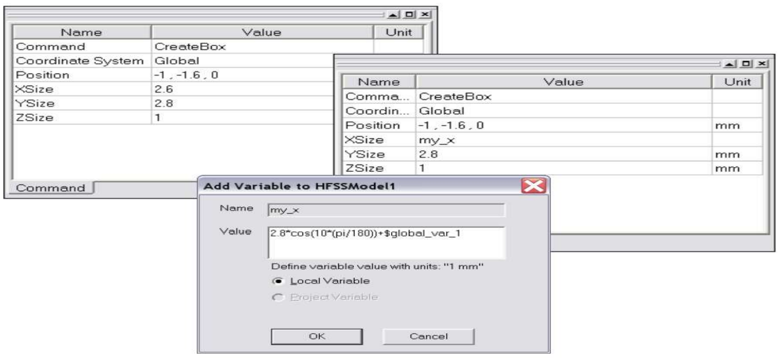


Fig 2.2(k) shows that Defining Parameters of Command

2.2.7 Boundary Conditions

• The wave equation that is solved by HFSS is derived from the differential form of Maxwell's Equations. For these expressions to be valid, it is assumed that the field vectors are single-valued, bounded, and have continuous distribution along with their derivatives. Along boundaries or sources, the fields are discontinuous and the derivatives have no meaning. Therefore boundary conditions define the field behavior across discontinuous boundaries.

• When used properly, boundary conditions can be successfully utilized to reduce the model complexity. In fact, HFSS automatically uses boundary conditions to reduce the complexity of the model. HFSS can be thought of as a virtual prototyping world for passive RF devices. Unlike the real world which is bounded by infinite space, the virtual prototyping world needs to be made finite. In order to achieve this finite space, HFSS applies a background or outer boundary condition which is applied to the region surrounding the geometric model. The model complexity usually is directly tied to the solution time and computer resources so it is a competitive advantage to utilize them whenever possible.

Common Boundary Conditions

There are three types of boundary conditions. The first two are largely the users responsibility to define them or ensure that they are defined correctly. The material boundary conditions are transparent to the user.

1. Excitations

Wave Ports(External)

Lumped Ports (Internal)

2. Surface Approximations

Symmetry Planes

Perfect Electric or Magnetic Surfaces

Radiation Surfaces

Background or Outer Surface

3. Material Properties

Boundary between two dielectrics

Finite Conductivity of a conductor

Technical Definition of Boundary Conditions

Excitation – An excitation port is a type of boundary condition Excitation that permits energy to flow into and out of a structure. See the section on Excitations.

Perfect E – Perfect E is a perfect electrical conductor, also Perfect E referred to as a perfect conductor. This type of boundary forces the electric field (E-Field) perpendicular to the surface. There are also two automatic Perfect E assignments: Any object surface that touches the background is automatically defined to be a Perfect E boundary and given the boundary condition name outer. Any object that is assigned the material pec (Perfect Electric Conductor) is automatically assigned the boundary condition Perfect E to its surface and given the boundary condition names metal.

Perfect H – Perfect H is a perfect magnetic conductor. For Perfect H and E-Field tangential to the surface.

Natural – for a Perfect H boundary that overlaps with a Natural perfect E boundary, this reverts the selected area to its original material, erasing the Perfect E boundary condition. It does not affect any material assignments. It can be used, for example, to model a cut-out in a ground plane for a coax feed.

Finite Conductivity –A Finite Conductivity boundary enable Finite Conductivity s you to define the surface of an object as a lossy (imperfect) conductor. It is an imperfect E boundary condition, and is analogous to the lossy metal material definition. To model a lossy surface, you provide loss in Siemens/meter and permeability parameters. Loss is calculated as a function of frequency. It is only valid for good conductors.

2.2.8 Adding a Solution Setup

In order to perform an Analysis in HFSS a Solution Setup must be added. To do this, right click on Analysis in the HFSS model tree.

By default, the General Tab will be displayed. The Solution Frequency and the Convergence Criteria are set here.

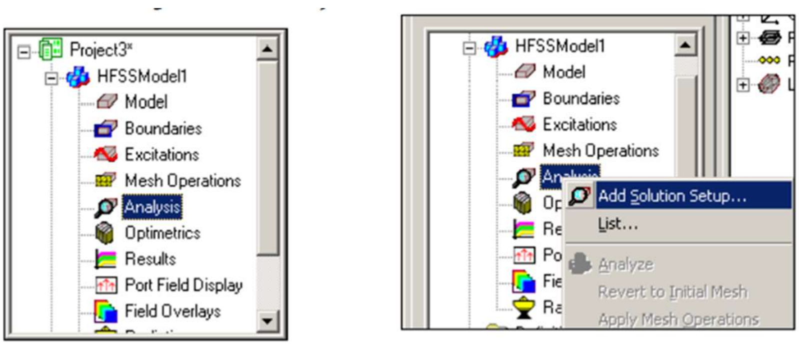


Fig 2.2(l) shows that Adding a Solution Setup

Enabling/Disabling a Solution Setup

When adding a new solution setup,by default, it will be enabled. To disable any setups, right click on the setup and remove the check mark next to Enable by left clicking once. Once a solution is disables, it will be grayed out in the project tree. To enable a disabled project, right click on the disabled setup and place a check mark next to Enable by left clicking once.

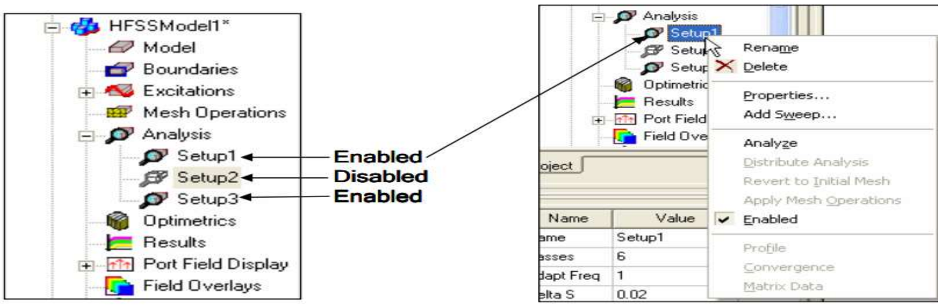


Fig 2.2(m) Shows that Enabling and Disabling of Solution Setup

General Tab

Solution Frequency – This frequency point is used by the adaptive mesher – to automatically refine the mesh to electrical performance of the device.

Solve Ports Only - The Port Solution uses an arbitrary, adaptive 2D eigenmode solver to determine the natural frequencies or modes that will be used to excite the structure. The ports only solution can be used to calculate only the modal field patterns for the 2D cross sections defined to be ports. This is useful for determining the number of modes, modal fields, the port length, and/or proper port setup prior to running a full solution.

Adaptive Solutions

Maximum Number of Passes - This number controls the maximum number of passes the adaptive mesh routine will perform as it attempts to satisfy the convergence criteria.

Maximum Delta S Per Pass – This number defines the convergence criteria for the adaptive meshing process.

Options Tab

Initial Mesh Options

Lambda Refinement - The Initial Mesh is based only on the 3D solid model, it has no bearing on the electrical performance of the device to be simulated. The Lambda Refinement process refines the Initial Mesh until most mesh element lengths are approximately onequarter wavelength for air and one-third wavelength for dielectrics. A wavelength is based on the Single

Frequency value entered in the Solution Frequency. In almost all cases Lambda Refineme Solution Frequency should be used.

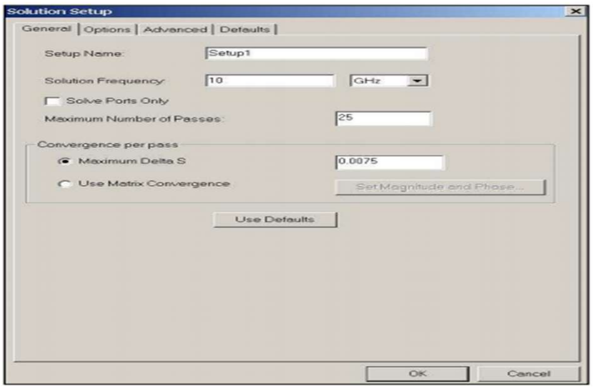


Fig 2.2(n) shows that Solution Setup for Adaptive Solution

Use Free Space Lambda – This will force the lambda refinement to target a mesh size approximately one-quarter of a wavelength for air. The material properties of objects will be ignored. This may be useful in applications that have dielectrics with very high conductivities. Brain tissue or salt water are examples of materials that will produce very high mesh counts even though the RF penetration into the material will be limited to a region very close to the surface

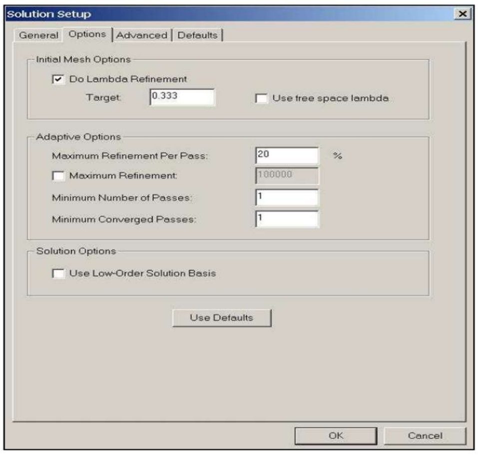


Fig 2.2(o) Shows that options in Solution setup

Options Tab

Adaptive Options

Refinement Per Pass -The mesh growth for each adaptive pass is controlled by the Refinement Per Pass. The Refinement Per Pass is a percentage. This ensures that between each pass the mesh is sufficiently perturbed and guarantees that you will not receive false convergences.

Minimum Number of Passes - An adaptive analysis will not stop unless the minimum number of passes you specify has been completed, even if convergence criteria have been met

Minimum Converged Passes - An adaptive analysis will not stop unless the minimum number of converged passes you specify has been completed. The convergence criteria must be met for at least this number of passes before the adaptive analysis will stop.

Use Matrix Convergence - Use Matrix Convergence - You can specify different stopping criteria for specific entries in the S-matrix. This is done by checking the Use Matrix Convergence box. The adaptive analysis will continue Matrix Convergence e until the magnitude and phase of the entries change by an amount less than the specified criteria from one pass to the next, or until the number of requested passes is completed.

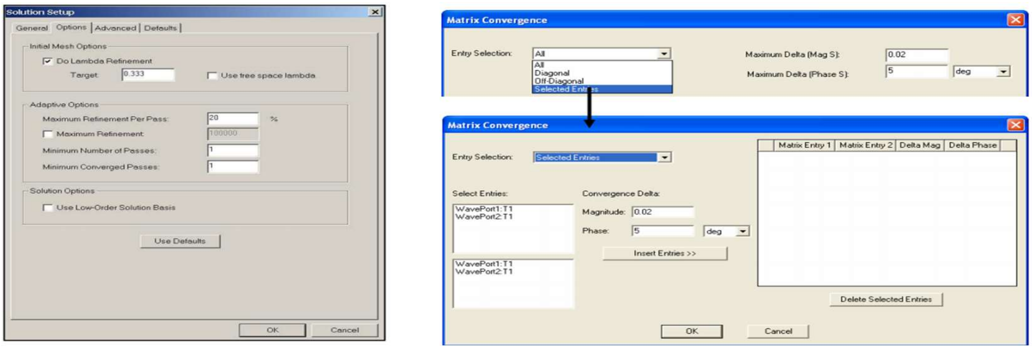


Fig 2.2(p) shows that Solution setup and Matrix Convergence

2.2.9 Frequency Sweeps

Using the converged mesh or initial mesh if no adaptive passes were requested, the swept frequency response of the device can be obtained. HFSS provides several methods for calculating the frequency response:

Discrete – performs a full solution at every frequency using the current mesh. The time required is the single frequency solve times the number of frequency points. Fields can be displayed at any frequency within the sweep range if the Save Fields Box is checked.

Fast – uses an Adaptive Sweep(ALPS) based solver to extrapolate an entire bandwidth of solution information from the center frequency. Very good for high-Q devices but it can not be used to solve for devices that pass through cut-off. Once the band has been extrapolated, a high number of frequency points can be calculated without a penalty. In addition, the Fields can be displayed at any frequency within the sweep range. The time and memory required to solve a fast frequency sweep may be much larger then the single frequency solve.

Interpolating – performs solves at discrete frequency points that are fit by interpolating. HFSS determines the frequency points to solve at based on the error in the interpolation between consecutive passes. The interpolation error and maximum number of points is defined by the user in the Edit Sweep. Edit Sweep. Edit Sweep. As with the fast frequency sweep, the Interpolating Sweep can generate a larger number of frequency points. But you only have the field solution for the last solved frequency. The maximum solution time is the single frequency solve times the maximum number of points

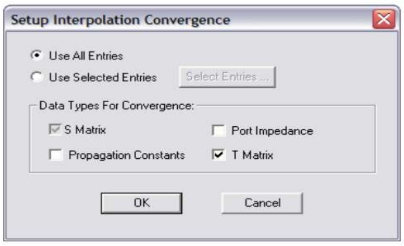


Fig 2.2 (q) shows that Setup Interpolation Convergence

Add Sweep after a Solution Setup has been added you can also add a Frequency Sweep. To do this, right-click on Setup in the HFSS Model Tree. The Edit Sweep window will appear

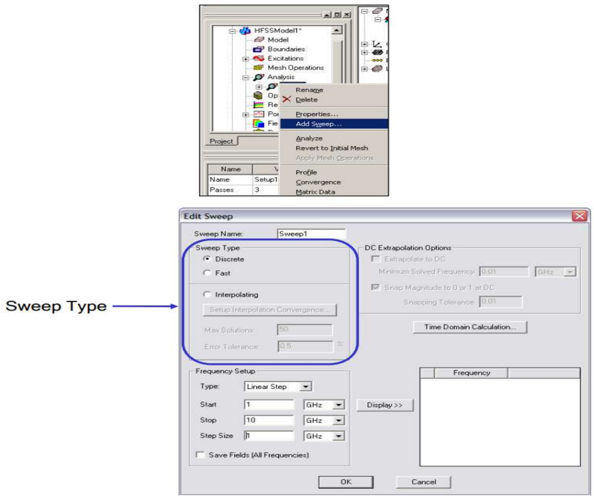


Fig 2.2 (r) shows that Setup in the HFSS Model Tree and Edit Sweep

Add Sweep (Continued) Frequency Setup After the sweep type has been chosen, the frequencies of interest must be specified.

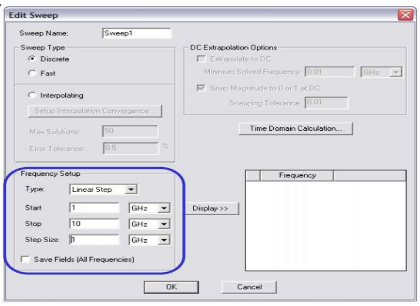


Fig 2.2 (s) shows that Edit Sweep and Frequency Setup

There are three Frequency Setup Options:
Linear Step -- specify a linear range of values with a constant step size

Linear Count -- specify a linear range of values and the number, or count, of points within the variable range

Single Points -- specify a single values for the sweep definition

Saving Fields: It is possible to save the Field data for every point in the Fast Sweep and the Discrete Sweep. To save the Field information make sure that the Save Fields (All Frequencies) box is checked. For the Interpolation Sweep, only the Field data for the last solved frequency will be available for post-processing.

DC Extrapolation Options: When exporting Spice subcircuits it is necessary to include the DC point. Since HFSS does not solve down to DC we can use DC Extrapolation. The DC Extrapolation option is available in the Discrete and Interpolating Sweeps.

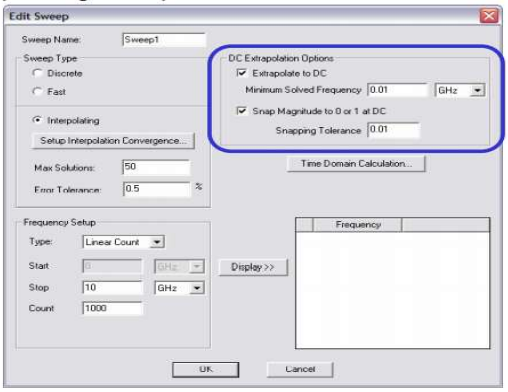


Fig 2.2 (t) shows that DC Extrapolation options in Edit Sweep

Time Domain Calculation: HFSS can calculate the maximum frequency required to obtain an accurate time domain result. HFSS uses the following equation:

Max. Freq. = (0.5/Signal Rise Time) x Time Steps Per Rise Time

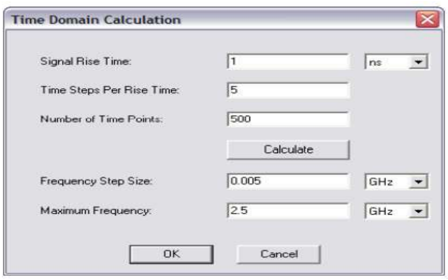


Fig 2.2.10(u) shows Time Domain Calculation

2.2.10 Plotting Data

Data plotting can take a variety of forms. The most often used format is 2D Cartesian plotting, but we also have the capability to plot in 3D as well. Below is a list of all the quantities that can be plotted on various graphs.

To Create a Plot:

1. Select HFSS > Results > Create Report
2. Select Report Type and Display Type from the selections above
3. Click OK and the Report Editor will be displayed – we will go over the options in this dialog on the next page.

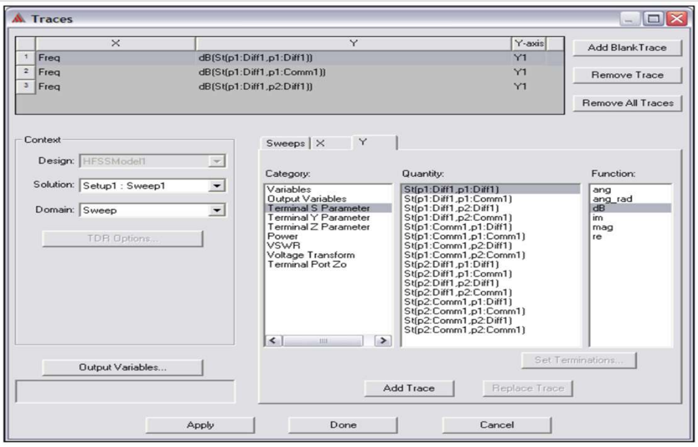


Fig 2.2 (v) shows that Plotting different types of Solution

4.Design – choose from available designs within a project Design

Sweep – choose from available sweeps including adaptives passes and imported data

Domain – defaults to Sweep, but can be switched to Time Domain domain for plotting S-parameters with an impulse or step response.

5. Sweep / X / Y Tabs

Sweep – controls the source of the independent variable Sweep in the plot.

X – controls any functional operator on the independent variable

Y – select the value to be plotted and any operator

6. Select Add Trace Add Trace Add Trace for as many values as you would like to plot

7. Select Done when finished

An example of a multi-trace plot of the sweep tab shown on the previous page is shown next.

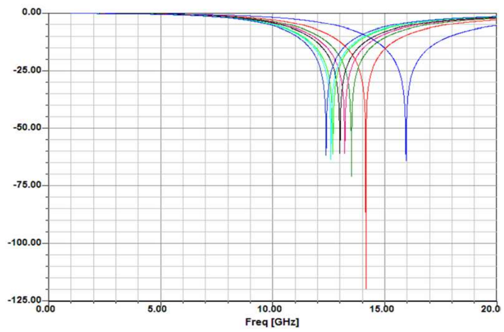


Fig 2.2 (w) shows that Plotting the Data between Gain vs Frequency

3D Plots – simply add a third dimension such that instead of plotting a family of curves, you can plot a 3D surface that represents your data changing with two independent variables. Below is a 3D plot of the previous family of curves.

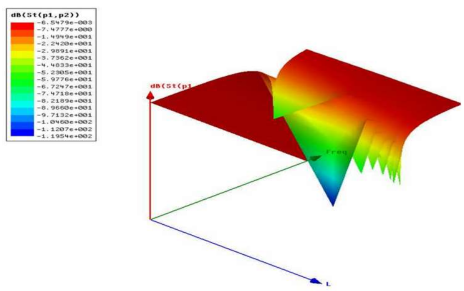
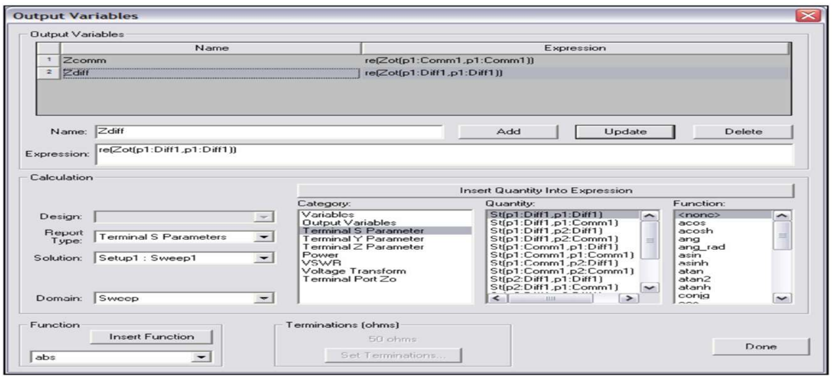


Fig 2.2 (x) shows that Family of Curves

Output Variables: In addition to being able to plot the built-in solved quantities, you can also create your own by using output variables. Clicking on the Output Variables button in the Traces dialog shown before, brings up the following dialog:



Data Plotting – Special Case – Antenna Parameters

Since antenna parameters require a special computation setup to determine the region over which the fields are to be computed, displaying antenna parameters is a two step process.

Create an Infinite Sphere setup:

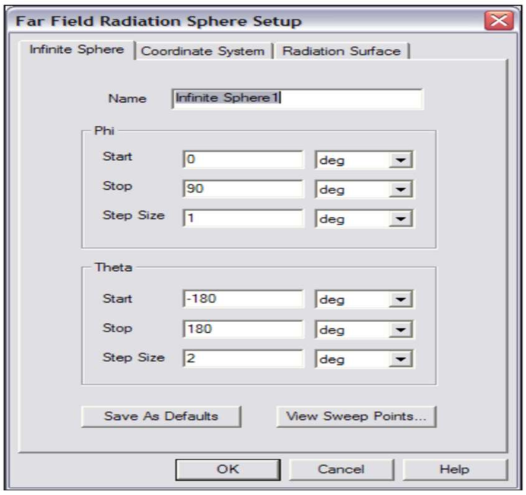
1.Select HFSS > Radiation > Insert Far Field Setup > Infinite Sphere

2. Enter the values and steps for Theta and Phi

3. You can also change the coordinate system to calculate based upon a shifted or rotated coordinate system. Select the Coordinate System Coordinate System tab, ate System and switch to the new CS.

4. You can also change the Radiation Surface over which the far fields are computed by simply switching to the Radiation Surface Radiation Surface Radiation Surface tab, and select a new surface from any that were previously defined.

5. Click OK



Creating a 2D plot:

1. Select HFSS > Results > Create Report

2. Select Far Field Far Field Far Field form the Report Type Report Type Report Type pull down

3. Select Radiation Pattern Radiation Pattern Radiation Pattern from the Display Type Display Type Display Type pull down

4. Select the quantity to be plotted from the Traces dialog Note: If multiple Infinite Sphere setups exist, make sure you select the appropriate one

5. Select Add Trace Add Trace Add Trace and Done For a definition of the available antenna parameters, see the online help Below is an example of the 2D slices of a patch antenna for LHCP and RHCP directivity.

