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DELHI TECHNOLOGICAL UNIVERSITY

COMPARISON STUDY ON MICROWAVE ANTENNAS

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A COMPARISON STUDY ON MICROWAVE ANTENNA EFFICIENCY

A Minor Project Presented

by

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ABSTRACT

A microwave antenna is a metallic device used for radiation of radio waves, which is used in transmission of signals. Two types of antennas are used, one to transmit data and the other to receive it. A transmission line is used as a guiding device which transmits electromagnetic energy from the source of the antenna. Along with this, a wireless system is used to optimize the radiation energy in a particular direction and it is also used to suppress the same in other directions. An antenna serves both as a direction device and a probing device. Therefore, an optimum design is needed to improve the performance of the whole system. A comparative study of antennas is presented in this project. Through this, we aim to create a robust model of comparison and analyze different simulated antennas on different parameters. A comprehensive evaluation scheme is provided on how to choose antennas according to the applications required. The research problems investigated in this project is how to increase the bandwidth and radiation efficiency of the antennas using slots and different design equations. Metamaterials have also been used as a substrate for performance enhancement. For our design purpose, we have used the already researched design equations obtained using different methods like FDTD and manipulated the size of the antennas to obtain different parameters for our study.

Keywords- Microwave antenna, Radio waves, transmission line, radiation energy, bandwidth, metamaterials, FDTD

INTRODUCTION

An antenna converts AC to EM waves and also performs the converse operation. Antennas were first created and discovered by Hertz when he was tinkering with the idea of proving the existence of EM waves. Hertz used the antenna as a proof for the existence of EM waves and subsequently revolutionized the world. Nowadays these antennas are used in applications quite diverse ranging from TV to GDR and GPS. They have been extensively used in every domain for benefiting civilians and military personnel. Our research work mainly deals with the project in the microwave frequency range.

We have designed antennas in the operation range from as low as 2.4 Ghz for applicability in ISM band using the microstrip patch antenna to as high as 13 Ghz with the slotted Vivaldi antenna. Microwave frequencies are essential to many applications. It is widely used for point-to-point communication systems both at Earth and for communication between satellites. This range of wavelengths from 1-30 Ghz is succeeded by the Mm waves. These bands cannot be utilized efficiently due to two main reasons. The first important reason is the fact that these wavelengths are attenuated quite harshly by the atmosphere, especially the oxygen molecules. Atmospheric effects and menial changes can therefore impact their propagation in quite huge ways making them unsuitable for transmission. Changes like heavy rain, snowfall, humidity, temperature, etc. are also essentialities that need to be considered.

Perhaps an example of a simple antenna is the ever-present dipole. It is a simple device made up of two wires and on which AC voltage is applied. The rate of oscillation of the waves transmitted is defined as the frequency of the operation. It can be also explained as the change in polarization per second. Giving respect to the father of the antenna, this physical quantity was named Hertz. The size of the antenna is straightforwardly related to the frequency of operation. The length is usually half of the operation wavelength. Since the product of the wavelength and the frequency equals the velocity of light, therefore wavelength and frequency are inversely related. This makes an increase in frequency lead to the shortening of the antenna dimensions.

In the research study, we have used a broad array of terms to compare the different antennas. This would be the right time to define these terms. We have used terms such as bandwidth, return loss, VSWR, Gain, Directivity and radiation efficiency as a measuring stick to guide potential users to applications. The term "return loss" is nothing but the first term in the scattering matrix of a network topology. This S11 when measured in dB is usually called return loss. Bandwidth for an antenna has multiple definitions. The most commonly used definition is the range of frequencies over which the return loss of an antenna is a less than -10 dB. This definition can also be replaced with another popular one. The other famous defining condition is the restriction placed on the VSWR. The range over which the VSWR is less than 2 can be used as bandwidth for the circuit. The VSWR is defined as the ratio of the maximum to minimum voltage transmitted in a waveguide. It is basically the measure of how well the information is transmitted from one end to another. It should be < 2 for more than 90% of the information to be transmitted effectively. The last three terms are fairly well defined in the antenna theory. Gain is simply a ratio of output power to input power. Directivity is nothing but a measure of how well coupled/focused a beam transmitted by the antenna is. Radiation efficiency is the ratio of max gain to max directivity highlighting a tradeoff between these above quantities.