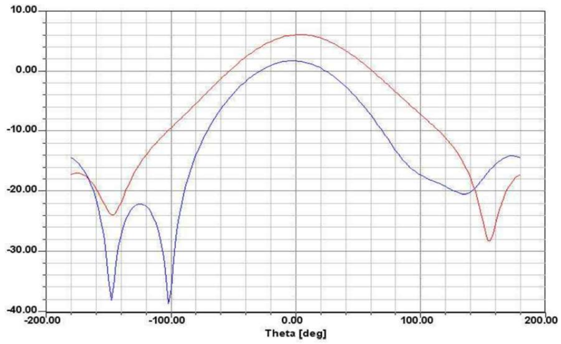


Fig 2.2 (y) shows that Data Plotting Antenna Parameters

Creating a 3D Plot: Follow the procedures above for the 3D plot, except change the Phi and Theta quantities to match the far field calculation. A Theta lso choose an antenna quantity to plot.Below is an example of a 3D plot for a patch antenna:

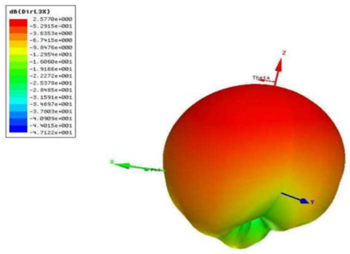


Fig 2.2 (z) shows that 3D Plot for Patch Antenna

When using master and slave boundary condition pairs to emulate an antenna array, you might want to apply an array factor to the computation of the antenna patterns. This can easily be done in HFSS

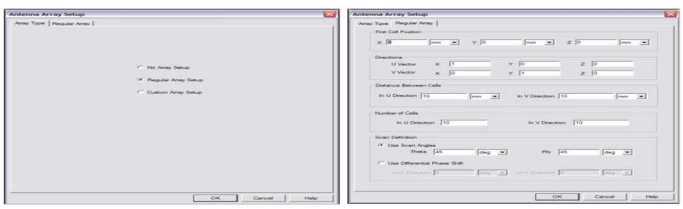
To create an Antenna Array Factor calculation:

1. Select HFSS > Radiation > Antenna Array Setup

2. Select No Regular, or Custom Array Custom Array

3. Switch to the next tab, and enter the characteristics of the array, or enter the filename that contains the element locations

4. Once you click OK, any plots or calculations that are displayed will be updated with the array factor calculation. To go back to the single element calculations, select No Array Setup.



2.3 HFSS Applications

Planar Antennas - Patches, Dipoles, Horns, Conformal Cell Phone Antennas, Spirals

Waveguide – Circular/Square Horns

Wire – Dipole, Helix

Arrays - Infinite Arrays, Frequency Selective Surfaces (FSS) & Photonic Band Gaps (PBG)

Radar Cross Section (RCS)

Microwave

Filters – Cavity Filters, Microstrip, Dielectric

EMC/EMI – Shield Enclosures, Coupling, Near- or Far-Field Radiation

Connectors – Coax, SFP/XFP, Backplane, Transitions

Waveguide – Filters, Resonators, Transitions, Couplers

Silicon/GaSa - Spiral Inductors, Transformers

Signal Integrity/High-Speed Digital

Package Modeling – BGA, QFP, Flip-Chip

PCB Board Modeling – Power/Ground planes, Mesh Grid Grounds, Backplanes

Connectors – SFP/XFP, VHDM, GBX, Nex Lev, Coax

Transitions – Differential/Single-ended Vias

2.4 Advantages

A key benefit of HFSS is its automatic adaptive meshing techniques, which require you to specify only geometry, material properties and the desired output.

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

HFSS pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/ implementing technologies such as tangential vector finite elements, adaptive meshing.

HFSS has evolved over a period of years with input from many users and industries. In industry, HFSS is the tool of choice for High productivity research, development, and virtual prototyping.

2.5 Conclusion

Hence, by using HFSS software we can design any type of Antenna according to our project . So that we can calculate Bandwidth, Gain, Return loss, Mutual coupling, S-Parameters and many other factors which gives best outcome through HFSS. In HFSS through ICONS we can design and Plot the Data in order to see the Outputs of Antennas. HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high-frequency electronic products such as antennas, antenna arrays, RF or microwave components, high-speed interconnects, filters, connectors, IC packages and printed circuit boards. In our project HFSS software has been used to design a MIMO patch model; the significant amount of frequency is achieved, where the patch antennas exhibit large electromagnetic signatures at certain frequencies outside the operating band. Therefore the work can be enhanced and in future we can implement the MIMO design to fields concentrating on military and unmanned vehicles.

CHAPTER-3

UWB MIMO Antenna

3.1 Introduction to the designs of the antenna

In this units we are going to discuss about the different types of designs we used and what is the reason behind going for the next design, what are the drawbacks of design1 compared to design2 and also technology which we need to use for our required design output and the application for which the antenna is designed for.The next sub section of this unit will discuss about the MIMO Technology that is MULTIPLE INPUT MULTIPLE OUTPUT . here we are going to know about ,What is the brief history and development of this MIMO, The principle on which the MIMO will works that is the basic two diversities MIMO uses for communication, About different MIMO terminologies like SISO, SIMO, MISO and also about MIMO beamforming smart antennas. Up next about the what are the CHALLENGES OF ULTRA WIDE BAND(UWB) ANTENNA DESIGN, Introduction to UWB Technology, the characteristics of ultra wide band and also about the working of it.

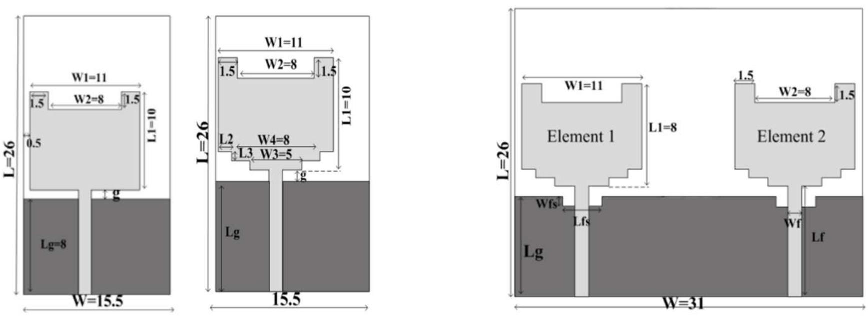


Fig:3.1(a) Single antenna element(design-1) Fig:3.1(b) Multi element antenna (design-2)

The designing of our required antenna, in this unit initially we will design single element antenna using HFSS software and check our results through simulating the designed antenna model, after considering the result values like gain , bandwidth and return loss of the antenna, we will go for the design 2 if the results will not match for the uwb range i.e the bandwidth of our antenna must be in the range of uwb range, f not then we will go for design of multi element antenna using HFSS , by going for multi element the gain and the required bandwidth will changes. The designing process will have different steps for the two antenna designs and finally we will conclude this unit by comparing the results of both the designs we developed in the HFSS software.

3.2 MIMO: Multiple Input Multiple Output

Multiple Input Multiple Output technology uses multiple antennas to make use of reflected signals to provide gains in channel robustness and throughput.

Multiple-input multiple-output, or MIMO, is a radio communications technology or RF technology that is being mentioned and used in many new technologies these days.

Wi-Fi, LTE; Long Term Evolution, and many other radio, wireless and RF technologies are using the new MIMO wireless technology to provide increased link capacity and spectral efficiency combined with improved link reliability using what were previously seen as interference paths.

Even now many there are many MIMO wireless routers on the market, and as this RF technology is becoming more widespread, more MIMO routers and other items of wireless MIMO equipment will be seen. As the technology is complex many engineers are asking what is MIMO and how does it work**.**

3.2.1 MIMO development and history

MIMO technology has been developed over many years. Not only did the basic MIMO concepts need to be formulated, but in addition to this, new technologies needed to be developed to enable MIMO to be fully implemented. New levels of processing were needed to allow some of the features of spatial multiplexing as well as to utilise some of the gains of spatial diversity.

Up until the 1990s, spatial diversity was often limited to systems that switched between two antennas or combined the signals to provide the best signal. Also various forms of beam switching were implemented, but in view of the levels of processing involved and the degrees of processing available, the systems were generally relatively limited. However with the additional levels of processing power that started to become available, it was possible to utilise both spatial diversity and full spatial multiplexing. The initial work on MIMO systems focussed on basic spatial diversity - here the MIMO system was used to limit the degradation caused by multipath propagation. However this was only the first step as system then started to utilise the multipath propagation to advantage, turning the additional signal paths into what might effectively be considered as additional channels to carry additional data.

Two researchers: Arogyaswami Paulraj and Thomas Kailath were first to propose the use of spatial multiplexing using MIMO in 1993 and in the following year their US patent was granted. However it fell to Bell Labs to be the first to demonstrate a laboratory prototype of spatial multiplexing in 1998.

3.2.2 MIMO -Multiple Input Multiple Output basics

A channel may be affected by fading and this will impact the signal to noise ratio. In turn this will impact the error rate, assuming digital data is being transmitted. The principle of diversity is to provide the receiver with multiple versions of the same signal. If these can be made to be affected in different ways by the signal path, the probability that they will all be affected at the same time is considerably reduced. Accordingly, diversity helps to stabilise a link and improves performance, reducing error rate.

Several different diversity modes are available and provide a number of advantages:

- **Time diversity*:*** Using time diversity, a message may be transmitted at different times, e.g. using different timeslots and channel coding.
- **Frequency diversity:** This form of diversity uses different frequencies. It may be in the form of using different channels, or technologies such as spread spectrum / OFDM.
- **Space diversity :** Space diversity used in the broadest sense of the definition is used as the basis for MIMO. It uses antennas located in different positions to take advantage of the different radio paths that exist in a typical terrestrial environment.

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.

One of the core ideas behind MIMO wireless systems space-time signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas, i.e. the use of multiple antennas located at different points. Accordingly MIMO wireless systems can be viewed as a logical extension to the smart antennas that have been used for many years to improve wireless.

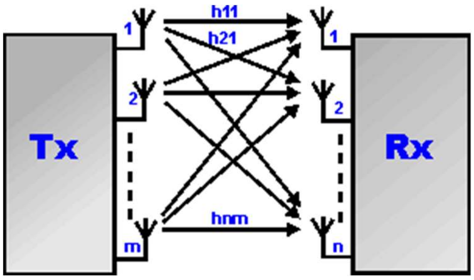


Fig 3.2(a): General outline of MIMO System.

It is found between a transmitter and a receiver, the signal can take many paths. Additionally by moving the antennas even a small distance the paths used will change. The variety of paths available occurs as a result of the number of objects that appear to the side or even in the direct path between the transmitter and receiver. Previously these multiple paths only served to introduce interference. By using MIMO, these additional paths can be used to advantage. They can be used to provide additional robustness to the radio link by improving the signal to noise ratio, or by increasing the link data capacity.

The two main formats for MIMO are given below:

- **Spatial diversity:** Spatial diversity used in this narrower sense often refers to transmit and receive diversity. These two methodologies are used to provide improvements in the signal to noise ratio and they are characterised by improving the reliability of the system with respect to the various forms of fading.
- **Spatial multiplexing :** This form of MIMO is used to provide additional data capacity by utilising the different paths to carry additional traffic, i.e. increasing the data throughput capability.

As a result of the use multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel while still obeying Shannon's law. By increasing the number of receive and transmit antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. This makes MIMO wireless technology one of the most important wireless techniques to be employed in recent years. As spectral bandwidth is becoming an ever more valuable commodity for radio communications systems, techniques are needed to use the available bandwidth more effectively. MIMO wireless technology is one of these techniques.

There is a number of different MIMO configurations or formats that can be used. These are termed SISO, SIMO, MISO and MIMO. These different MIMO formats offer different advantages and disadvantages - these can be balanced to provide the optimum solution for any given application. The different MIMO formats - SISO, SIMO, MISO and MIMO require different numbers of antennas as well as having different levels of complexity. Also dependent upon the format, processing may be needed at one end of the link or the other - this can have an impact on any decisions made.

3.2.3 SISO, SIMO, MISO, MIMO terminology:

The different forms of antenna technology refer to single or multiple inputs and outputs. These are related to the radio link. In this way the input is the transmitter as it transmits into the link or signal path, and the output is the receiver. It is at the output of the wireless link.

therefore the different forms of single / multiple antenna links are defined as below:

- SISO - Single Input Single Output
- SIMO - Single Input Multiple output
- MISO - Multiple Input Single Output
- MIMO - Multiple Input multiple Output

The term MU-MIMO is also used for a multiple user version of MIMO as described below.

MIMO – SISO:

The simplest form of radio link can be defined in MIMO terms as **SISO - Single Input Single Output**. This is effectively a standard radio channel - this transmitter operates with one antenna as does the receiver. There is no diversity and no additional processing required.
The advantage of a SIS system is its simplicity. SISO requires no processing in terms of the various forms of diversity that may be used. However the SISO channel is limited in its performance. Interference and fading will impact the system more than a MIMO system using some form of diversity, and the channel bandwidth is limited by Shannon's law - the throughput being dependent upon the channel bandwidth and the signal to noise ratio.

Fig:3.2(b): SISO - Single Input Single Output

MIMO – SIMO:

The SIMO or **Single Input Multiple Output** version of MIMO occurs where the transmitter has a single antenna and the receiver has multiple antennas. This is also known as receive diversity. It is often used to enable a receiver system that receives signals from a number of independent sources to combat the effects of fading. It has been used for many years with short wave listening / receiving stations to combat the effects of ionospheric fading and interference.

Fig:3.2(c): Single Input Multiple Output

SIMO has the advantage that it is relatively easy to implement although it does have some disadvantages in that the processing is required in the receiver. The use of SIMO may be quite acceptable in many applications, but where the receiver is located in a mobile device such as a cellphone handset, the levels of processing may be limited by size, cost and battery drain.

There are two forms of SIMO that can be used:

- ***Switched diversity SIMO:*** This form of SIMO looks for the strongest signal and switches to that antenna.
- ***Maximum ratio combining SIMO:*** This form of SIMO takes both signals and sums them to give the a combination. In this way, the signals from both antennas contribute to the overall signal.

MIMO – MISO:

MISO is also termed transmit diversity. In this case, the same data is transmitted redundantly from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to receive extract the required data.

Fig:3.2(d): Multiple Input Single Output

The advantage of using MISO is that the multiple antennas and the redundancy coding / processing is moved from the receiver to the transmitter. In instances such as cellphone UEs, this can be a significant advantage in terms of space for the antennas and reducing the level of processing required in the receiver for the redundancy coding. This has a positive impact on size, cost and battery life as the lower level of processing requires less battery consumption.

MIMO:

Where there are more than one antenna at either end of the radio link, this is termed MIMO - Multiple Input Multiple Output. MIMO can be used to provide improvements in both channel robustness as well as channel throughput.

Fig:3.2(e): Multiple Input Multiple Output

In order to be able to benefit from MIMO fully it is necessary to be able to utilise coding on the channels to separate the data from the different paths. This requires processing, but provides additional channel robustness / data throughput capacity.There are many formats of MIMO that can be used from SISO, through SIMO and MISO to the full MIMO systems. These are all able to provide significant improvements of performance, but generally at the cost of additional processing and the number of antennas used. Balances of performance against costs, size, processing available and the resulting battery life need to be made when choosing the correct option.

3.2.4 MIMO antenna & MIMO beamforming development:

For many years antenna technology has been used to improve the performance of systems. Directive antennas have been used for very many years to improve signal levels and reduce interference. Directive antenna systems have, for example, been used to improve the capacity of cellular telecommunications systems. By splitting a cell site into sector where each antenna illuminates

60° or 120° the capacity can be greatly increased - tripled when using 120° antennas. With the development of more adaptive systems and greater levels of processing power, it is possible to utilise antenna beamforming techniques with systems such as MIMO.

MIMO beamforming smart antennas:

Beamforming techniques can be used with any antenna system - not just on MIMO systems. They are used to create a certain required antenna directive pattern to give the required performance under the given conditions. Smart antennas are normally used - these are antennas that can be controlled automatically according the required performance and the prevailing conditions.

Smart antennas can be divided into two groups:

- ***Phased array systems:*** Phased array systems are switched and have a number of pre-defined patterns - the required one being switched according to the direction required.
- ***Adaptive array systems (AAS):*** This type of antenna uses what is termed adaptive beamforming and it has an infinite number of patterns and can be adjusted to the requirements in real time.

MIMO beamforming using phased array systems requires the overall system to determine the direction of arrival of the incoming signal and then switch in the most appropriate beam. This is something of a compromise because the fixed beam is unlikely to exactly match the required direction.Adaptive array systems are able to direct the beam in the exact direction needed, and also move the beam in real time - this is a particular advantage for moving systems - a factor that often happens with mobile telecommunications. However the cost is the considerable extra complexity required.

3.3 Challenges of Ultra-Wide Band (UWB) Antenna Design

The prospective of Ultra-Wide Band (UWB) technology is enormous due to its remarkable advantages such as the capability of providing high speed data rates at short transmission distances with low power dissipation. The swift growth in wireless communication systems has made UWB an exceptional technology to replace the conventional wireless technologies in today's use like Bluetooth and wireless LANs, etc. A lot of research has been done to develop UWB LNAs, mixers and entire frontends but not that much to develop UWB antennas. Recently, academic and industrial communities have realized the tradeoffs between antenna design and transceiver complexity. In general, the transceiver complexity has been increased, with the introduction of advanced wireless transmission techniques. In order to enhance the performance of transceiver without sacrificing its costly architecture, advanced antenna design should be used as the antenna is an integral part of the transceiver. Also,the complexity of the overall transceiver is reduced. The UWB technology provides the real wireless freedom with existing long range radio technologies such as Wi-Fi, worldwide interoperability for microwave access (Wi MAX), wireless local area network (WLAN), and cellular wide area communications by replacing short wired links. UWB offers the desirable cost-effective, power-efficient, high bandwidth solution for transmitting multiple digital video and audio streams data among the short range devices. The hardest challenge in designing a UWB antenna is to attain wide impedance bandwidth with high radiation efficiency. The concurrent surge of wirelessdevices, with high level of miniaturization and high frequency of operation, has enhanced the interest in designing high performance antenna types. Therefore, there is a growing demand for small and low cost UWB antennas that are able to provide satisfactory performance in both time and frequency domains. The trend in recent wireless systems, including UWB based systems, are to build small, low-profile integrated circuits so as to be compatible with portable wireless devices. Also, the size affects the gain and bandwidth. Therefore, the size of the antenna is considered as one of the critical issues in UWB system design. Recently, there is a demand to increase the data rate of existing wireless communication systems. One major challenge is to achieve the desired performance at adequate transmission range using limited transmitted power . Another challenge is to design UWB waveform that efficiently utilizes the bandwidth and power allowed by the FCC spectral mask. Moreover, to ensure that the transmitted power level satisfies the spectral mask, adequate characterization and optimization of transmission techniques (e.g., adaptive power control, duty cycle optimization) may be required.

3.3.1 Introduction To Ultra Wide Band Technology:

The word ‘Ultra wide band (UWB) commonly refers to signals or systems that either have a large relative, or a large absolute bandwidth. The frequency bandwidth of an antenna can be expressed in terms of either the absolute bandwidth (ABW) or the fractional bandwidth (FBW). Assuming that the antenna bandwidth has a lower edge frequency of fL, an upper edge frequency of fU and a center frequency of fC. The ABW is defined as the difference between the upper and the lower edge frequencies of operation while the FBW can be defined as the percentage of the ratio between the absolute bandwidth and the center frequency as given in Eq. (1-1) and Eq. (1-2), respectively:

ABW= f　　　　Eq. (1-1)

$$FBW=\frac{ABW}{fc} = \left(\frac{fu-fl}{fc}\right) * 100$$ Eq. (1-2)

Where $fc = \frac{fu+fl}{2}$

Another definition for the bandwidth in case of broadband antennas which is the ratio of the upper edge frequency fu to the lower edge frequency fl, as given in Eq. (1-3):

$$BW=\frac{fu}{fl}$$ Eq. (1-3)

By large absolute bandwidth we usually refer to a system with more than 500 MHz bandwidth, in accordance with the FCC definition of UWB radiation such a large bandwidth offers specific advantages with respect to signal robustness, information content and/or implementation simplicity, but lead to fundamental differences from conventional, narrowband systems. Difference between the conventional narrowband system and the ultra-wide band system is the conventional NB radio systems use NB signals which are sinusoidal waveforms with a very narrow frequency spectrum in both transmission and reception. While an Ultra-wideband radio system can transmit and receive very short duration pulses. These pulses are considered UWB signals because they have very narrow time duration with very large instantaneous bandwidth starting from 500 MHz up to 7.5 GHz M.-G. di Benedetto et al(2006); B.Allen et al.(2006) .Figure 1.1 shows the time and frequency behavior for conventional narrowband versus UWB communication

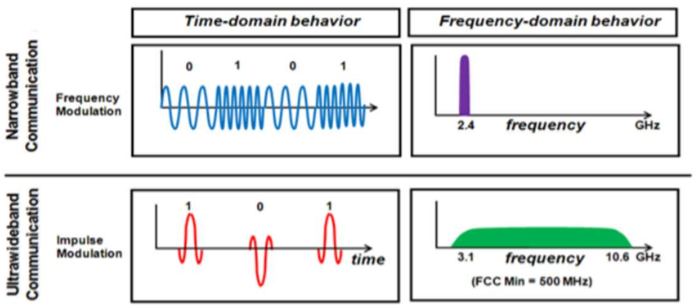


Fig:3.3 (a): Time- and frequency-domain behaviors for conventional narrowband versus UWB communications

The most common short duration pulses used in the UWB system is the Gaussian doublet because its shape and size can be easily generated, they are often characterized as multipath immune or multipath resistant. The power consumption or the maximum power available to the antenna as a part of UWB system is of the order of 0.5mW because of the spreading of the energy of the UWB signals over a large frequency band, according to the FCC spectral mask shown in Figure 3.3.1. The effective isotropic radiated power (EIRP) is an important feature of radar and communication transmitter R. J. Mailloux (2005), which can be defined as the product of its gain and input power.

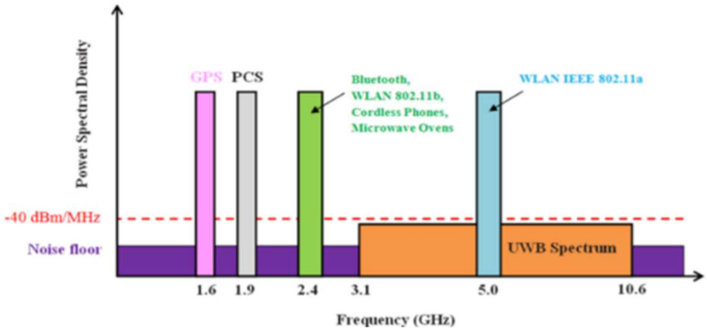


Fig:3.3 (b): UWB versus other radio communication systems

Figure 3.3.1.1 shows the FCC spectral mask of the indoor UWB EIRP emission level. It can be seen that the maximum signal power is limited to −41.3 dBm per MHz throughout the whole UWB frequency range from 3.1 to 10.6 GHz. All the UWB systems and devices must work within this spectral mask for legal operation in order to comply with the FCC standards and regulations.

The below figure illustrates the spectral mask for indoor UWB systems. According to the spectral mask, the PSD of UWB signal measured in 1 MHz bandwidth must not exceed -41.3 dBm, which complies with the Part 15 general emission limits to successfully control radio interference. For particularly sensitive bands, such as the

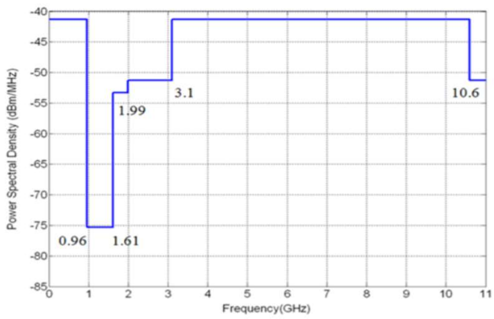


Fig:3.3 (c): FCC spectral mask for indoor UWB systems

3.3.2 Characteristics of UWB:

UWB is a new technology, which has substantial development potential in elementary areas like Communication, Automotive, Localization services, Security, Imaging and sensors. The growing number of media-intensive devices in the wireless personal area networks (WPANs) such as PCs, digital camcorders, digital cameras, high-definition TVs (HDTVs), gaming systems as well as the office devices such as Cordless connection to peripherals, Notebook, printer, PDA, fax machine, mouse, keyboard need a high bandwidth wireless solution for easy connection and media exchange. UWB radio is predicted as one of the most promising technologies for above mention applications, due to its several advantages such as:

- **High Bandwidth**: According to the FCC definition of UWB system, any transmitting system, which transmits signals in a bandwidth greater than 500 MHz or 20% bandwidth. UWB technology works in the bandwidth range of 3.1 GHz to 10.6 GHz.
- **Low power spectral density**: The main reason of the UWB technology to coexist without causing interference to other services such as GPS, WLAN, WiMAX, Wi-Fi and cellular network system is low power spectral density .
- **Low Cost**: UWB technology did not required any carrier signal for transmission. Also, there is no need for a Radio Frequency (RF) converter or modulator. Hence, transmitters and receivers are simpler and easier to design and implement at low cost.
- **Low Power Consumption**: UWB technology needs less than 1 mW of power to transmit hundreds of Kbps as far as 5 meters due to absence of carrier signal. Thus, UWB devices operate efficiently at low power levels.
- **High Data Transfer Rates**: The data transmission is done over high transfer rates of 500Mb/s over 5m, 250Mb/s over 10m, 200Kb/s over 50m, 10Kb/s over 100m due to availability of enormous amount of bandwidth.
- **Secure**: UWB technology operates on a wide bandwidth at very low power level, which generates low probability for intercept thus making it highly secure. Practically, it is highly difficult to filter a pulse signal from a background of electronic noise. Thus, it becomes almost impossible for external user to detect the signal

3.3.3 Working of UWB

UWB data transmission behavior is significantly different from conventional narrowband RF and spread spectrum (SS) technologies like Bluetooth and WiFi, as it does not requires carrier signal to transfer information. A UWB transmitter works by sending billions of pulses of low duty cycles across 3.1 GHz to 10.6 GHz at a limited transmit power of -41dBm/MHz, which transmits with power level less than one thousand times of an average cell phone. Due to the low emission limit on power, the other radio systems consider UWB signal as noise, which results in a low probability of interception and detection. The corresponding receiver then translates the received sinusoidal pulses into data.

These pulses are carrying information in coded form and extremely brief with a capacity of almost unlimited number of users, which improves speed by listening for a familiar pulse sequence sent by the transmitter . UWB share the same wireless transmission medium with a number of users simultaneously transmitting pulses using spread spectrum technology. Therefore, UWB provides a superior wireless connectivity among WPAN devices due to its high data throughput potential in short-range at very low power. UWB operates in single-band mode and multi-band mode; single-band mode is similar to spread spectrum technology, whereas, in case of multi-band mode whole frequency spectrum is divided into smaller, non-overlapping bandwidths above 500 MHz..

Shannon's equation shows, capacity increasing as a function of bandwidth faster than the signal to noise ratio .

- $C = BW * log_2(1 + SNR)$ Eq. (1-4)
- $SNR = \frac{P}{BW * No}$ Eq. (1-5)

where C is channel capacity, BW is channel bandwidth in Hz, P is received signal power, N0 is the average noise or interference power over the bandwidth, and SNR is signal to noise ratio.

It is observed from Shannon's equation that to increase channel capacity requires linear increases in bandwidth. Whereas, to achieve similar channel capacity using power level, requires a multifold increase in power. Due to this reason, UWB is capable of transmitting high data rates with low power consumption.

3.4 Design Challenges in UWB MIMO antenna systems:

- **Isolation:** Mutual coupling between antennas is a major concern while designing MIMO systems. Mutual coupling not only affects the antenna efficiency but also influences the correlation. Isolation better than -16 dB is required throughout the operating region of the antenna system.

- **Bandwidth:** Return loss (in dB) should be less than -10 dB from 3.1 to 10.6 GHz so that the impedance bandwidth covers the entire UWB. Simultaneous enhancement of isolation and impedance bandwidth in a single antenna structure is one of the toughest challenges that exist in the design of a UWB MIMO antenna system.

- **Size:** Recently, MIMO has been adapted to mobile phones, which use various communication technologies such as WCDMA, WiMAX, WLAN, and UWB in order to realize high speed data transmission. Obviously, such an application requires a compact wide-band MIMO antenna because of the limited space available in wireless devices. Hence a compact UWB MIMO antenna system with low mutual coupling among the antennas is desired for UWB applications.

3.4.1 Design 1: Single Element Antenna

The frequency corresponding to the lower resonances of a rectangular planar monopole antenna can be approximately calculated by

$$Frl = \frac{144}{\left(Lg+L1+g+\left(\frac{w}{2p*\sqrt{1+er}}+\frac{w1}{2p*\sqrt{1+er}}\right)\right)} \text{ GHz.} \qquad (1)$$

Based on Formula (1), a planar monopole antenna is designed as shown in Figure 2(a). If Lg and L1 denote the length of the ground plane and radiation patch, respectively, and g is the gap between them according to Eq. (1), the calculated Frl (for Lg = 8.5 mm, L1 = 10 mm, g = 0.5 mm) is 6.8 GHz.Because the compact size of the antenna element and ground plane result in poor impedance matching.

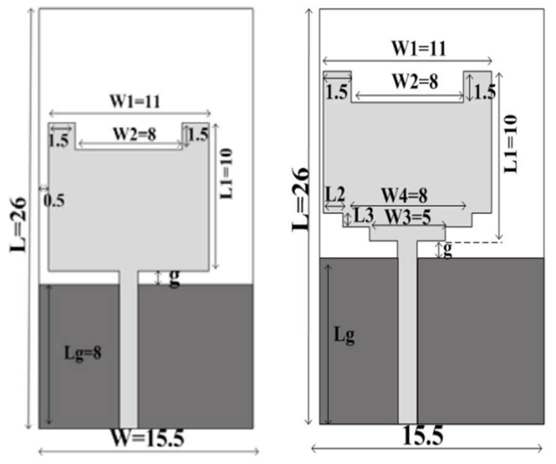
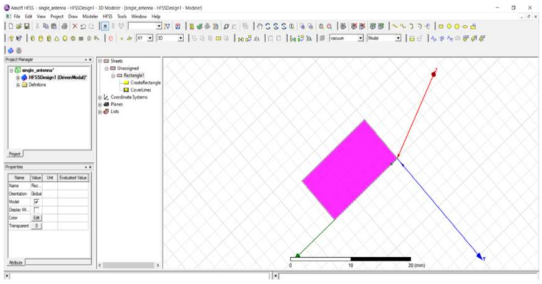


Fig:3.4 (a) Configuration of antenna 1 (b) configuration of antenna 2

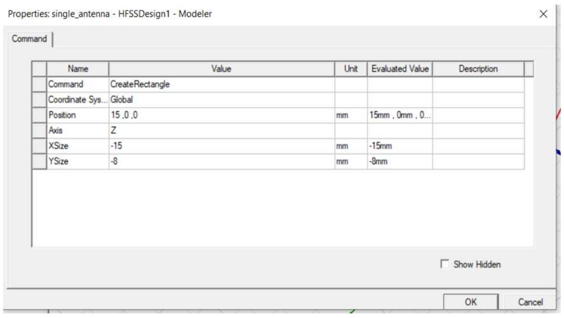
To shift the resonant frequency to lower frequency and improve input impedance matching, a staircase structure is applied by the UWB antenna presented in Figure 3.4.1(b). Moreover, by changing L2 and L3, the lower cut of frequency could be varied from 6 GHz to about 4.5 GHz. The variation of S1 with different L2 and L3 implies that the staircase has great effect on the input impedance matching.

3.4.2: Design of Single Antenna element in HFSS Software

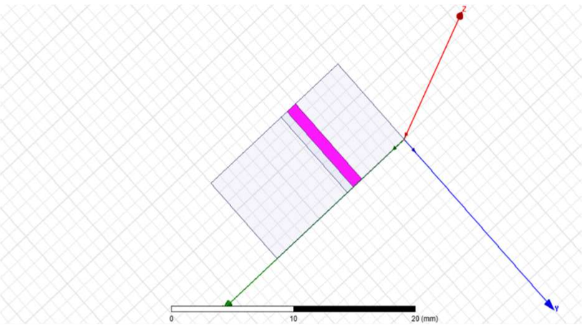
Step1: Open the HFSS software, insert the HFSS design into the project and start the design by selecting the rectangle and name it as ground plane.

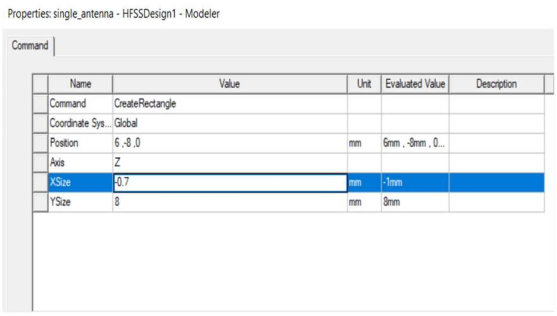


Step2: Now adjust the positions of the rectangle as for our need by selecting create rectangle option



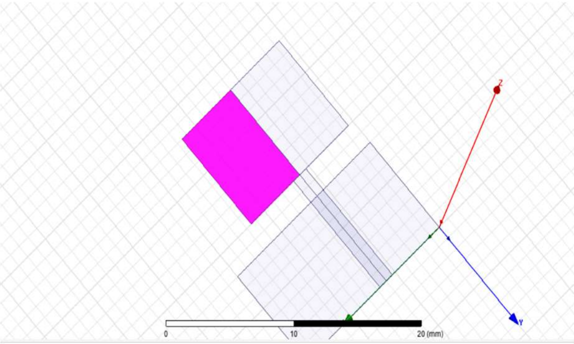
Step3: Place two rectangle as shown in the below figure in the middle of the first rectangle and also adjust the positions of the rectangle by selecting create triangle option (x size=-0.7 and x size=0.7 for each rectangles).

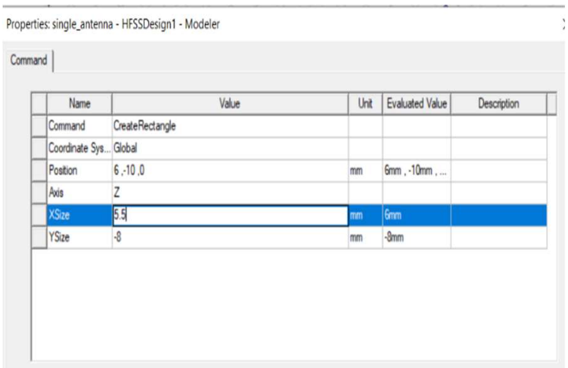




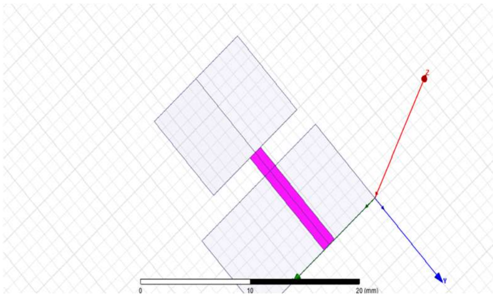
Step4: Using two rectangles create a square and adjust their positions with difference x size= 5.5

& -5.5 for 2 rectangles.

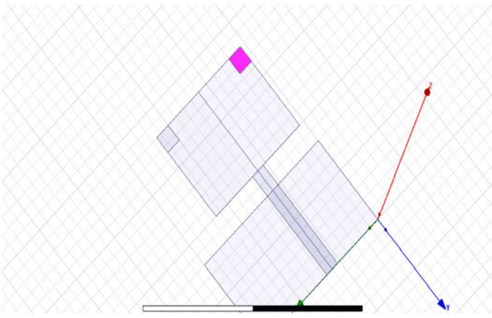


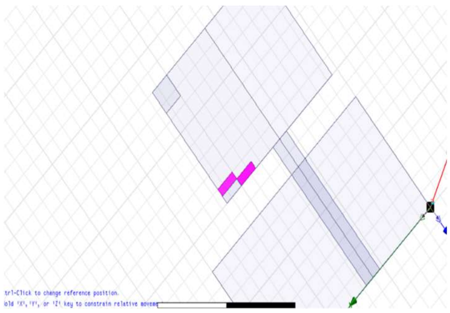


Step5:Place a new triangle connecting the ground and the patch like shown in the below image and name it as the feed triangle with the required measurements.

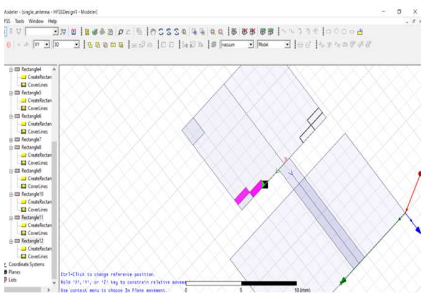


Step6: In order to create the required patch antenna shape we need to place some rectangles in the corners of the square like structure created by two rectangles.

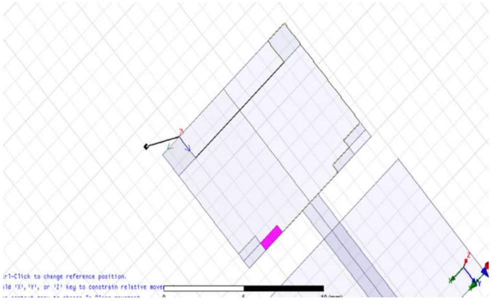




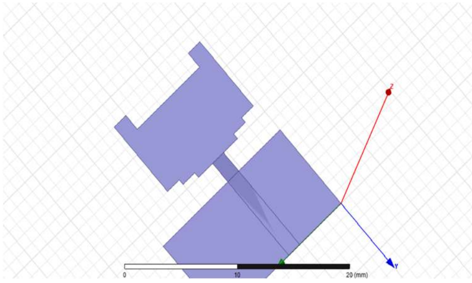
Step7: With the help of the mirror option available in the HFSS software we can create the 4th corner of the square



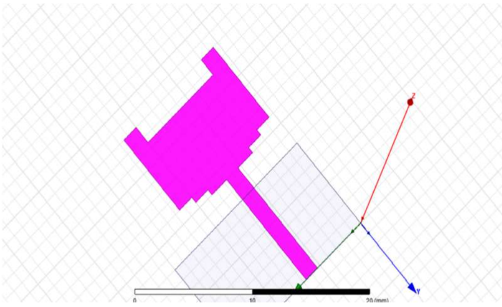
Step8: Using the draw line option we create a polyline around the rectangle into required patch shape



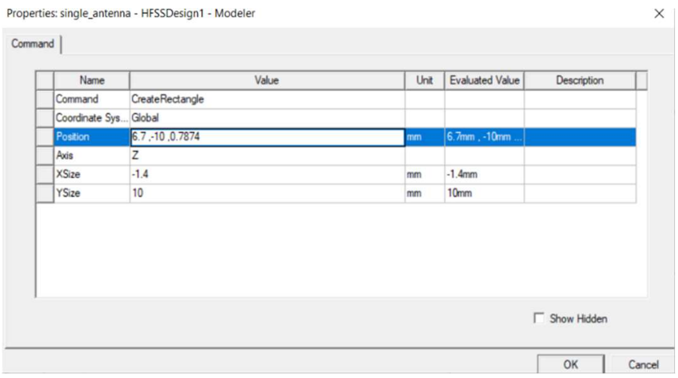
Step9: After deleting the remaining rectangles our design looks like as shown in the below image.



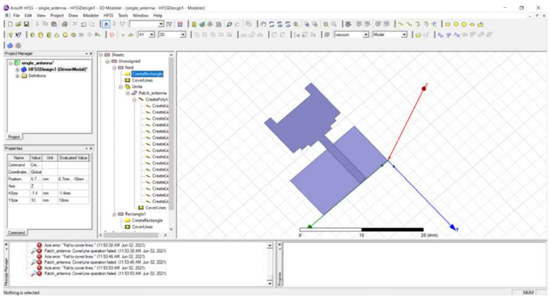
Step 10: Unite both the feed and patch antenna by selecting them through edit then boolean and unite them, name it as patch antenna.



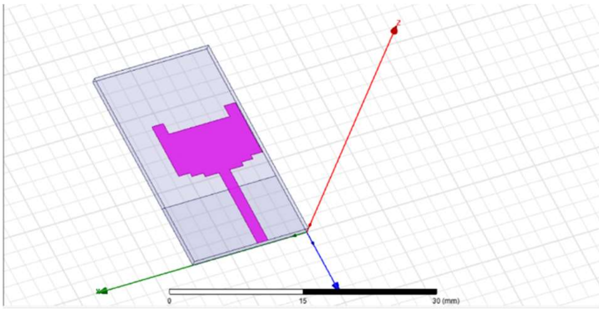
Step11: The patch antenna positions are adjusted , we are placing the patch antenna at a height of 0.7874 which means we are going to use the substrate of thickness 0.7874.



Step 12: So, as we used the polyline for structuring our patch antenna shape we need to select each and every polyline and change z-axis value to 0.7874

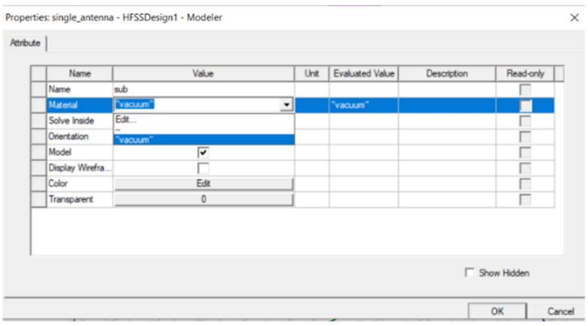


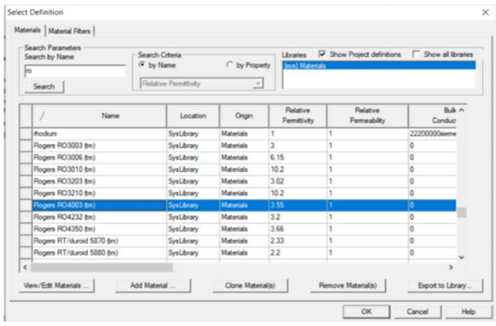
Step13: Create a box structure which is in 3 dimensions and place it as shown in the below image , the height of that box is adjusted to 0.7874 where by doing this it will acts as a connection between the ground plane and the patch antenna , make the transparency of that box to 0.8 so that we can clearly see both the patch antenna and the ground at a time



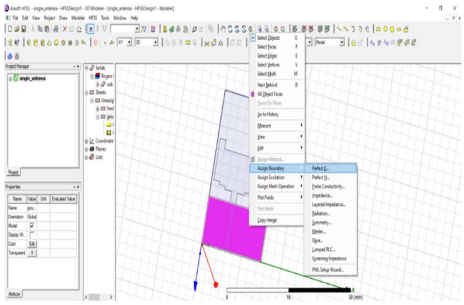
Step 14: Change that box name as substrate and edit the material of the substrate as shown in the series of images

Step 15: Select the material option and press the edit and then search for rogers RO4003 from the list which is having permitivity of 3.55 as our substrate material.

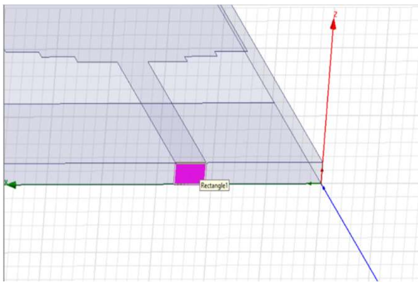




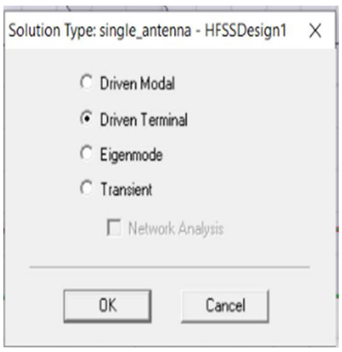
Step16: We get the shape of our antenna its time to assign the boundaries for each individual rectangle, Assign the boundary as perfect E for both the ground plane and patch antenna as the process shown in the below image.

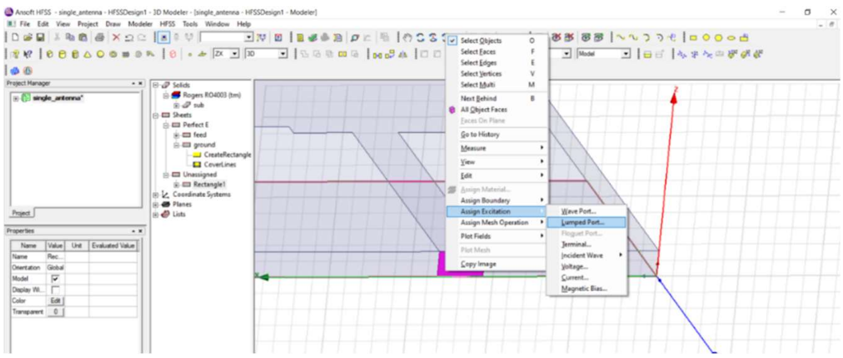


Step 17: And finally after assigning the boundaries as perfect e we need to attach both the ground and patch antenna using a rectangle in ZX axis with thehelp of this we give feed to our antenna element.

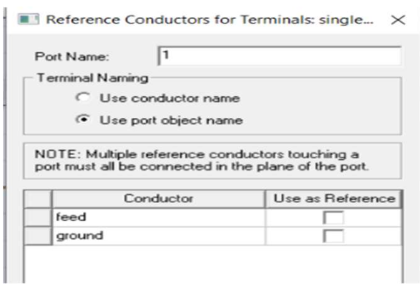


Step 18: Before giving the excitation to it first we need to change the HFSS solution type from driven model to driven terminal

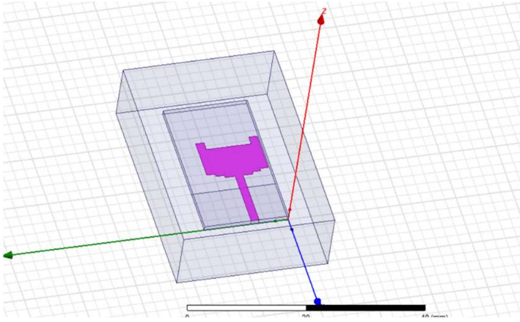




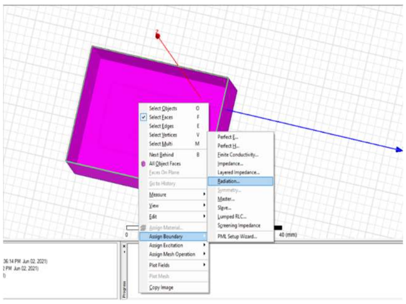
Step19: Assign excitation as lumped port and then change the terminal naming to use port object name.