Antennas play a major role in the world. If the performance of an antenna is poor, the system will get hampered and will lead to a multitude of problems. Thus, it is necessary for there to be a qualitative study on the development of antennas over the years and how we can choose an antenna for us based on the applications. We have compared 6 antennas in depth along with their design models in HFSS or CST whichever seemed to be a better tool. We have also consolidated this information in a table at the end of the report while giving numerical analysis in the calculation part.

LITERATURE REVIEW

Dual band single layered rectangular microstrip patch antennas were first studied experimentally which showed that on changing the length and width of the antenna, there is presence of dual resonance in which the lower resonance frequency increases and upper resonance frequency is almost constant. A wideband microstrip patch antenna finds uses in local area networks. Different materials for substrate were tested and on giving the input in the range of 4.7-6.5GHz, the output can be controlled in a range of 5-5.8GHz. For bandwidth extension, stacked microstrip patch antennas were developed in which a conductive plate is placed above the patch to improve the bandwidth in this case.

The microstrip antenna which has an improved gain is made as a planar array. But by joining parasitic components in the direction of radiation, it can also be constructed, over a patch. It was found that the bandwidth of the patch antennas increases by placing a parasitic component above the patch. 3 components

1) Radiating component
2) Parasitic component to improve bandwidth (matching element)
3) Parasitic component to improve the gain(director)

are used to improve the overall efficiency.

Among the designed antennas, the Vivaldi antenna is considered the most advanced antenna because of its increased sphere of applications such as wireless communications, military and biomedical engineering. In the beginning, a high gain Vivaldi antenna was constructed by mounting a dielectric constant. The wideband applications were later presented by designing the feeding structure of the antenna effectively. In order to improve the voltage standing wave ratio (VSWR), the notched radiator with etched slots were used. Vivaldi antennas are used in applications such as biomedical in which the frequency range required is 0.5-4 GHz.

The Yagi-Uda antenna was created by H. Yagi and S. Uda and it was distributed in English within the Procedures of the Majestic Foundation in Japan in February 1926 and until 1928 this paper was credited with bringing the concept of the Yagi-Uda antenna to the world. The fundamental Yagi-Uda antenna comprises a parallel set of straight dipole radiators. The furthest left component is somewhat bigger than resounding length and is called a reflector. The following component is a dipole component with a feed line. The furthest right components are slightly less than resonance length and are called directors. The space between components is approximately 0.2λ-0.3λ. The radiation is mainly to the right of the array and along the axis. Yagi-Uda antenna achieves gain of around 10db-20db. A customary Yagi-Uda comprises a number of direct dipole components with one of these components energized specifically by a feeding transmission line whereas the others act as parasitic radiators whose current are actuated by shared coupling. The parasitic components within the heading of the beam are smaller in length than the feed component. The distance between the driven element and the reflector is lower than the space between the driven element and the nearest director, presenting a size of sref of 0.25λ. In this antenna only a single element is fed directly and a feed network is not needed. In the USA and Europe, yagi is used in radio links and radar systems. Recent works have highlighted that microstrip antennas can be configured in a Yagi-uda model, which has applications like low angle satellite reception, predominantly used in mobile communications.

The microstrip Yagi array antenna has one patch element (driven), one parasitic reflector patch, and director patches, in a number of two or three. In this Yagi combined with microstrip, the flow of electromagnetic energy is through both space and the substrate from the driven patch to the parasitic patch. The patches are kept close in order to simulate a Yagi dipole behavior by which through surface waves, coupling can be done in the substrate. We notice that even though the coupling procedure is different in the conventional and the microstrip Yagi, the design rules are quite similar and the common major problem on how to increase the bandwidth is to increase the thickness of the dielectric substrate from the Radiator patch to the ground.

Ref No.	Approach	Conclusion
1	Modified ground plane with pairs of L-shaped slits and parasitic structures	Bandwidth of more than 130% (2.95-14.27 GHz) radiation efficiency is greater than 86%
3	VSWR and Radiation Pattern	Return loss of -29.2133 dB at 1.8 GHz
5	Inverted U-shaped slots and two L-shaped parasitic elements	Bandwidth of more than 130% (2.9-14.3 GHz) & good omni-directional radiation pattern
8	I-shaped slot on the feed-line and a pair of S-shaped slots in the ground plane	Wider impedance bandwidth & radiation efficiency is greater than 82%
12	Ground plane with inverted T-shaped notch	Bandwidth of more than 120% (3.12–12.73 GHz)
14	Half-wavelength parasitic element printed on the rear side of the substrate.	Impedance bandwidth of antenna is 3.1-11.4 GHz (114%)
15	Two monopoles of the same size and a small strip bar	Band notch mechanism of the antenna was examined with current distribution
16	Embedding a notch in the ground plane	Frequency band of 2.95 to 11.7 GHz with the stop band of 4.92 - 5.86 GHz.