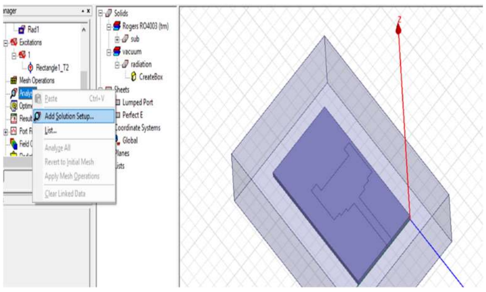
Step 20: It's time for the radiation , create a air box of the required dimensions and check that our antenna element is in the centre of that air box which we had created

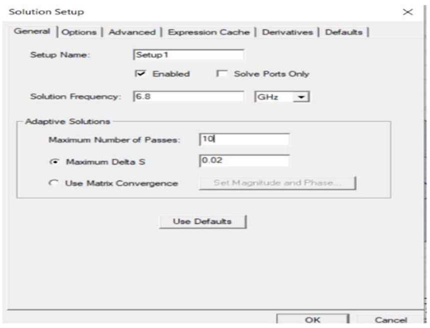


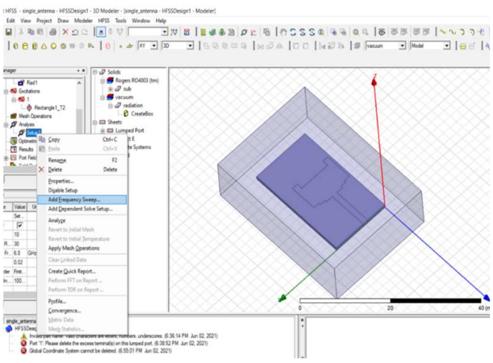
Step 21: Select , select faces option and select all the 6 faces of the air box as shown in the below image and then assign boundaries as radiation



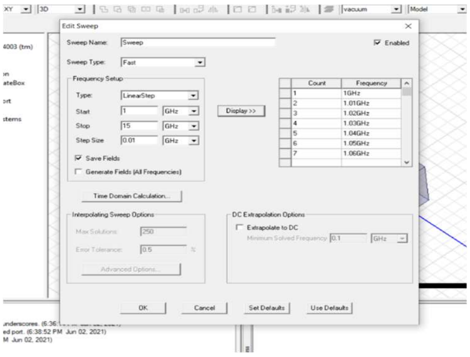
Step 22: Now we need to add solution setup for our antenna by selecting analysis and add solution setup and change the solution setup to required solution frequency in this case it is 6.8Ghz



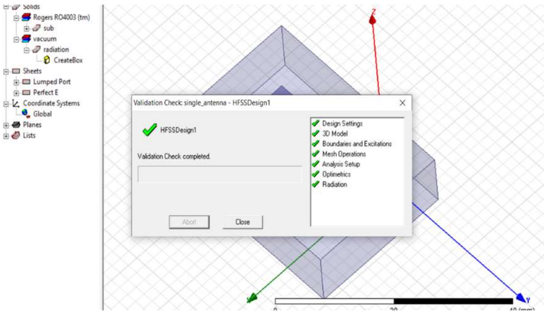




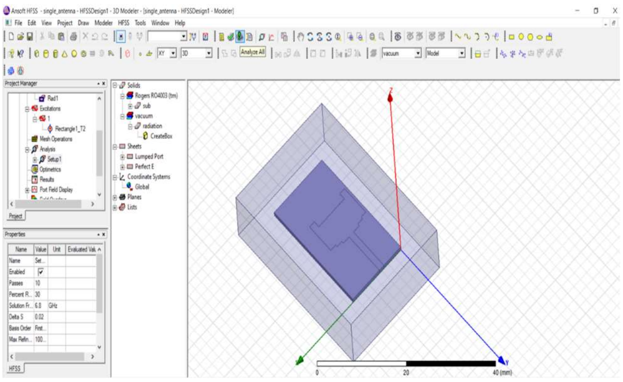
Step 30: By right clicking that setup we can add frequency sweep ,change the sweep type to fast and and adjust the start ,stop and step size as required



Step 31: The most important step we need to validate our design wheather we had done all the required steps perfectly or not that is it will check , design settings,3d model, boundaries and excitations, mesh operations ,analysis setup, optimetrics and radiation, if any of this step was not done then it will validate as error at that particular step, but to get our design output correctly it must need to show as ok in all the vallidations.



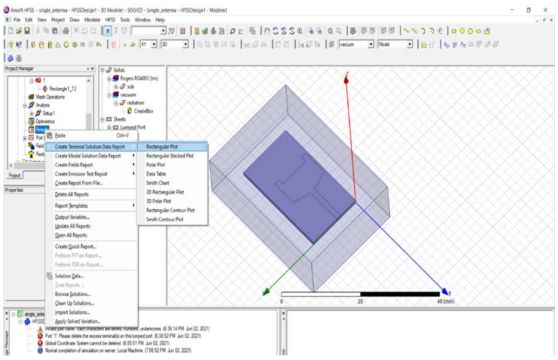
Step 32: And finally after this validation check we will analyze the design by clicking on the analyze all option it will run through some checks and then our design is ready to take our required outputs.

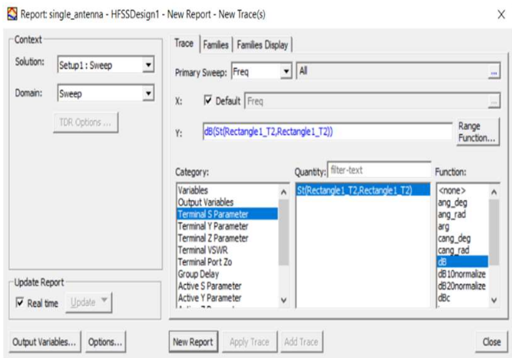


3.5 Results of Design1 Single element antenna

To analyze the results of our modeled antenna we need to follow some steps in order to get the s11 parameters graph which will helps us to find both bandwidth and return loss of our antenna, select the results

Results option from the project manager portal, press right click on it and choose create terminal solution data report and then rectangular plot as shown in the below image. Now select the category as Terminal s parameter and choose the function in db and press the new report ,then we will get our s parameter graph .





The Resultant graph shows the bandwidth and the return loss of our antenna, with the help of marker we mark certain points in the graph to identify the bandwidth i.e 4.7400 and the return loss is -18.4891

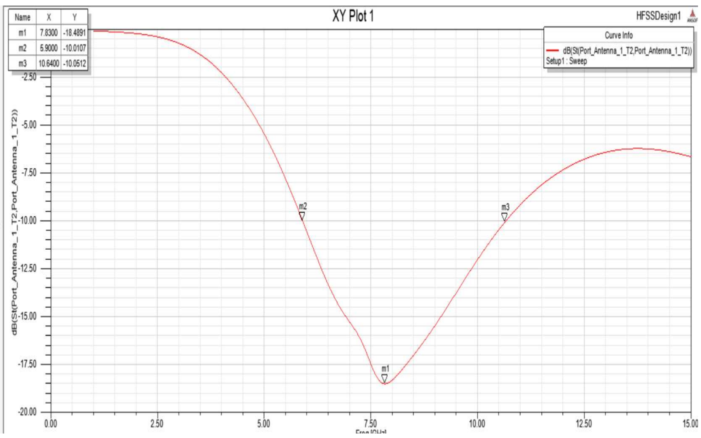
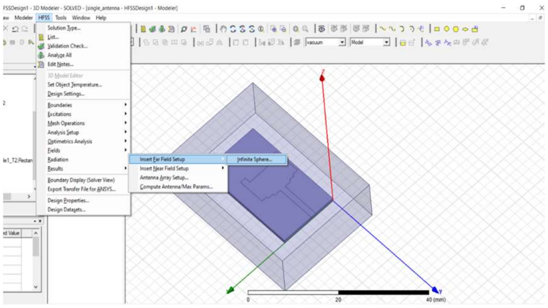
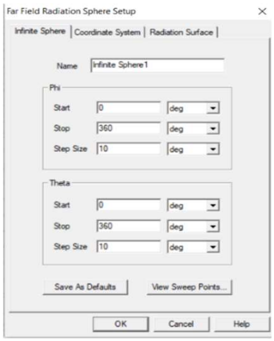


Fig:3.5(a) S11 parameter, Bandwidth & Return loss

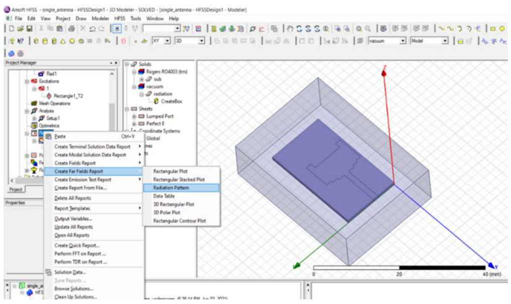
To get the radiation pattern and 3d gain plot at first we need to create infinite sphere, click the HFSS and choose radiation option select insert far field setup, then infinite sphere as shown in the below figure follow this steps



Here we need to adjust the far field radiation sphere setup , change both the phi and theta values, set the start, stop as 0, 360 and step size to 10 as shown in the below Image



The steps need to follow for the radiation pattern is to right click the results , choose create far field report and then radiation pattern.



The radiation Pattern is shown in the bellow image for all the frequency ranges and 360 infinite sphere.

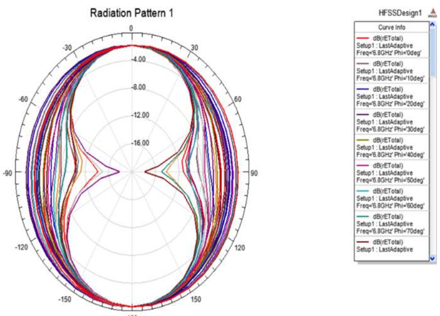
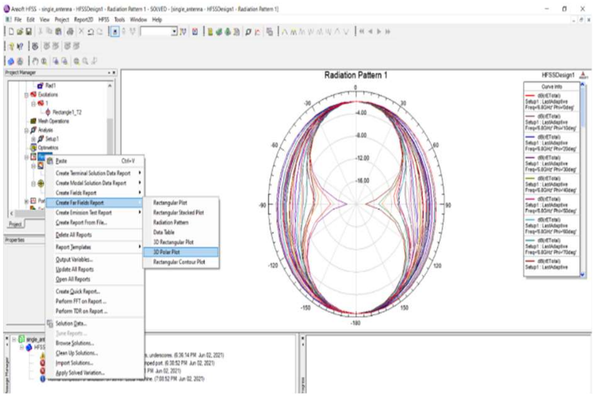
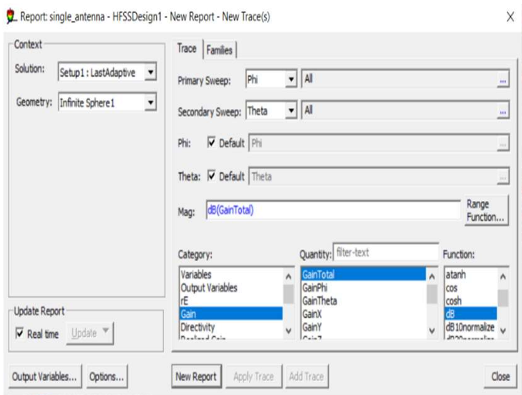


Fig:3.5(b) Radiation Pattern for single element antenna

Finally we need to check the gain of our antenna, gain is the most important factor for any antenna, steps to find gain of our antenna is to right click the results , choose create far field report and then select 3d polar plot



After this step a portal will open where where primary sweep, secondary sweep , category and function which we want to use , now select the gain from the category and gain total from quantity and finally select our function type in db then we will get a 3d polar plot



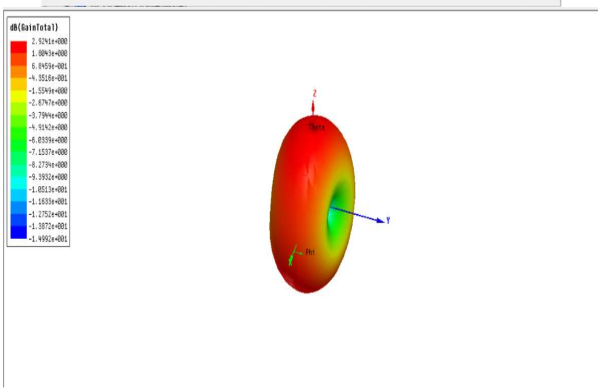


Fig:3.5(c) Gain of the single element antenna

This is the gain our antenna, from the fig 3.5(c) we can say that the gain is 2.9241

3.6 Design 2 : Multi element antenna

When the two antennas are placed close to each other as shown in Figure 3.6, the bandwidth still cannot cover the entire UWB frequency band . For improving impedance matching at the low and high frequencies, a small rectangular slot in Wfs × Lfs mm2 is cut on the ground plane. Also by changing Wfs from 0 to 0.8 mm, the high cut of frequency varies from more than 12 GHz to about 11.2 GHz. Overall,

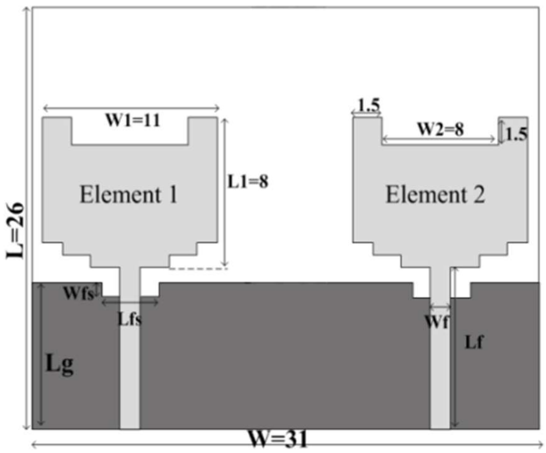
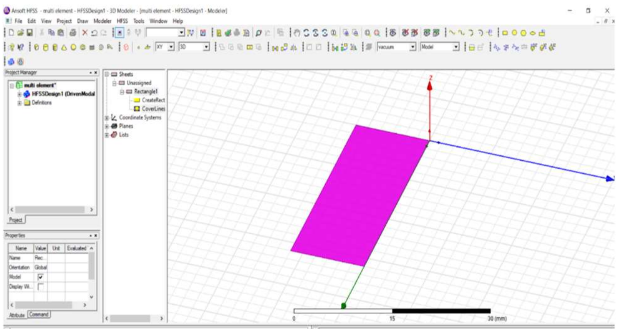


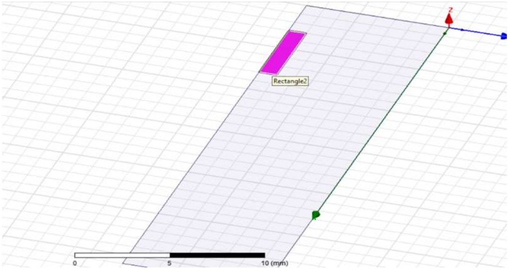
Fig 3.6(a): Multiple Element Antenna

3.6.2: Design of Multiple Antenna element in HFSS Software

Step1: Open the HFSS software, insert the HFSS design into the project and start the design by selecting the rectangle and name it as ground plane.

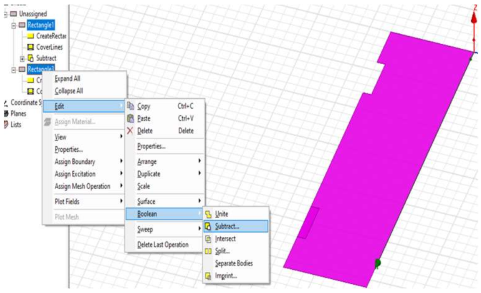


Step2: As we can see that to improve the impedance matching we need to cut two slots at the two patch antennas positions, Initially select a rectangle and place it at the one side of the ground rectangle and adjust it to the required size and later repeat the same by creating another rectangle at second patch antenna position.

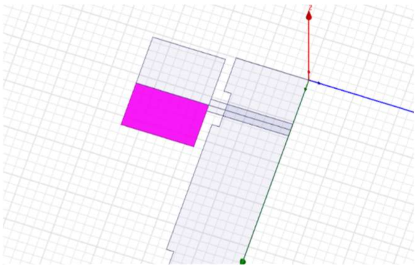


Name	Value	Unit	Evaluated Value	Description
Command	CreateRectangle			
Coordinate Sys...	Global			
Position	8 ,-7.2 ,0	mm	8mm , -7.2mm , ...	
Axis	Z			
XSize	-4	mm	-4mm	
YSize	-0.8	mm	-0.8mm	

Step 3:After creating two small rectangles on the ground plane now we need to create a patch in that spot so we will select those rectangles and use edit , the Boolean and subtract the two small rectangles from the ground rectangle.

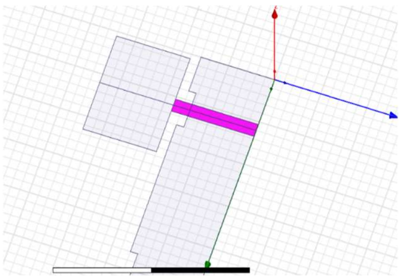


Step4: Place two rectangle as shown in the below figure in the middle of the first rectangle and also adjust the positions of the rectangle by selecting create triangle option (x size=-0.7 and x size=0.7 for each rectangles).

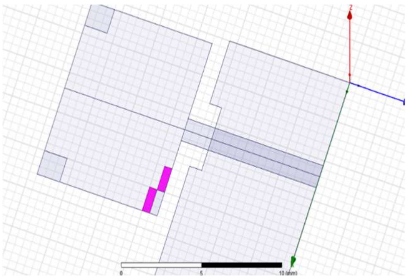


Step5: Using two rectangles create a square and adjust their positions with difference x size= 5.5 & -5.5 for 2 rectangles.

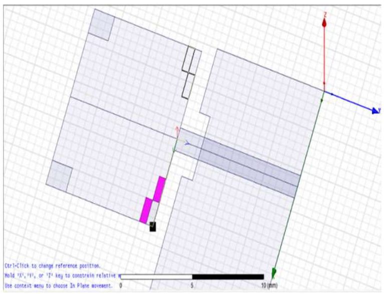
Step6: Place a new triangle connecting the ground and the patch like shown in the below image and name it as the feed triangle with the required measurements.



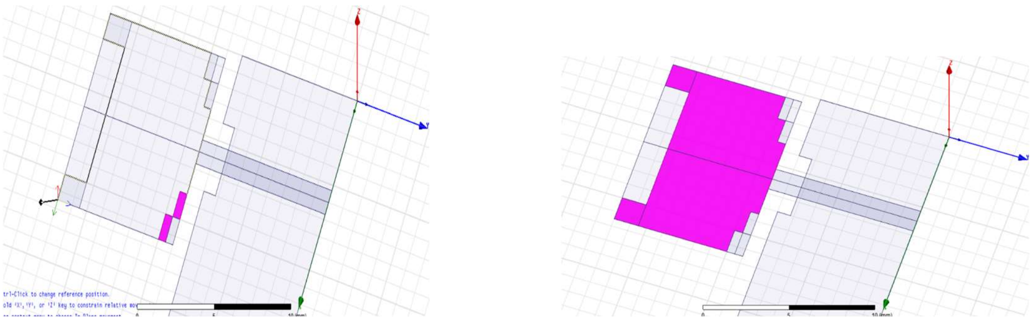
Step7: In order to create the required patch antenna shape we need to place some rectangles in the corners of the square like structure created by two rectangles.



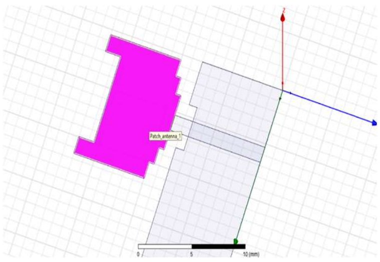
Step8: With the help of the mirror option available in the HFSS software we can create the 4th corner of the square



Step9: Using the draw line option we create a polyline around the rectangle into required patch shape

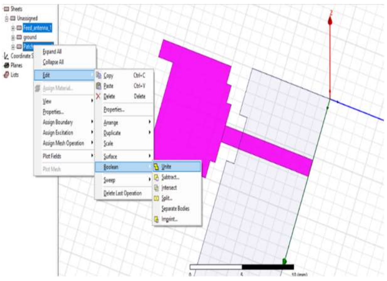


Step10: After deleting the remaining rectangles our design looks like as shown in the below image.

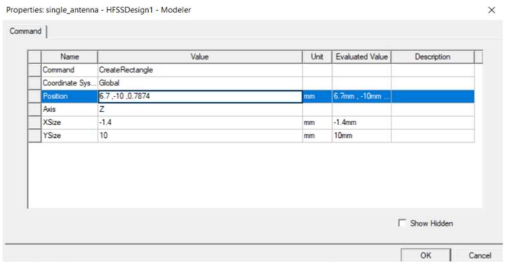


Step11: Unite both the feed and patch antenna by selecting them through edit then boolean and

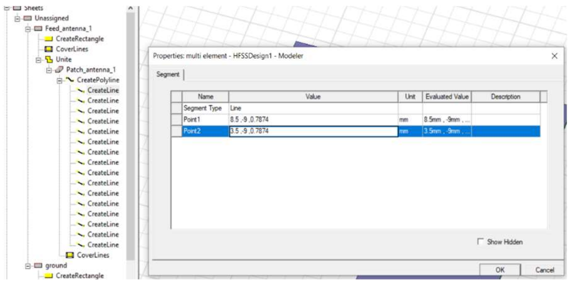
unite them, name it as patch antenna.



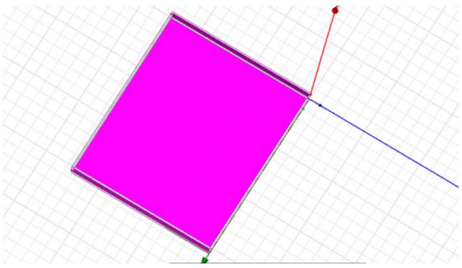
Step12: The patch antenna positions are adjusted , we are placing the patch antenna at a height of 0.7874 which means we are going to use the substrate of thickness 0.7874.



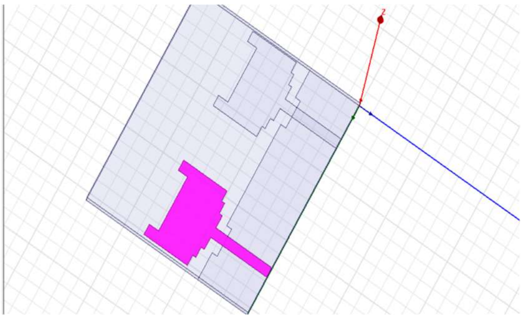
Step13: So, as we used the polyline for structuring our patch antenna shape we need to select each and every polyline and change z-axis value to 0.7874



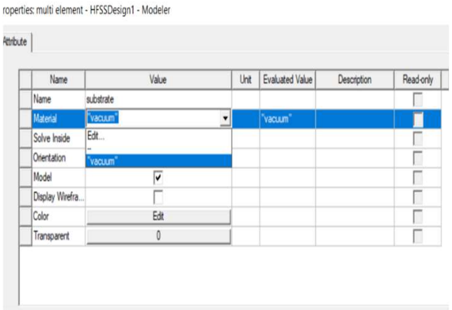
Step14: Create a box structure which is in 3 dimensions and place it as shown in the below image , the height of that box is adjusted to 0.7874 where by doing this it will acts as a connection between the ground plane and the patch antenna , make the transparency of that box to 0.8 so that we can clearly see both the patch antenna and the ground at a time

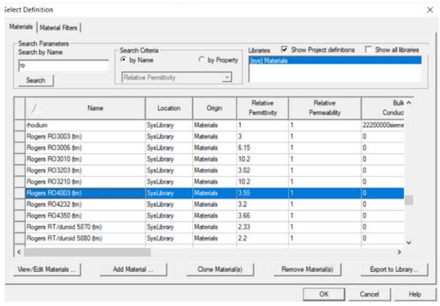


Step15: With the help of duplicate mirror option we need to create patch antenna2

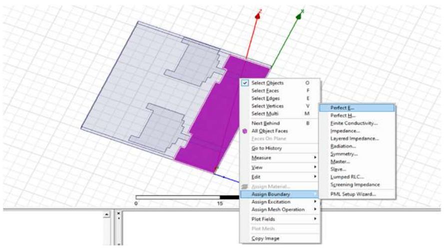


Step16: Change that box name as substrate and edit the material of the substrate as shown in the series of images,Select the material option and press the edit and then search for rogers RO4003 from the list which is having permitivity of 3.55 as our substrate material.

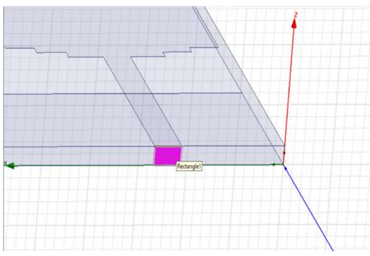




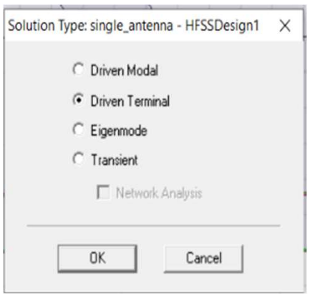
Step17: We get the shape of our antenna its time to assign the boundaries for each individual rectangle, Assign the boundary as perfect E for both the ground plane and patch antenna as the process shown in the below image.

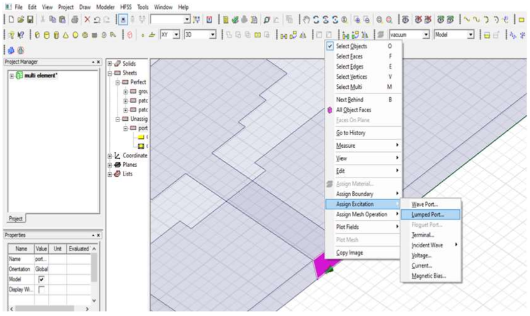


Step18: And finally after assigning the boundaries as perfect e we need to attach both the ground and patch antenna using a rectangle in ZX axis with thehelp of this we give feed to our antenna element.

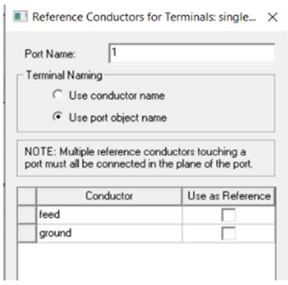


Step 19: Before giving the excitation to it first we need to change the HFSS solution type from driven model to driven terminal

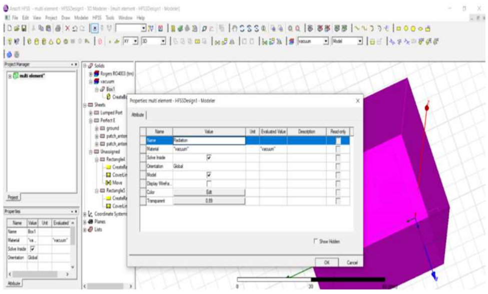




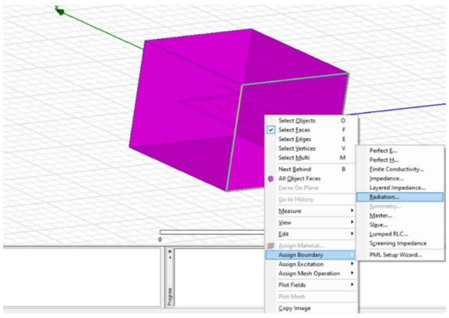
Step20: Assign excitation as lumped port and then change the terminal naming to use port object name.



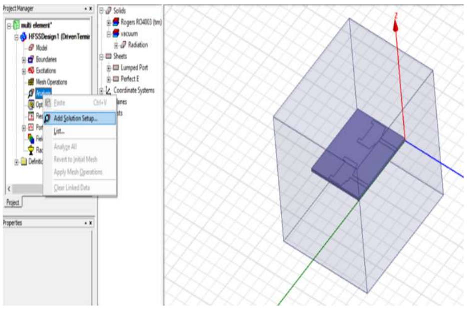
Step 21: It's time for the radiation , create a air box of the required dimensions and check that our antenna element is in the centre of that air box which we had created

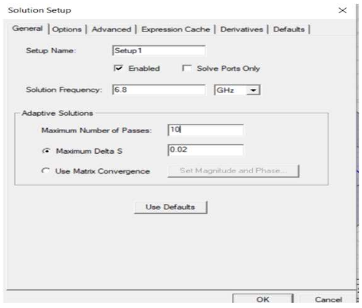


Step22: Select , select faces option and select all the 6 faces of the air box as shown in the below image and then assign boundaries as radiation.

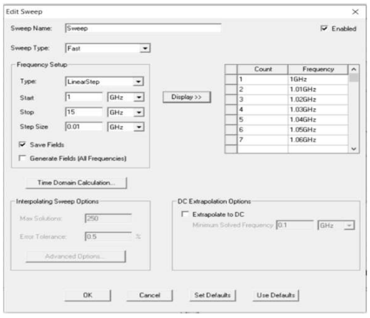


Step 23: Now we need to add solution setup for our antenna by selecting analysis and add solution setup and change the solution setup to required solution frequency in this case it is 6.8Ghz

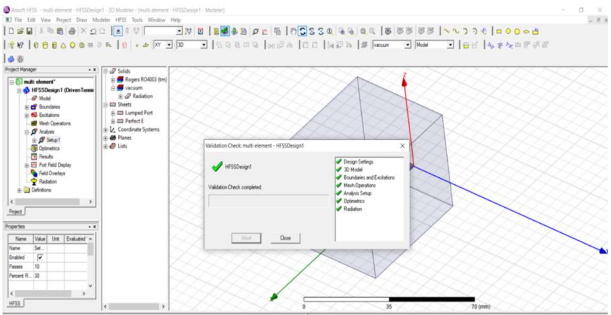




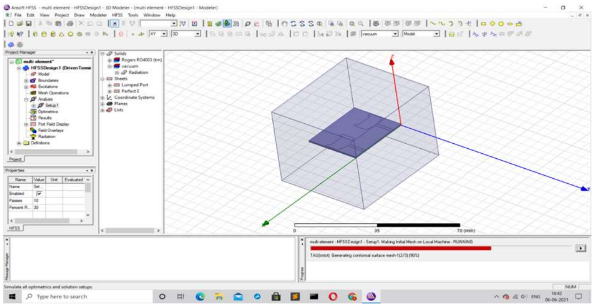
Step 24: By right clicking that setup we can add frequency sweep ,change the sweep type to fast and and adjust the start ,stop and step size as required



Step 25: The most important step we need to validate our design wheather we had done all the required steps perfectly or not that is it will check , design settings,3d model, boundaries and excitations, mesh operations ,analysis setup, optimetrics and radiation, if any of this step was not done then it will validate as error at that particular step, but to get our design output correctly it must need to show as ok in all the vallidations.



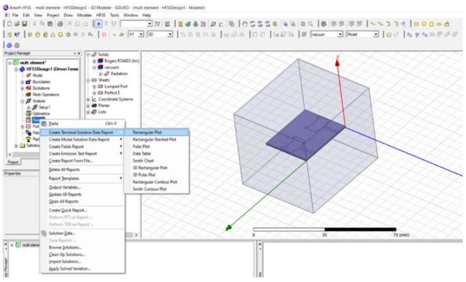
Step 26: And finally after this validation check we will analyze the design by clicking on the analyze all option it will run through some checks and then our design is ready to take our required outputs.



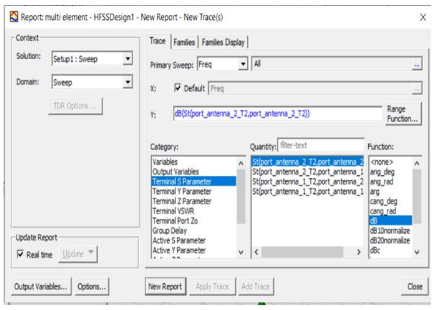
3.7 Results of Design 2 multi element antenna

To analyze the results of our modeled antenna we need to follow some steps in order to get the s11 & s21 parameters graph and isolation which will helps us to find both bandwidth and return loss of our antenna, select the result

Results option from the project manager portal, press right click on it and choose create terminal solution data report and then rectangular plot as shown in the below image.



Now select the category as Terminal s parameter and choose the function in db and press the new report ,then we will get our s parameter graph



The Resultant graph shows the bandwidth and the return loss of our antenna, with the help of marker we mark certain points in the graph to identify the bandwidth i.e 6.13 and the return loss is -16.2962

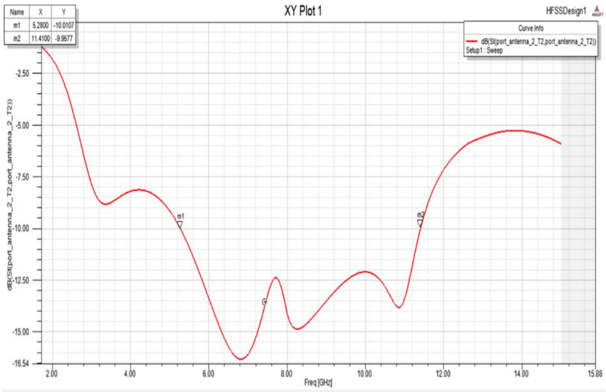


Fig:3.7(a) S11 parameters of multi element antenna

From that graph we can obtain the isolation value, with the help of the marker we can mark the isolation value in the graph, we obtained the isolation value of-17.0514.

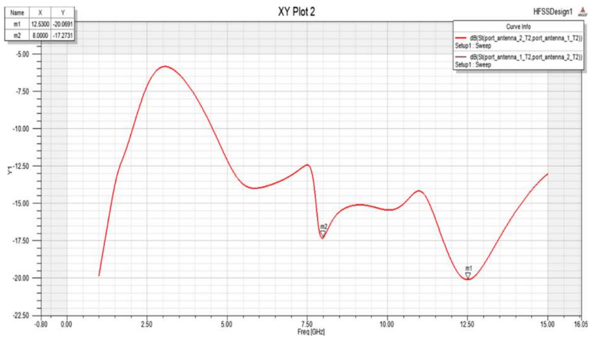
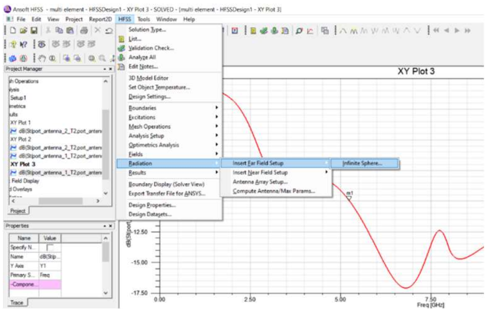
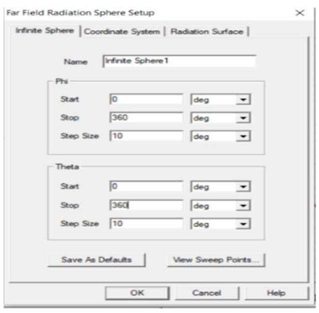


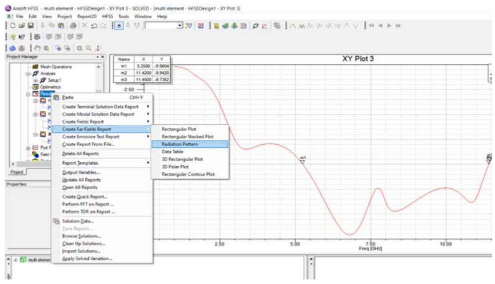
Fig:3.7(b) S21 parameters with isolation value

To get the radiation pattern and 3d gain plot at first we need to create infinite sphere, click the HFSS and choose radiation option select insert far field setup, then infinite sphere as shown in the below figure follow this steps . Here we need to adjust the far field radiation sphere setup , change both the phi and theta values, set the start, stop as 0, 360 and step size to 10 as shown.





The steps need to follow for the radiation pattern is to right click the results , choose create far field report and then radiation pattern.



The radiation Pattern is shown in the bellow image for all the frequency ranges and 360 infinite sphere.

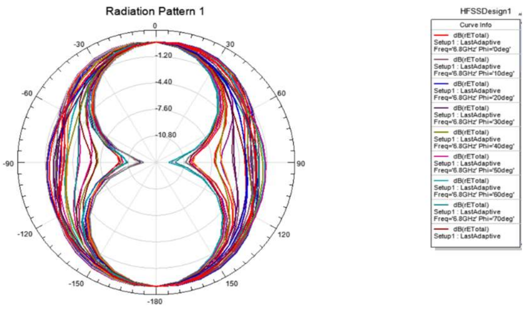
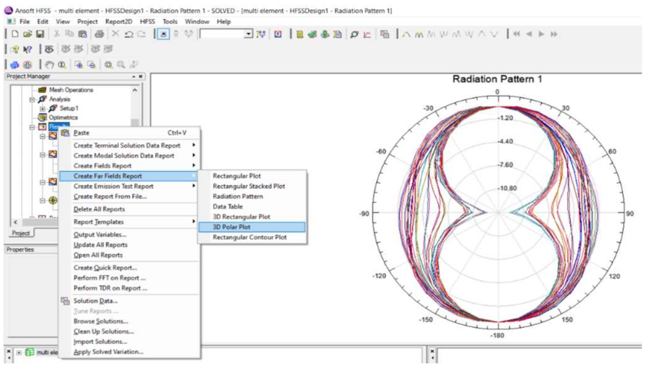
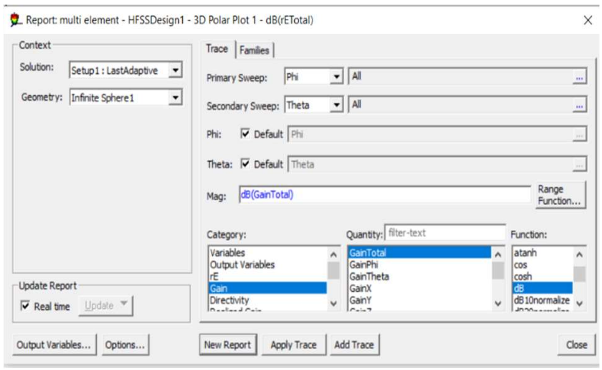


Fig:3.7(c) Radiation Pattern for multi element antenna

Finally we need to check the gain of our antenna, gain is the most important factor for any antenna, steps to find gain of our antenna is to right click the results , choose create far field report and then select 3d polar plot



After this step a portal will open where where primary sweep, secondary sweep , category and function which we want to use , now select the gain from the category and gain total from quantity and finally select our function type in db then we will get a 3d polar plot



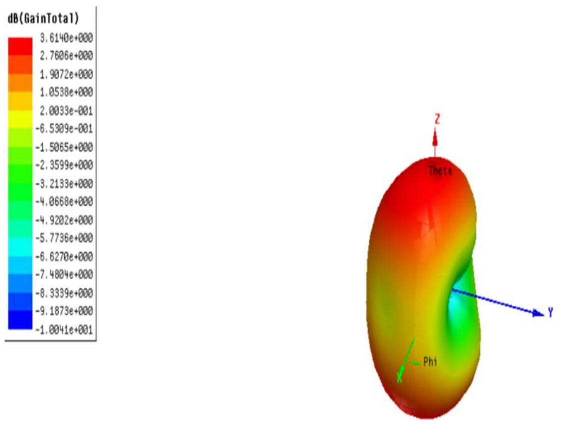


Fig:3.7(d) Gain of the Multi element antenna

This is the gain our antenna, from the fig 3.7(d) we can say that the gain is 3.6140

3.8 Conclusion

By comparing the results of our two antenna designs we can conclude that though the return loss is more for design1 when compared with design2, The gain of the antenna is increased in the design 2 as we used multiple antennas that is array of antennas, this helped us to improve our directional gain. The bandwidth of the design 2 is also more when compared with the design 1, our required range of bandwidth for ultra wide band is 3.1 to 10.6 GHz, as we can see the bandwidth for the design 2 is 6.377, but because of implementing this two array antennas into single patch the mutual coupling between them increases this will results in fault output of the antenna , so we need to modify this design further with different techniques to reduce the mutual coupling and to increase the isolation between the antenna elements.

CHAPTER-4

High Isolation Compact MIMO Antenna

In this chapter, we will discuss about isolation, different types of methods to improve isolation between antenna elements, the method we used in our design to improve isolation (means having less mutual coupling) and the design of the antenna using Electromagnetic Band Gap (EBG) Structure and how to obtain the results.

4.1 Introduction:

Compact antenna designs with good isolation provide improved efficiency when employed internally in handheld and portable wireless systems. Antennas embedded within compact devices, such as handheld computers and cellular telephones, must be optimized to limit interactions with surroundings. Such antenna isolation permits good efficiency within different enclosures and reduces the engineering time needed to incorporate antennas within new enclosures. Evaluation of antenna performance can be performed on an antenna within an anechoic chamber or measurements can be made on the complete wireless system of which the antenna is a part. Such measurements will show that antenna isolation is a critical parameter when evaluating wireless designs as part of multiple systems within the same enclosure.

Generally, antenna isolation is implemented when multiple antennas are placed/present on the same board - that is, the isolation between a smartphone GPS and Wi-Fi antenna, for instance. When specified in this manner, the isolation should be as large as possible. Hence, we can say that the isolate on is to separate different antennas into different portions of the board as the radiation emitted from reflector less antennas will naturally fall off with distance. It is also defined as a measure how tightly coupled antennas are.

4.2 Improvement of Isolation

4.2.1 Isolation

Isolation is reciprocal, i.e., it is a function of both antenna gains and transmittance between the two elements. A low isolation value between two antennas means the antennas pick up each other's radiation. We know that decreasing the mutual coupling increases the isolation between antenna elements. The method of measuring isolation is done by connecting both antennas to a Vector Network Analyzer, and measuring S21/S12 parameter. For antennas on a smartphone, the isolation can be as low as -10dB or less at the low band. This will cause a loss in both antenna’s efficiency. We can also say that decreasing mutual coupling means increasing isolation. Antenna to antenna isolation can be increased by:

- ✦ Increasing the physical separation between the antennas.
- ✦ Using different polarizations for the antennas in question.
- ✦ If the antennas have different frequencies, using filters to reduce efficiency at the opposite antenna's frequency.
- ✦ Reducing the correlation coefficient between the antenna's radiation patterns - that is, have the antenna's peak radiation in different or opposite directions.

4.2.2 Need of isolation

Isolation needs to be designed to suppress the following sources of interference:

- ➢ Direct radiation
- ➢ Enclosure resonances
- ➢ Waveguide mode excitation
- ➢ Noise coupling

1.Direct radiation:

This involves simply reducing the strength of radiation sent from one antenna and received by another antenna. This is a function of directionality, polarization sensitivity, and any shielding elements.

2. Enclosure resonances:

Emitted radiation can excite resonances inside an enclosure, which then causes interference between different board sections due to reflections and multipath propagation. Enclosure resonances appear as small spikes in the radiation pattern.

3. Waveguide mode excitation:

Propagating parallel-plane waveguide modes can be excited when an antenna is excited and radiates at certain frequencies. This problem is not the result of a mis-planned return path;

instead, this is an effect that occurs due to radiation from an antenna. Similarly, surface waves can be excited by a radiating antenna, particularly planar antennas, which can then be guided to a different board section thanks to the refractive index contrast between the substrate refractive index and air.

4. Noise coupling:

Noise from one section can propagate into another section as EMI. The issue with EMI between antennas is partially solved with smart floor planning.

4.2.3 Methods for improving Isolation

In order to improve isolation, there are many techniques as follows:

- ➢ Decoupling Structures
- ➢ Parasitic Elements
- ➢ EBG Structures (Electromagnetic Band Gap)
- ➢ Frequency Selective Surface (FSS)
- ➢ Split Ring Resonator (SRR)
- ➢ Complementary Split Ring Resonator (CSRR)
- ➢ Meta materials
- ➢ Neutralization line
- ➢ Near Field Resonator
- ➢ Perpendicular Feeding

1.Decoupling Structures:

The Inserted Decoupling Network Scheme: Decoupling networks have many configurations such as the neutralization line, transmission line, reactive component, coupled-resonator, etc. Neutralization lines were connected with antenna radiators for isolation enhancement. However, the lack of a systematic approach to determine the location of the neutralization line makes this kind of DT heavily rely on the time-consuming optimization process. A decoupling feed network (DFN) is usually connected to antenna feed lines to increase port isolation.

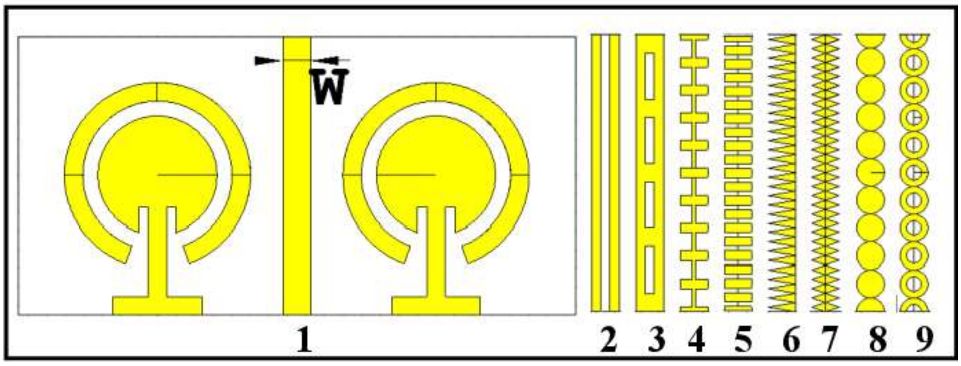


Fig 4.2(a): Decoupling Structure Pattern

2.Parasitic elements

A parasitic element is an element, which depends on other's feed. It does not have its own feed. Hence, in this type of arrays we employ such elements, which help in increasing the radiation indirectly. These parasitic elements are not directly connected to the feed.