THEORETICAL BACKGROUND

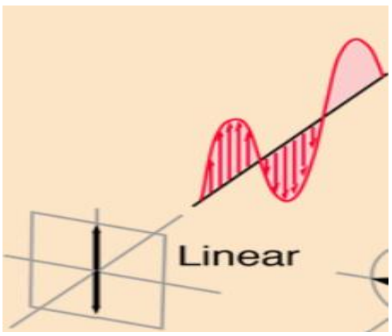
So how does an antenna work?

As mentioned at the start, the aim of an antenna is to convert the fed power into EM waves to transmit to a faraway receiver. This wave will then be subsequently received by another antenna operation similarly to the transmitter and the signal received will be demodulated and the encoded information will be used for its motive. The background to all things EM waves is the Maxwell equations. Since these equations describe the way electric and magnetic fields behave, they are quite important analytical tools for an antenna designer. A change in magnetic field causes a subsequent creation of the magnetic field and a changing electric field will be responsible for a current that creates a magnetic field. These laws help us visualize the inner working of an antenna and are pretty accurate descriptions of how the transfer of energy takes place.

Now the question arises whether an antenna can work as a transmitter and a receiver. This quality of reciprocity of the antenna is very very important in their employment around the world. Passive antennas work in the same way regardless of whether they are transmitting or receiving. The polarization and other properties for an antenna remain the same regardless of whether its acting as a transmitter or a receiver. For adequate understanding of how an antenna works, there is a need for knowing some more basic terms. The most important of them is perhaps the term "Polarization". Everyone knows what polarized glasses are. Polarized glasses basically reduce the effect of sunlight and thus reduce unwanted strain. But the term polarization actually refers to the plane in which the EM wave is vibrating. Since the antenna is a transducer, there is much needed for accurate understanding of how the EM wave is polarized. Usually there are two kinds of polarization seen in an antenna emitted wave.

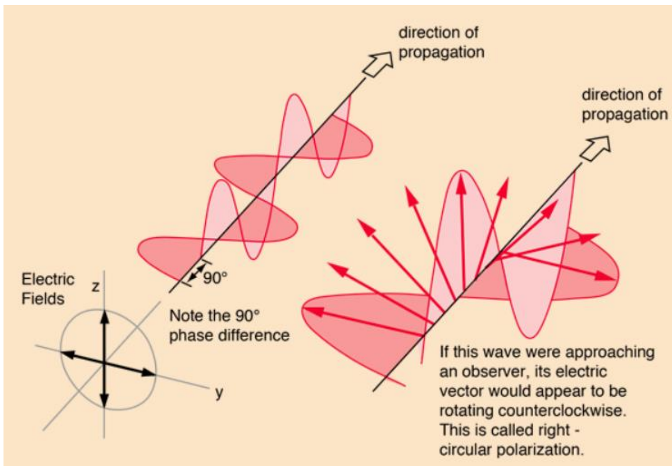
1. Linearly polarised:

   In this polarisation, the EM wave vibrates in the plane of propagation. Consider a light wave going towards the positive z axis. The electric field of the linearly polarised wave would thus be oscillating in the YZ or the XZ plane. If the E field was normal or parallel to the surface of Earth, the antenna's polarisation would be linear. One would be called vertical polarisation and the other would be named horizontal polarisation.