The below image shows an example of a parasitic array. The mesh structure seen in the picture, is nothing but a set of reflectors. These reflectors are not electrically connected. They increase the signal strength by increasing the directivity of the beam.

Let us look at the important parts of a Parasitic array and how they work. The main parts are 1) Driven element

2)Parasitic elements

- Reflector
- Director

3)Boom

- Driven element

The antennas radiate individually and while in array, the radiation of all the elements sum up to form the radiation beam. All the elements of the array need not be connected to the feed. The dipole that is connected to the feed is known as a driven element.

Fig 4.2(b): Example of Parasitic Array

- Parasitic Elements

The elements, which are added do not possess an electrical connection between them to the driven element or the feed. They are positioned so that they lie in the induction field of the driven element. Hence, they are known as parasitic elements.

- Reflector

If one of the parasitic elements, which is 5% longer than driven element, is placed close to the driven element is longer, then it acts as a concave mirror, which reflects the energy in the direction of the radiation pattern rather than its own direction and hence is known as a reflector.

- Director

A parasitic element, which is 5% shorter than the driven element, from which it receives energy, tends to increase radiation in its own direction and therefore, behaves like convergent convex lens. This element is called as a director. A number of directors are placed to increase the directivity.

- Boom

The element on which all these are placed is called a boom. It is a non-metallic structure which provides insulation, so that there will not be any short circuit between the other elements of the array.

These are all the main elements, which contribute the radiation. This can be better understood with the help of a diagram

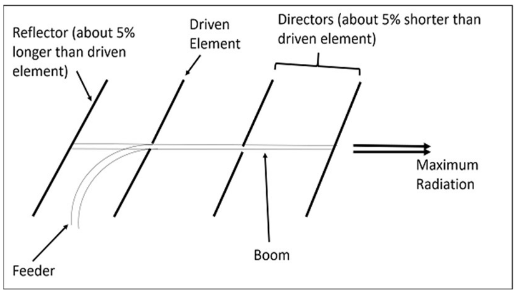


Fig 4.2(c): Elements in Parasitic Array

The image shown above is that of a parasitic array, which shows the parts of parasitic array such as the driven element, the directors and the reflector. The feed is given through the feeder. The arrays are used at frequencies ranging from 2MHz to several GHz. These are especially used to get high directivity, and better forward gain with a uni-directional. The most common example of this type of array is the Yagi-Uda antenna. Quad antenna may also be quoted as another example.

3.EBG Structures (Electromagnetic Band Gap)

Conceptually, these structures can be analyzed electrostatically or using a circuit model; both aspects provide an understanding of how these structures aid isolation. In terms of a circuit model, these structures can be analyzed as LC band-stop filters, producing high impedance at the resonance frequency for the structure. Placing multiple EBG structures in parallel (i.e., in multiple layers) or in series (i.e., next to each other on the same layer), allows the resonance and bandwidth to be precisely tuned to desired values. Moreover, stacking in parallel effectively forms a higher order filter and narrows the structure's bandwidth.

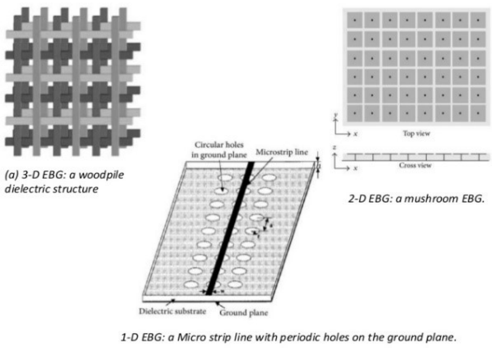


Fig 4.2(d): Different Types of EBG Structures

4.Frequency Selective Surface (FSS)

A frequency-selective surface (FSS) is any thin, repetitive surface (such as the screen on a microwave oven) designed to reflect, transmit or absorb electromagnetic fields based on the frequency of the field. In this sense, an FSS is a type of optical filter or metal-mesh optical filters in which the filtering is accomplished by virtue of the regular, periodic (usually metallic, but sometimes dielectric) pattern on the surface of the FSS. Though not explicitly mentioned in the name, FSS's also have properties which vary with incidence angle and polarization as well - these are unavoidable consequences of the way in which FSS's are constructed.

Frequency-selective surfaces have been most commonly used in the radio frequency region of the electromagnetic spectrum and find use in applications as diverse as the aforementioned microwave oven, antenna radomes and modern metamaterials. Sometimes frequency selective surfaces are referred to simply as periodic surfaces and are a 2-dimensional analog of the new periodic volumes known as photonic crystals.

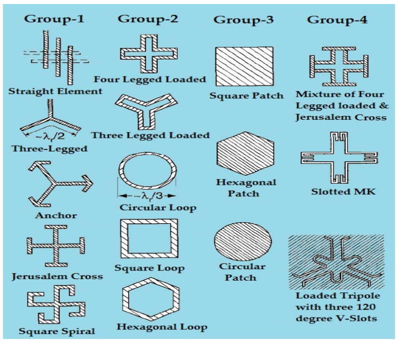


Fig 4.2(e): Different Frequency Selective Surface Structures

Many factors are involved in understanding the operation and application of frequency selective surfaces. These include analysis techniques, operating principles, design principles, manufacturing techniques and methods for integrating these structures into space, ground and airborne platforms.

5.Split Ring Resonator (SRR)

A split-ring resonator (SRR) is an artificially produced structure common to metamaterials. Their purpose is to produce the desired magnetic susceptibility (magnetic response) in various types of metamaterials up to 200 terahertz. These media create the necessary strong magnetic coupling to an applied electromagnetic field, not otherwise available in conventional materials. For example, an effect such as negative permeability is produced with a periodic array of split ring resonators.

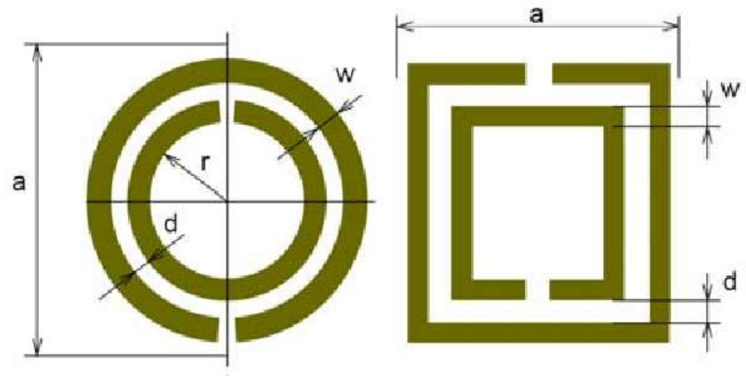


Fig 4.2(f): Circular and Square Split Ring Resonator

A single cell SRR has a pair of enclosed loops with splits in them at opposite ends. The loops are made of nonmagnetic metal like copper and have a small gap between them. The loops can be concentric, or square, and gapped as needed. A magnetic flux penetrating the metal rings will induce rotating currents in the rings, which produce their own flux to enhance or oppose the incident field (depending on the SRRs resonant properties). This field pattern is dipolar. The small gaps between the rings produces large capacitance values which lower the resonating frequency. Hence the dimensions of the structure are small compared to the resonant wavelength. This results in low radiative losses, and very high-quality factors.

6.Complementary Split Ring Resonator (CSRR)

Complementary split ring resonators (CSRR), have been proposed to decouple the array elements. Also, various studies have reported that CSRR structures offer higher amounts of coupling suppression than others. SRR and CSRR structures are well known single negative metamaterial elements. The first model of mu-negative (MNG) SRR was originally proposed by Pendry et al. The application of Babinet's principle leads to the implementation of complementary SRR. The epsilon negative (ENG) CSRR was first introduced and derived by applying duality to the SRR, replacing metal with dielectric and vice versa. The electrical and magnetic properties of the CSRR are interchanged with respect to the SRR. However, the resonant frequency of both the CSRR and the SRR should be approximately the same. Therefore, in a straightforward way the resonance frequency of the CSRR can be derived from SRR.The major advantage of the CSRR is high filtering (band-rejection) capability which is useful for coupling suppression, compact size (less than one-tenth of a λ) and easy fabrication.

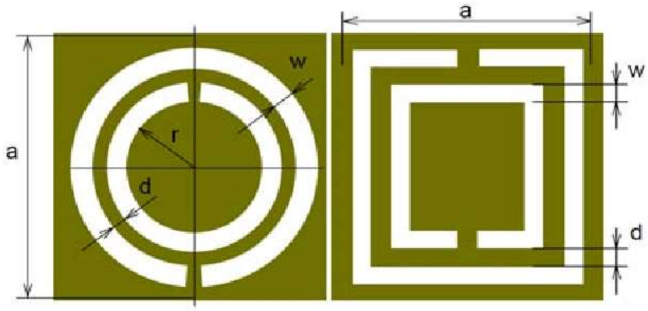


Fig 4.2(g): Circular and Square Complementary Split Ring Resonator

7.Meta materials

A metamaterial (from the Greek word μετά meta, meaning "beyond" and the Latin word materia, meaning "matter" or "material") is any material engineered to have a property that is not found in naturally occurring materials. They are made from assemblies of multiple elements fashioned from composite materials such as metals and plastics. The materials are usually arranged in repeating patterns, at scales that are smaller than the wavelengths of the phenomena they influence. Metamaterials derive their properties not from the properties of the base materials, but from their newly designed structures. Their precise shape, geometry, size, orientation and arrangement gives them their smart properties capable of manipulating electromagnetic waves: by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with conventional materials. Appropriately designed metamaterials can affect waves of electromagnetic radiation or sound in a manner not observed in bulk materials. Those that exhibit a negative index of refraction for particular wavelengths have been the focus of a large amount of research. These materials are known as negative-index metamaterials.

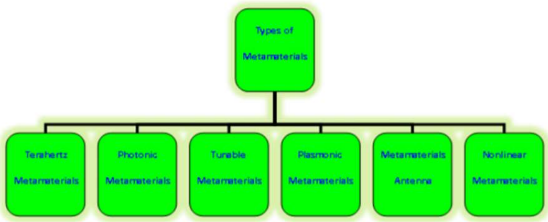


Fig 4.2(h): Types of Meta materials

Potential applications of metamaterials are diverse and include optical filters, medical devices, remote aerospace applications, sensor detection and infrastructure monitoring, smart solar power management, crowd control, radomes, high-frequency battlefield communication and lenses for high-gain antennas, improving ultrasonic sensors, and even shielding structures from earthquakes. Metamaterials offer the potential to create super lenses. Such a lens could allow imaging below the diffraction limit that is the minimum resolution that can be achieved by conventional glass lenses. A form of 'invisibility' was demonstrated using gradient-index materials. Acoustic and seismic metamaterials are also research areas. Metamaterial research is interdisciplinary and involves such fields as electrical engineering, electromagnetics, classical optics, solid state physics, microwave and antenna engineering, optoelectronics, material sciences, nanoscience and semiconductor engineering.

8.Neutralization line

The neutralization line is implemented to minimize the mutual coupling between the radiating patches. Consider an example, a design consists of two radiating elements and a U-shaped thin conducting strip is connected between them. Here that U-shaped thin conducting strip is the neutralization line. To improve the isolation, a rectangular strip is placed symmetrically between the neutralization lines. The simulated S-parameters of the antenna using neutralization line reduce the coupling between the patches. Thus, this technique is very effective to successfully improve the isolation which is one of the important factors for MIMO antenna to be used in the wireless applications. This can be explained by observing the flow of current on the neutralization line and on the ground plane. The direction of current at the center ground plane and on the rectangular strip are in opposite direction. This causes the cancelation of the field and hence the improvement in isolation is achieved between the two radiating elements.

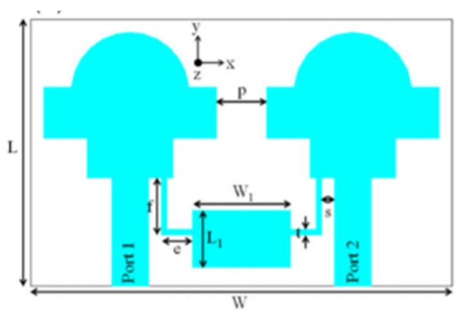


Fig 4.2(i): Example Design of Neutralization Line

9.Near Field Resonator

When a time varying magnetic field is generated from an antenna, it induces a time varying electric field which surrounds the primary magnetic field. This electric field then induces another time varying magnetic field creating a chain reaction of electric and magnetic field in space. Consequently, the magnetic field and the electrical field propagate in an interlinked form which is called an electromagnetic wave. The primary magnetic field continuously becomes an electromagnetic field and fully forms an electromagnetic wave at around distance of from the originated antenna, where is the signal wavelength. Although the primary magnetic field is emitted from the antenna, the electromagnetic wave which is induced from the magnetic field is no longer retroactive to the antenna. The range beyond point is called the far field where the electromagnetic wave is practically used in conventional wireless communication systems, while the range from the antenna to this point is called the near field. Since electromagnetic wave barely exists in the near field, it is difficult to use the conventional wireless communication system. However, the characteristic of near field enables resonant inductive coupling, which leads to a feasible communication channel for the near field. This near field channel can be utilized by simply using coils (resonators) that are strongly coupled at the same resonant frequency.

4.2.4 Electromagnetic Band Gap Structure

Even if you've never heard of an electromagnetic bandgap (EBG) structure, you've probably heard of via fences. A via fence is likely the simplest type of EBG structure you'll encounter in most RF designs, but variations on via fence structures can be designed to provide wideband isolation between antenna arrays. These structures can be used to address two of the four isolation points listed above: surface wave suppression and waveguide mode suppression.

Conceptually, these structures can be analyzed electrostatically or using a circuit model; both aspects provide an understanding of how these structures aid isolation. In terms of a circuit model, these structures can be analyzed as LC band stop filters, producing high impedance at the resonance frequency for the structure. Placing multiple EBG structures in parallel (i.e., in multiple layers) or in series (i.e., next to each other on the same layer), allows the resonance and bandwidth to be precisely tuned to desired values. Moreover, stacking in parallel effectively forms a higher order filter and narrows the structure's bandwidth.

Although EBG structures take up more board space than a via fence, they can be designed to provide much higher isolation. In addition to providing antenna isolation through surface wave and waveguide mode suppression, EBG structures also help suppress simultaneous switching noise (SSN) in a PDN. This makes them quite useful for analog components running at a single frequency or a small number of frequencies, but they are not so useful for digital PDNs. This is because, like digital signals, SSN in a digital PDN occurs over a broad bandwidth.

The design and analysis tools in Altium Designer can help you design a matching network, analyze circuit models for EBGs, or layout your boards for sufficient isolation. The layout tools are ideal for designing EBGs in your board, and its simulation tools can help you tune your matching networks and analyze circuit models for your isolation structures. Altium Designer also includes an integrated set of tools for building schematics, managing components, and preparing deliverables for your manufacturer.

The proposed EBG structure is shown in Figures. An EBG structure can be described by an equivalent capacitance C, introduced by the gaps between the adjacent stubs, and furthermore, inductor L is the result of the current flowing through the stubs. The center frequency of the bandgap is given by:

$$F_c = \frac{1}{(2\pi\sqrt{lc})} GHz$$

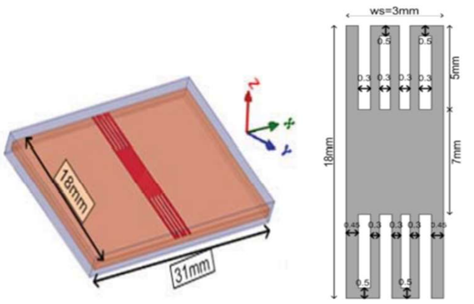


Fig 4.2(j): Proposed EBG Structure

In order to predict the frequency selective behavior of the EBG structures, the dispersion characteristics should be extracted. The dispersion characteristic is the plot of propagation constant of every mode versus frequency. To obtain such plots, eigenvalues of the electromagnetic problem should be found. Band gaps occur in frequency intervals, where no dispersion curves in the slow-wave region are present. To show the effectiveness of the band-gap design, the dispersion diagram of the optimized dimension EBG structure is plotted in Figure 6(c) based on the eigenmode analysis. Finally, EBG cell dimensions are tuned to have a bandgap over the desired frequency band.

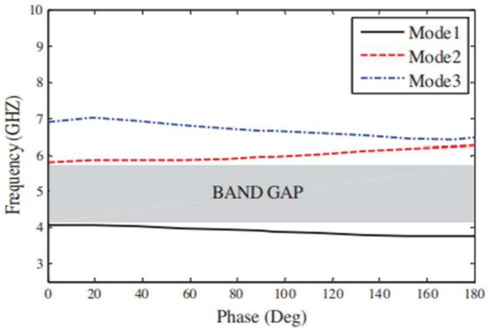


Fig 4.2(k): Dispersion diagram of the proposed EBG

4.3 High Isolation MIMO Antenna Designs:

4.3.1 Design-3 Antenna with only stubs

We know that in order to improve the isolation and decrease the mutual coupling between the antenna elements we are using the method EBG Structure and it will be done by 2 methods. In design-3, we are implementing the first step. In first step we are going to add only stubs on the ground plane using the dimensions mentioned in Table.

Variable	Dimensions (mm)	Variable	Dimensions (mm)
L	26	W	31
L_{fs}	4	W_{fs}	0.8
L_f	9	W_f	1.4
L_1	8	W_1	11
L_2	1.5	W_2	8
L_3	0.5	W_3	5
L_g	8	W_4	8
L_s	7	W_s	3
D_s	6	L_{s1}	5
gs	0.45	gw	0.3

Table 1: Dimensions of the proposed antenna

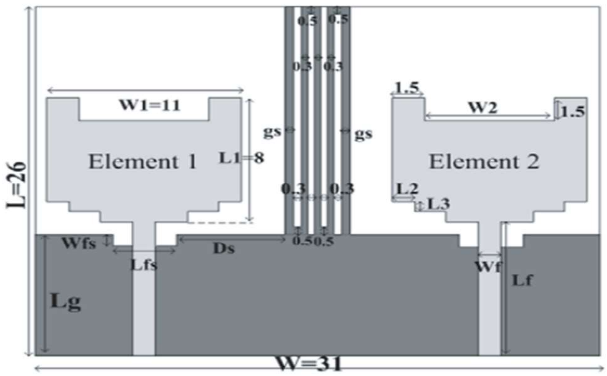
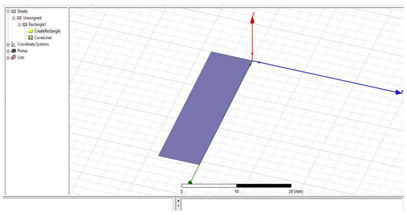


Fig 4.3(a): Design of antenna with only stubs

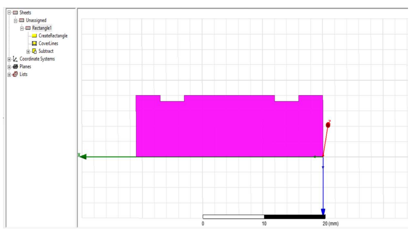
Following are the steps involves in designing the antenna with only stubs:

Step 1: To create ground plane, first draw a rectangle of dimensions 31 x 8mm2 using rectangle in HFSS software.

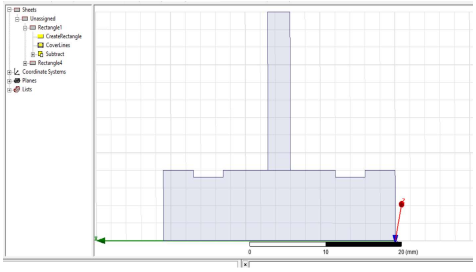


Step 2: To make slots on the ground plane. Draw two rectangles at positions (4, -8,0) and (23, -8,0) with dimensions 4 x 0.8 mm2.

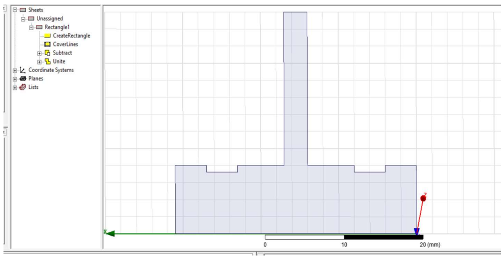
Step 3: Cut the slots from the ground plane using subtract function. Select rectangle 1, rectangle 2 and rectangle 3 in the same order, Right click à Edit à Boolean à Subtract. Then it removes rectangle 2 and rectangle 3 from rectangle 1.



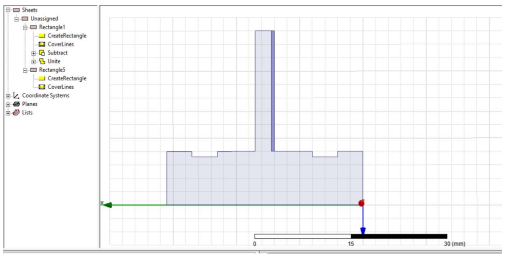
Step 4: Now to add stubs draw a rectangle 4 with dimensions 18 x 3 mm2 at position (14,-8,0).



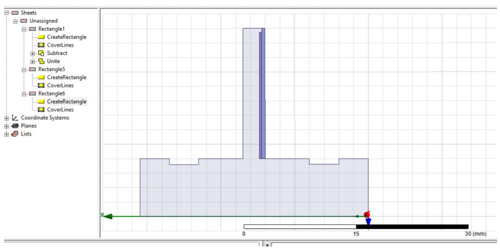
Step 5: Combine both of them using unite function. Select rectangle 1 and rectangle 4 in the same order, Right click à Edit à Boolean à Unite. Then it combines rectangle 1 and rectangle 4. Name it as Ground.



Step 6: Draw a rectangle 5 with dimensions 18 x 0.45mm2 at position (14,-26,0) as shown below.

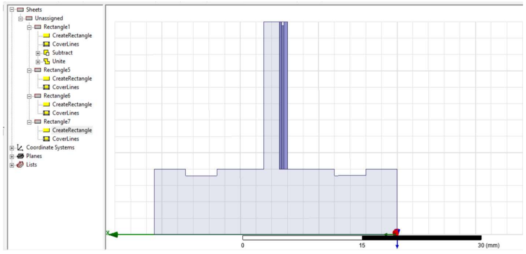


Step 7: Draw a rectangle 6 with dimensions 17.5 x 0.3mm2 at position (14.45,-8,0) as shown below.

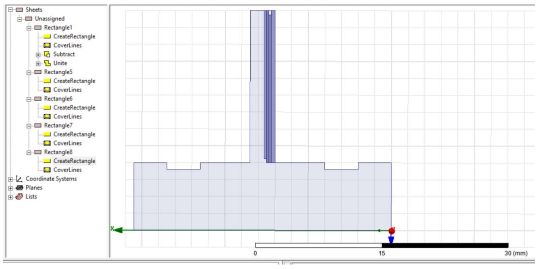


Step 8: Draw a rectangle 7 with dimensions 18 x 0.3mm2 at position (14.75,-8,0) as shown

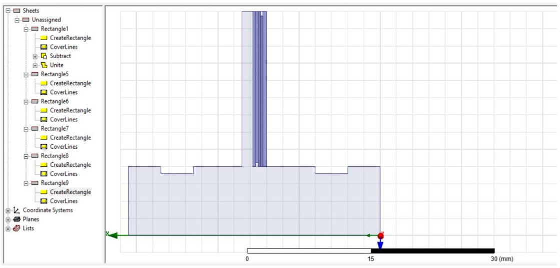
below.



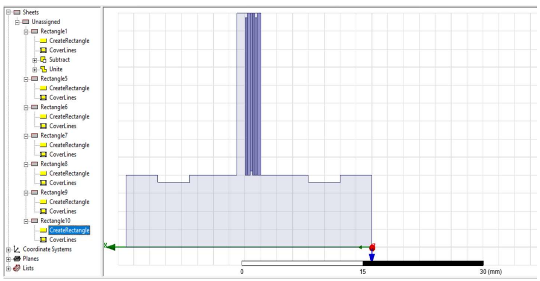
Step 9: Draw a rectangle 8 with dimensions 17.5 x 0.3mm2 at position (15.05,-26,0) as shown below.



Step 10: Draw a rectangle 9 with dimensions 18 x 0.3mm2 at position (15.35,-26,0) as shown below.

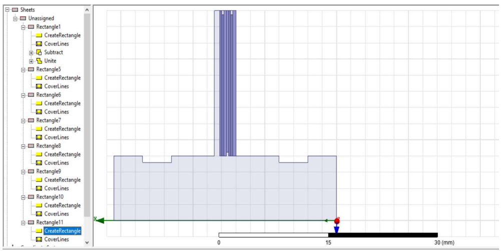


Step 11: Draw a rectangle 10 with dimensions 17.5 x 0.3mm2 at position (15.65,-26,0) as shown below.

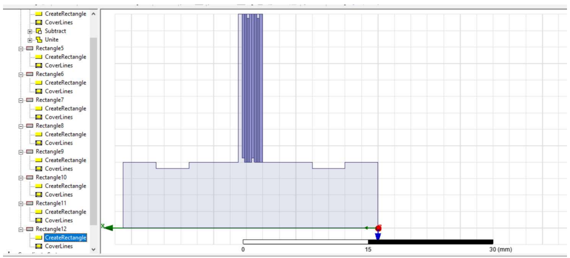


Step 12: Draw a rectangle 11 with dimensions 18 x 0.3mm2 at position (15.95,-8,0) as shown

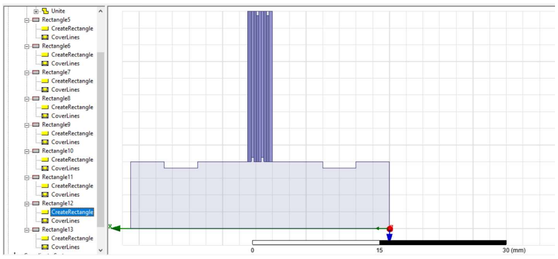
below.



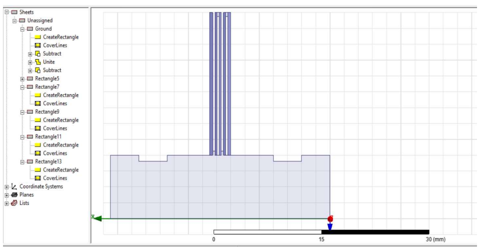
Step 13: Draw a rectangle 12 with dimensions 17.5 x 0.3mm2 at position (16.25,-26,0) as shown below.



Step 14: Draw a rectangle 13 with dimensions 18x 0.45mm2 at position (17,-26,0) as shown below.

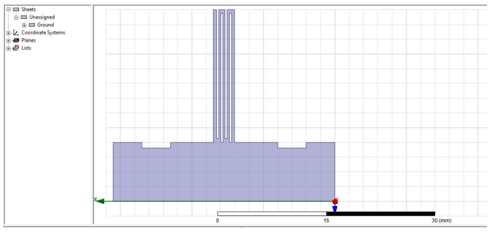


Step 15: Cut the slots from the ground plane using subtract function. Select ground, rectangle 6, rectangle 8, rectangle 10, rectangle 12 in the same order, Right click → Edit → Boolean → Subtract. Then it removes rectangle 6, rectangle 8, rectangle 10, rectangle from ground plane.

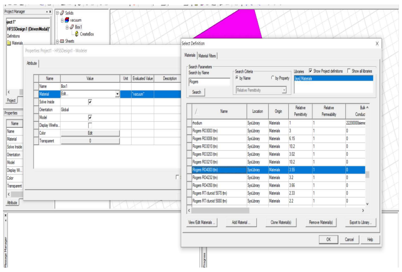


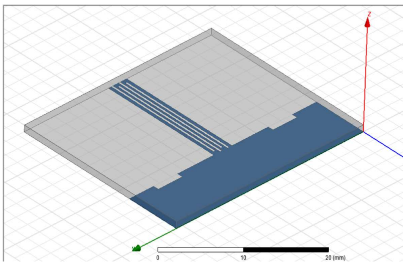
Step 16: Select rectangle 5, rectangle 7, rectangle 9, rectangle 11, rectangle 13 and delete them,

Right click → Edit → Boolean → Delete. This is the ground plane with only stubs.

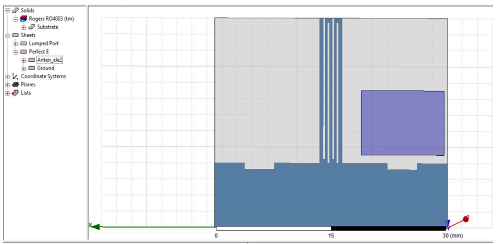


Step 17: To create substrate, first draw a rectangular box of dimensions 26 x 31mm2 at position (0,0,0) and dielectric material Rogers RO4003 with a thickness of 0.7874 using box in HFSS software.

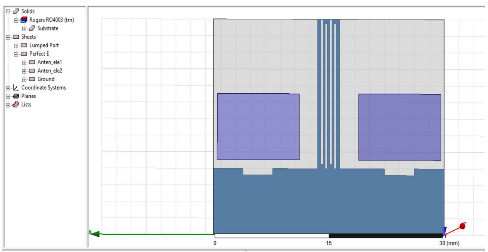




Step 18: Now draw a rectangle at position (0.5,-9,0.7874) with dimension 8 x 11 mm2 and name it as Anten_ele2 to create patch2.

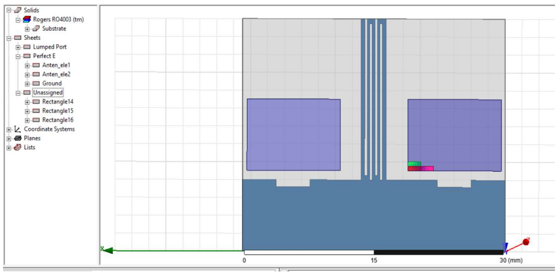


Step 19: Now draw another rectangle at position (30.5,-9,0.7874) with dimension 8 x 11 mm2 and name it as Anten_ele1 to create patch1.

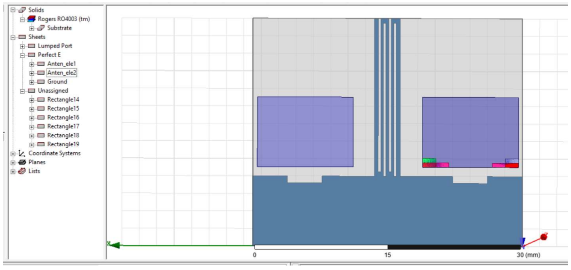


Step 20: Now to form stair-case structure draw 3 rectangles with dimension 1.5 x 0.5 mm2 as

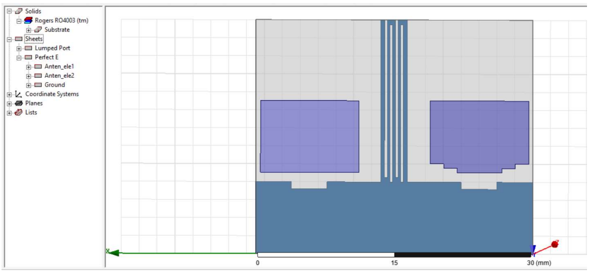
shown below.



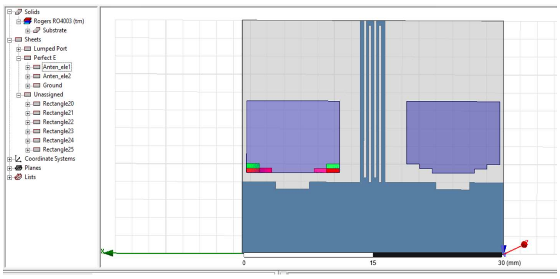
Step 21: Similarly, to form stair-case structure on opposite side draw 3 rectangles with dimension 1.5 x 0.5 mm2 on opposite side as shown below.

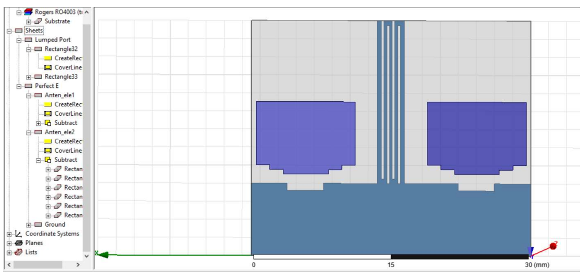


Step 22: Now subtract rectangles numbered 14,15,16,17,18,19 from Anten_ele2 i.e., from patch2.Then it looks as shown below.

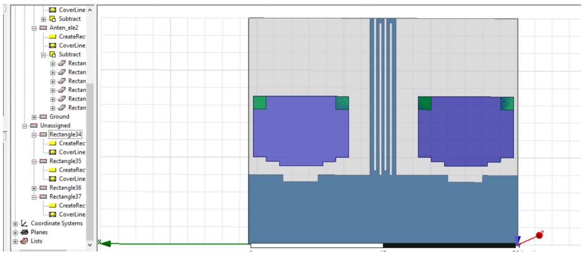


Step 23: Follow both step and step for Anten_ele1 i.e., patch1.After that it will be as shown below.

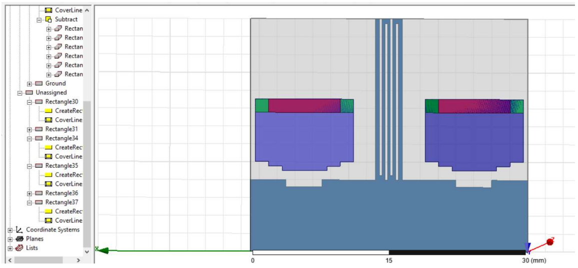




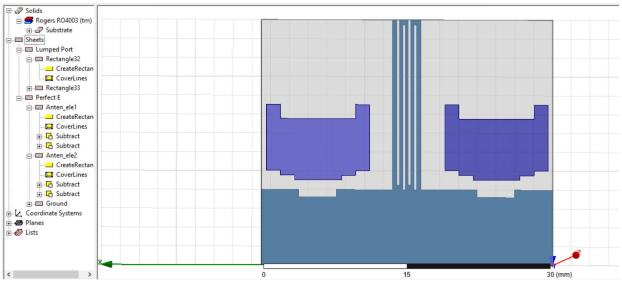
Step 24: Draw a square with dimension 1.5 x 1.5 mm2 on top right and left corners/edges of patch1 and patch as shown below.



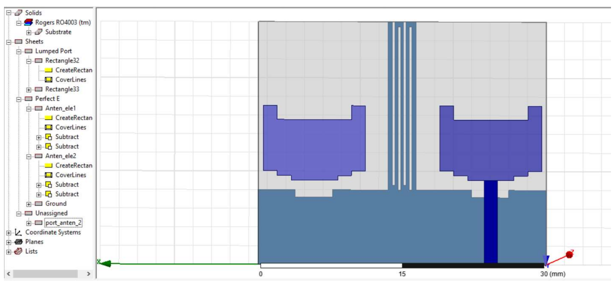
Step 25: Now draw a rectangle in between these two squares in both patch1 and patch2.



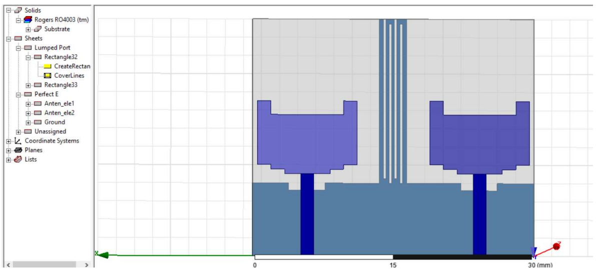
Step 26: Subtract rectangle 31 from patch2 and rectangle 30 from patch1.Then delete the four squares to obtain the required patch design.



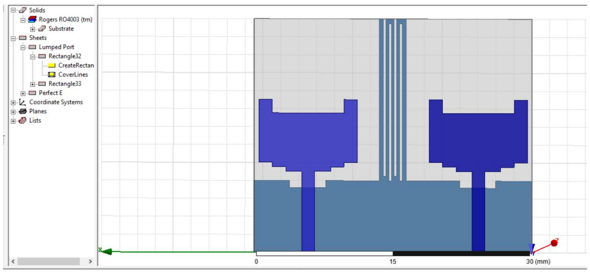
Step 27: Now draw a rectangle at position (5.3,0,0.7874) with dimension 1.4 x 9 mm2 and name it as port_anten_2(it is the microstrip feedline for element 2).



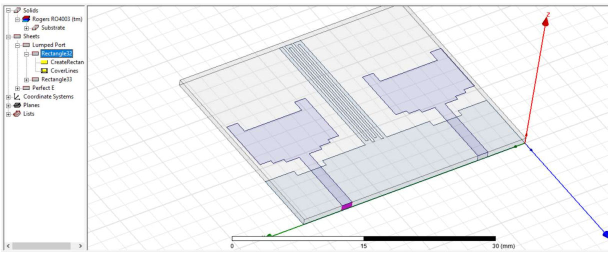
Step 29: Now draw a rectangle at position (24.3,0,0.7874) with dimension 1.4 x 9 mm2 and name it as port_anten_1(it is the microstrip feedline for element 1).



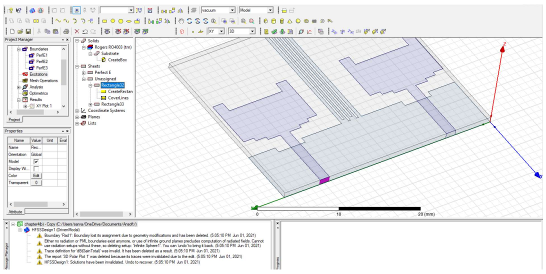
Step 30: Unite Anten_ele1 with port_anten_1 and Anten_ele2 with port_anten_2.

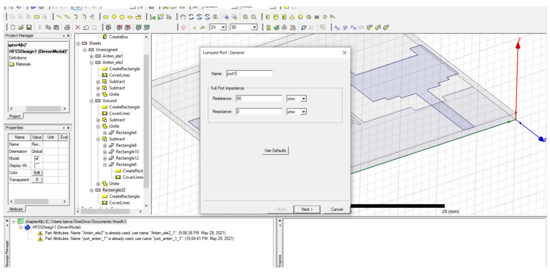


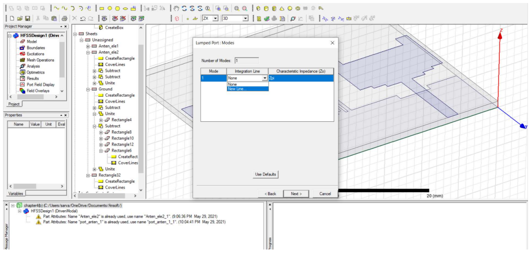
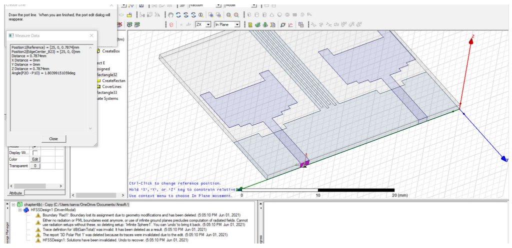
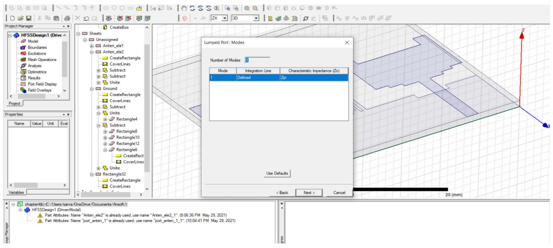
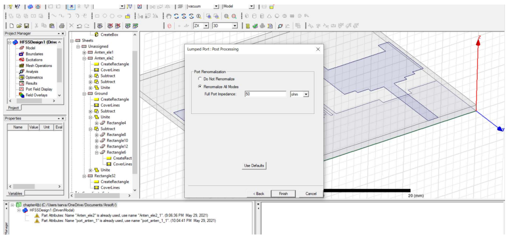
Step 31: Now we need to add feed to both ports. First for Anten_ele1, draw a small rectangle as shown by changing plane from XY to ZX.



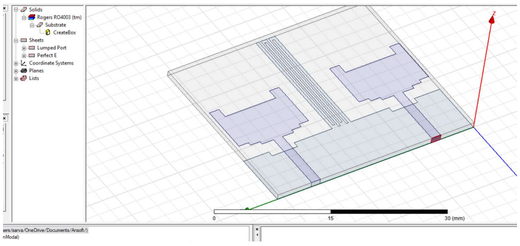
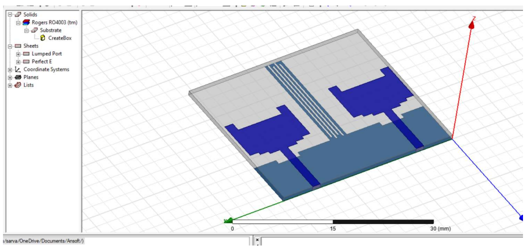
Step 32: To add excitation to port1.Select that rectangle→Right Click→Select Faces→Assign Excitation→Lumped port.





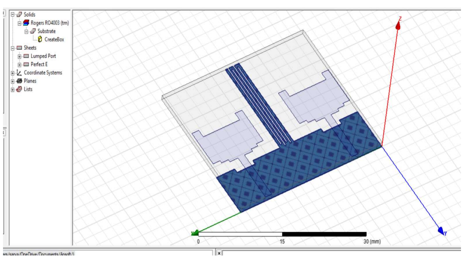
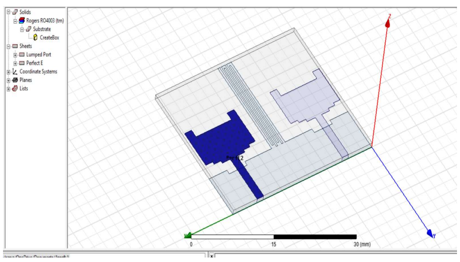
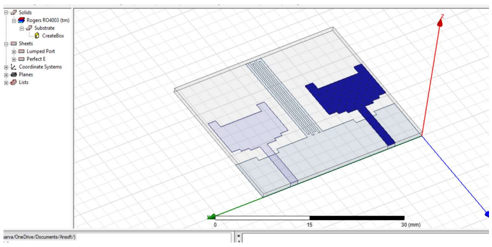





Step 33: Repeat the same steps for port2 also.

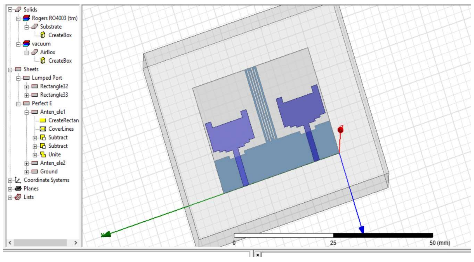



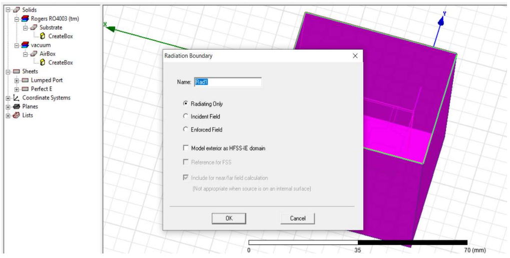
This is the design of the antenna.

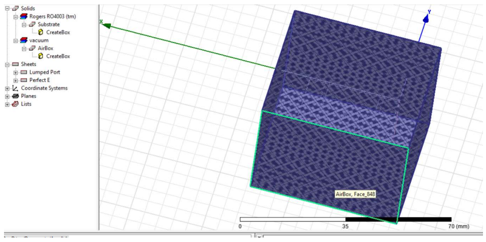
Step 34: We need to add PerfectE boundary to ground, Anten_ele1, Anten_ele2.Select each one→Right click →Assign boundary→PerfectE. Follow same steps for ground, Anten_ele1, Anten_ele2.

Step 35: Create an Airbox with dimension and add Radiation boundary to Airbox. Select all phases of airbox→Right click →Assign boundary→Radiation.







4.3.2 Design-4 Antenna with EBG Structure

In design-4, we are implementing the second step. In second step, the stubs on the ground plane are linked by a small metal strip with dimension of W s × Ls mm2 in Table.

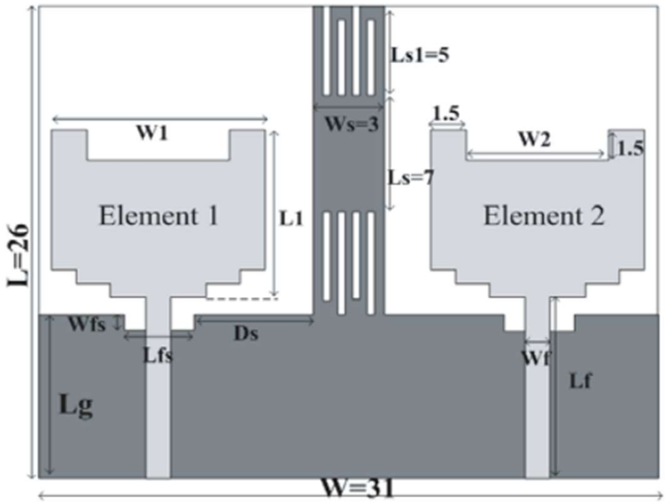
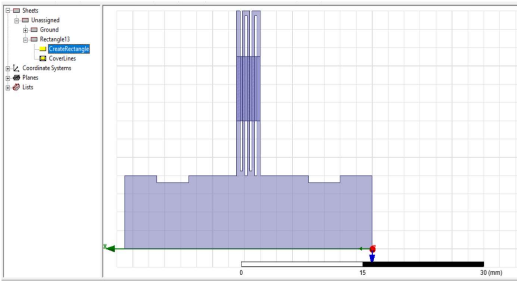


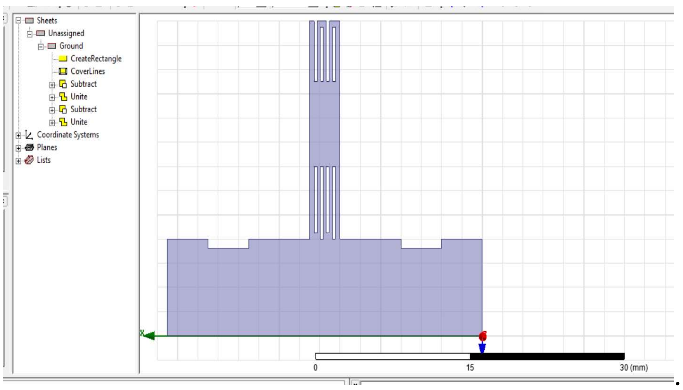
Fig 4.3(b): Design of the proposed MIMO Antenna

For this design, the same steps from step-1 to step-16 of the design-3 are followed. After that the following steps needed to be performed.

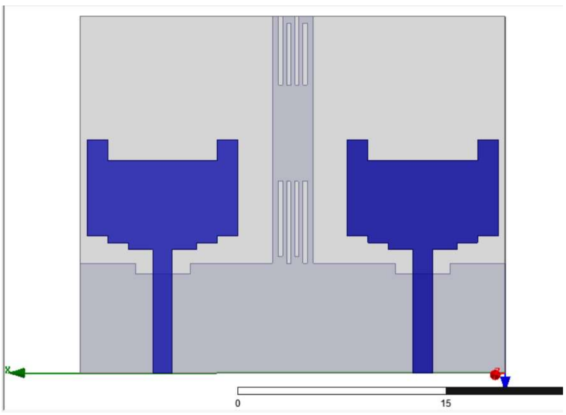
- Now stubs on the ground plane are linked by a small metal rectangular strip with dimension of 3 x 7 mm2 at position (14,-21,0) . This has formed a comb-line structure on the ground.



- Combine ground and small metal strip using unite function. Select ground and rectangle 13 in the same order, Right click → Edit → Boolean → Unite. Then it combines ground and rectangle 13.



After the above two steps, the remaining steps are same as step-17 to step-35 of design-3 antenna. Then the designed antenna is simulated and results are obtained.

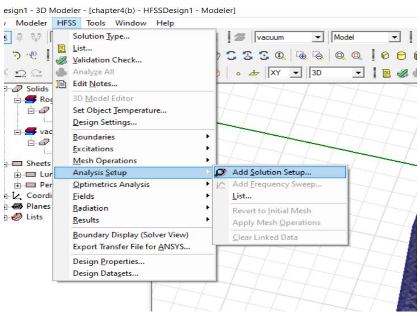


4.4 Results

To obtain the results we need to follow the steps:

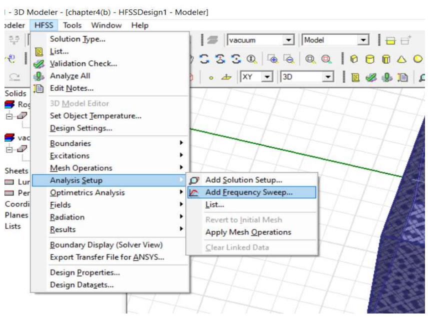
1)Add solution setup

- HFSS → Analysis setup → Add solution set up
- Set resonance frequency as Solution frequency



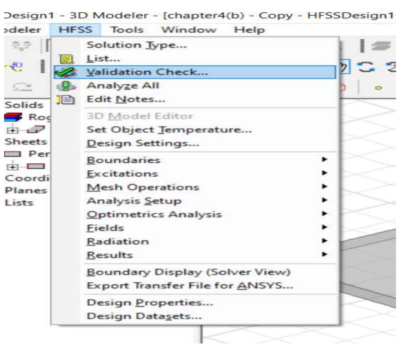
2)Add frequency sweep

- HFSS → Analysis Setup → Add Frequency Sweep

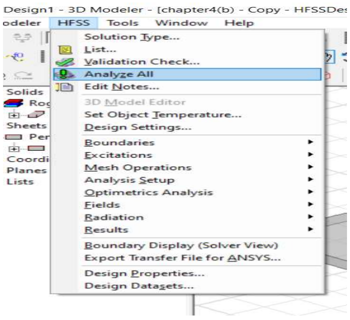


3)Validation check

- HFSS → Validation Check



4)Analyze all



4.4.1 Results of Design-3

The prototype of the antenna with only stubs is designed and simulated. The simulated S-parameters of the design-3 are shown in figure. The impedance bandwidth with return loss (S11 < -10dB) i.e., -23dB, can cover the bandwidth 3.16GHz to12.11GHz and the mutual coupling is less than -25dB i.e., -48.38dB covers the UWB band. Here we can see the gain of the antenna is 3.7971dB in 3D Polar plot in Fig.

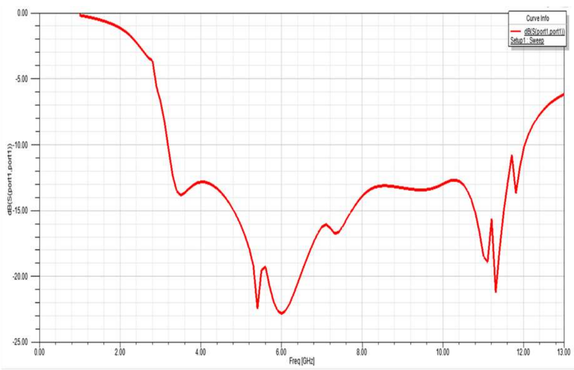


Fig 4.4(a): S11 parameter for the MIMO antenna with only stubs

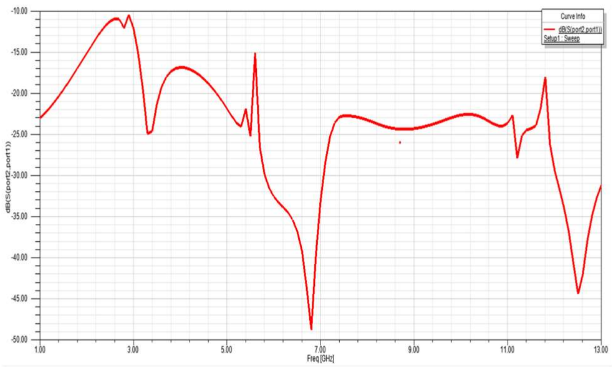


Fig 4.4(b): S21parameter for the MIMO antenna with only stubs

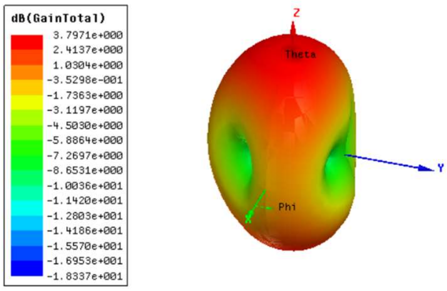


Fig 4.4(c): 3D-Polar plot for gain of MIMO antenna with only stubs

4.4.2 Results of Design-4

The paradigm of the described MIMO antenna is designed and simulated. The simulated S-parameters of the final design are shown in Figure 12,13. The impedance bandwidth with return loss (S11 < -10dB) i.e.-23.4dB, can cover the whole UWB bandwidth 3.19GHz to 12.05GHz and the mutual coupling is less than -25dB i.e., -53dB covers the UWB band.

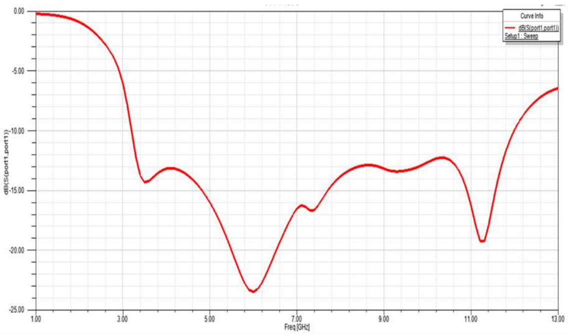


Fig 4.4(d): S11 parameter for the proposed two port MIMO antenna-Reflection Coefficient.

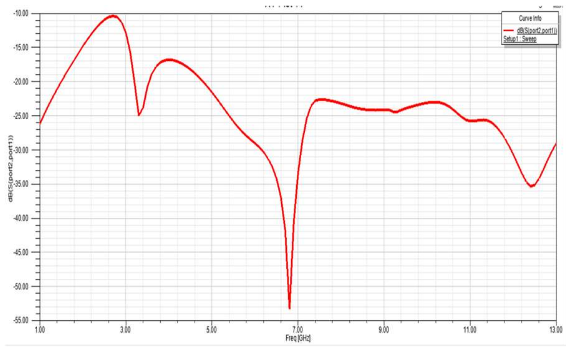


Fig 4.4(e): S21 parameter for the proposed two port MIMO antenna-Isolation.

The measured peak gain ranges from 3.8 to 7.2dB across the UWB band as shown in Figure 14. Figure 15 represent the measured efficiencies of the antenna and the measured efficiency is above 95% across the UWB frequency band. The overall gain of the antenna is 3.88dB shown in Figure 16.

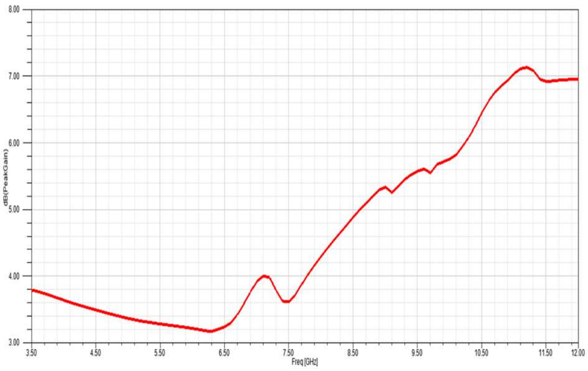


Fig 4.4(f): Peak Gain of proposed MIMO Antenna

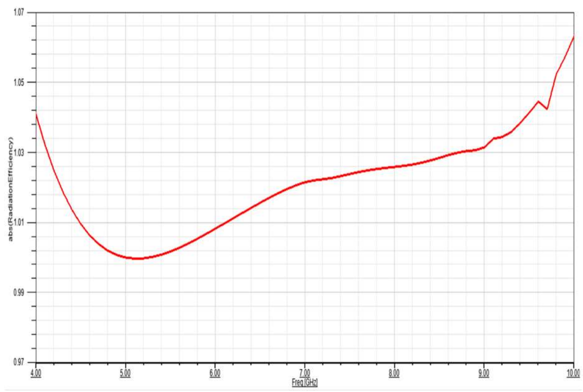


Fig 4.4(g) Efficiency of proposed MIMO Antenna

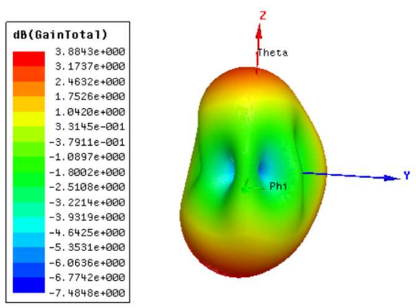


Fig 4.4(h): 3D-Polar plot for gain of proposed MIMO Antenna

Envelope correlation coefficient (ECC) is an important parameter for evaluating the MIMO/diversity performance. Two methods can be used to find ECC: 1) based on the far field radiation pattern 2) based on the knowledge of scattering parameters. The far-field method is very time-consuming and requires complex and advanced calculations. Therefore, s-parameter method is adopted for the calculated correlation coefficient in this study, as in:

The calculated result of the proposed MIMO antenna is exhibited in Figure 11. It shows that the proposed antenna has the ECC less than 0.3. Since the obtained ECC value is close to zero, the proposed antenna is more suitable for MIMO and UWB communications.

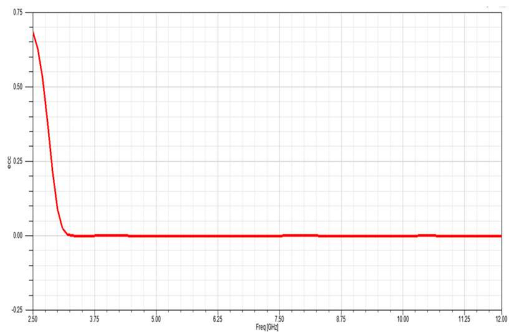
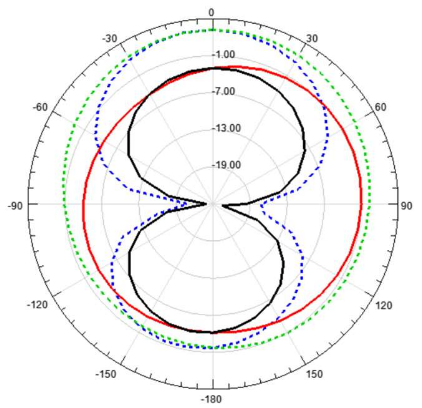
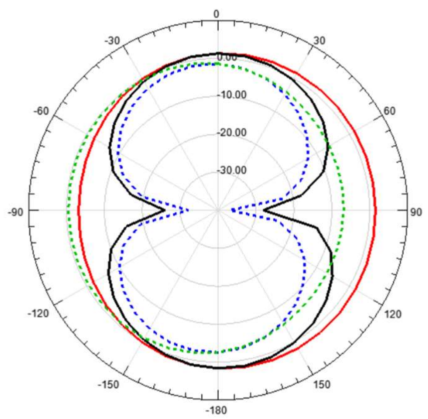


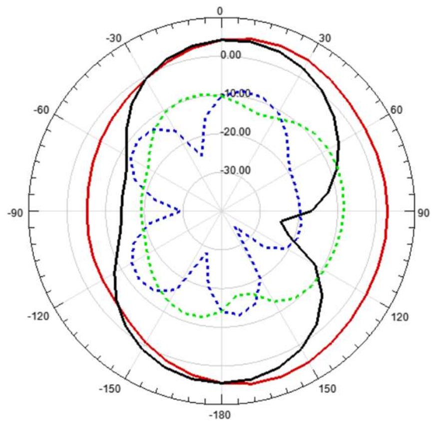
Fig 4.4(i): Correlation Coefficient for proposed MIMO Antenna

Figure 18 represents the radiation patterns of the proposed MIMO antenna at the frequencies of 3 GHz, 6 GHz and 10 GHz in the x-z (H) and y-z (E) planes when both port 1 and port 2 of the proposed MIMO antenna are excited.





(a)Measured Radiation Pattern at 3GHz **b) Measured Radiation Pattern at 6GHz**



(c)Measured Radiation Patterns at 10GHz

___ XZ plane(phi = 0deg) --- XZ plane(phi = 0deg)

Co-pol Cross-pol

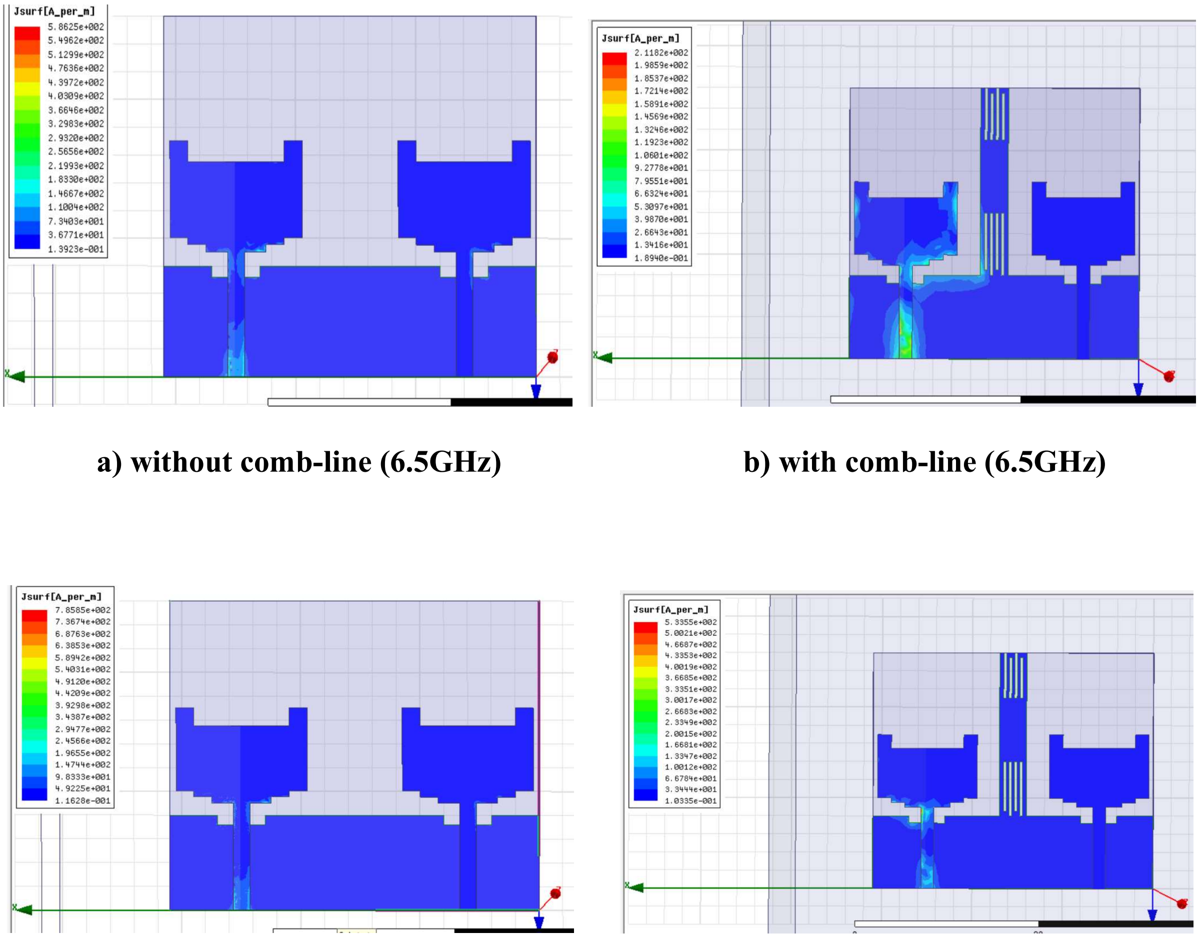
___YZ plane(phi = 90deg) --- YZ plane(phi = 90deg)

Co-pol Cross-pol

Fig 4.4(j): Simulated radiation patterns with both port1 and port2 excited (a)at 3GHz, (b)at 6GHz and (c)at 10GHz.

To additionally explore the effect of comb-line structure, the simulated surface current distributions of the antenna with and without any comb-line structure at 6.5 GHz and 9 GHz are shown in Figure 11.

When port 1 is exited and port 2 terminated with a 50-Ω load without using the comb-line structure, a strong induced current appears on port 2. Besides, a definite quantity of ground current also flows to the ground plane of the other element when the two antennas are keenly placed. The acquired current increases mutual coupling between the two ports. However, when the comb-line structure is linked to the ground plane and port 1 exited, notable amounts of current are integrated on the comb-line structure, which disables the induced current on port 2 antenna element. Thereby, a low mutual coupling between the two ports or antenna elements is achieved. This effect is the same when port 2 is exited and port 1 terminated with a 50-Ω load.



a) without comb-line (6.5GHz) b) with comb-line (6.5GHz)

c) without comb line 9GHz d) with comb line 9GHz

Fig 4.4(k) Surface current distributions of the MIMO antenna with and without comb-line structure.

4.5 Conclusion

From the results obtained, it can be affirmed that isolation is a very important parameter while designing an antenna. Here we have keenly studied about isolation and its need, also examined various types of techniques to improve the isolation between the ports in an antenna and to combine UWB technology with MIMO techniques to reduce the mutual coupling between elements while attaining a compact size. In our design, we have implemented EBG structure technique for improving isolation because it is an efficient technique to enhance isolation and increase impedance bandwidth across the whole UWB band. When we compare the results of both design-3 and design-4, the return loss and gain values are increased from design-3 to design-4. In design-3 the isolation is good but it doesn't provide the required isolation in the band range of 5-6GHz. This problem is overcomed in design-4 by placing a small metal strip on the stubs that has provided good isolation in that 5-6GHz range too. Hence, we can conclude that the design of MIMO antenna for UWB application using Electromagnetic Band Gap Structure is an efficient technique to improve isolation or to reduce mutual coupling of the antenna.

CHAPTER-5

Results and Discussion

When we compare all the design results, we can say that the proposed antenna has increased gain compared to the previous designs. We have acquired the required UWB range i.e., 3.19 to 12.05 GHz and improved isolation of -53dB with good return loss value i.e., -23.4dB.

Initially we have designed a single element antenna with resonant frequency 6.85GHz that resulted in obtaining the bandwidth 5.90GHz to 10.64GHz and obtained a gain of 2.9241dB with a return loss -18.6337dB. Since the required bandwidth is not obtained and also to increase the gain we have placed two antenna elements close to each other at a distance 8mm and observed that the gain has been increased to 3.6530dB but isolation is -17.2218dB to improve isolation and to decrease the mutual coupling we have many techniques on that we have used Electromagnetic Band Gap (EBG) Structure.

S.No	**Parameters**	**Values of Design 1**	**Values of Design 2**	**Values of Design 3**	**Values of Design 4**
1.	Gain	2.9241	3.6530	3.7971	3.8843
2.	Return Loss	-18.6337	-16.8319	-29.6892	-23.4
3.	Bandwidth	4.9200(5.90 to 10.64 GHz)	6.3700(5.2 to 11.57 GHz)	8.95(3.16 to 12.11 GHz)	8.89 (3.19 to 12.05 GHz)
4.	Isolation	--	-17.2218	-48.3873	-53.0333

Table 5.1 Comparison of results of all the designs

We have implemented this EBG Structure using two mechanisms i.e., (1) Stubs of the ground plane can reduce the mutual coupling between the two elements by capturing currents towards them. Using stubs improved the impedance matching for UWB operation and also increased the isolation between 2 antenna elements. But we have not obtained the low mutual coupling at 5-6 GHz. The simulated S11 and S21 parameter values of the MIMO antenna are shown.Due to the symmetrical structure of the antenna and S22 and S12 are similar to S11 and S21, respectively so we have only decided S11 and S21. Hence, we can observe that using the stubs has increased the isolation between the two radiating elements, improved impedance matching and satisfied the specifications for UWB operation, when compared with the case without any decoupling structure. The calculated result of the proposed MIMO antenna shows that the proposed antenna has the ECC less than 0.3. Since the obtained ECC value is close to zero, the proposed antenna is more suitable for MIMO and UWB communications. The radiation patterns of the proposed MIMO antenna at the frequencies of 3 GHz, 6 GHz and 10 GHz in the x-z (H) and y-z (E) planes when both port 1 and port 2 of the proposed MIMO antenna are excited. Envelope Correlation Coefficient is also analysed which resulted in isolation less than -25dB i.e., -55.2dB, ECC < 0.3 for required operating frequency range. The Co-polarization and Cross-polarization for the proposed antenna are also with good difference. The proposed antenna also exhibited a satisfactory gain of 3.2 to 7dB in the mentioned operating range. So, from the obtained results we can conclude that the proposed antenna is compact and suitable for UWB MIMO applications such as LTE, Wi-Fi and WLAN applications.

CHAPTER-6

Conclusion

A Dual port compact high isolation MIMO antenna with comb-line structure is employed in this model. The MIMO antenna achieved wide band range of 5.90 to 10.64 GHz. In order to increase in bandwidth to cover UWB Spectrum and also to include MIMO technology, we have placed two identical antennas close to each other and also added an EBG Structure (i.e., comb-line structure) to the ground plane. This antenna with comb-line structure has ultra-wide band range of 3.19 to 12.08GHz with 8.89 GHz impedance bandwidth. Envelope Correlation Coefficient is also analysed which resulted in isolation less than -25dB i.e., -55.2dB, ECC < 0.3 for required operating frequency range. The Co-polarization and Cross-polarization for the proposed antenna are also with good difference. The proposed antenna also exhibited a satisfactory gain of 3.2 to 7dB in the mentioned operating range. So, from the obtained results we can conclude that the proposed antenna is compact and suitable for UWB MIMO applications such as LTE, Wi-Fi and WLAN applications.

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