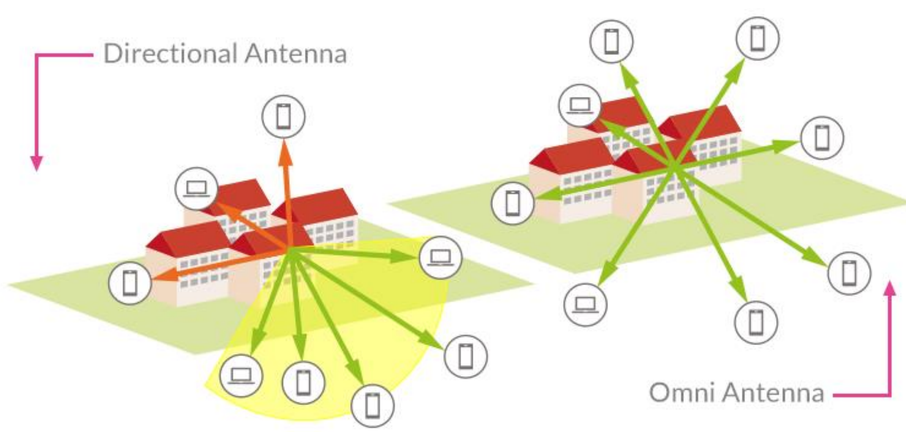


2. Circularly polarised:

In this type of polarised EM wave, the plane of polarisation rotates circularly in one period of the EM wave. If the direction of rotation is clockwise, the wave is called RHC and if counter clockwise is called LHC.



Omnidirectional antennas are preferred when dealing with mobile devices because they can provide us with a respectable gain in all directions and thus cause no polarization issues. However fixed antennas are a lot more efficient when correctly aligned. Polarisation must be considered when designing an antenna to get the maximum gain and the lowest losses.



The second major term that comes into consideration is resonance and bandwidth. These are both key issues in antenna theory. Although we have defined what bandwidth actually means, there needs to be more that needs consideration. Reflected power and Gain are the two characteristics of an antenna that usually limit or hamper its use. Usually, antennas are designed for one resonant frequency. We have done this as well when considering the patch antennas. The parameters have been calculated for 2.4 Ghz and especially for the FR4 substrate with a fixed substrate height. Once the antenna is outside this range of designed frequency, the working is troubled a lot and there is an issue of very high return losses. Furthermore, the second factor called gain is also troublesome as it leads to tradeoffs in directivity and other important parameters.

Once we have analyzed the above-mentioned terminology, we need to move on to more practical problems. The problem I am referring to is that of wave feeding. There is a need to analyze which feeding technique will be the best for which application. Since the input connection provides an impedance, thus this needs to be properly matched to avoid reflection losses. There can be a choice between contact and non-contact feeding of a planar antenna with equipment like coaxial lines. However, there is a tradeoff between these choices, with the coaxial probes usually providing much lower bandwidth and have a difficult implementation. Proximity coupled feeding can also be tried in which two substrates are taken and a radiating element is constructed on top of the elevated substrate. Aperture coupling can be employed with a radiating stub being coupled via a slot. This usually is taken as a last resort method to increase bandwidth and reduce losses.

Specifically, in the microstrip antenna, the dimensions are compensated with the fringing effect with the L being converted to Leff and created as a bit less than Lambda/2. This fringing effect is the reason why microstrip lines don't radiate but microstrip patch antennas do. The feed point is chosen based on the W parameter. Usually to reduce input load impedance, the feed line is moved as close to the center as possible, as we constructed in the circular patch antenna. A characteristic impedance providing coax can also be connected underneath the constructed patch in a microstrip antenna.

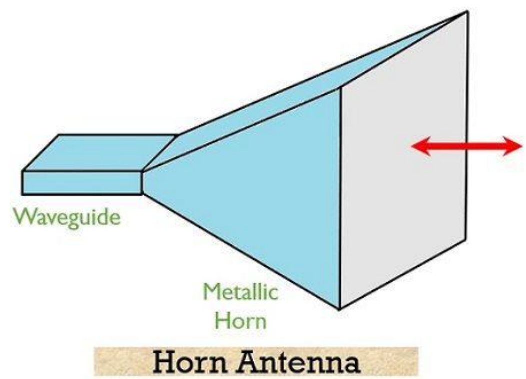
Let’s now shift from general antennas to those we have simulated over the course of this semester. We have primary implemented and created 6 antenna structures. All of them have been planar antennas. To understand the choice of our antennas, there is a necessity to first understand the types of different antennas.

1. <u>Microstrip patch antennas:</u>

   Microstrip patch antennas are extremely good for lower microwave frequency ranges. It is a very primitive way of constructing a microwave antenna but it provides extremely balanced results. It essentially has a copper radiating patch on top of a substrate sitting above a ground. These can be operated from frequencies as low as 100 MHz to 100 GHz. However, these become quite lossy at higher ranges due to substrate loss tangents and their size increases rapidly. They are economical, light and provide decent performance while being easy to construct. These are extensively used in WBAN (Wireless Body Area N/W) applications focusing on wearable and implantable devices. Thus, they are a boon to the medical staff, military personnel and quite a lot of other professions. They can be found in medical monitoring equipment, security systems as well as sports related healthcare devices.

2. Horn antennas:

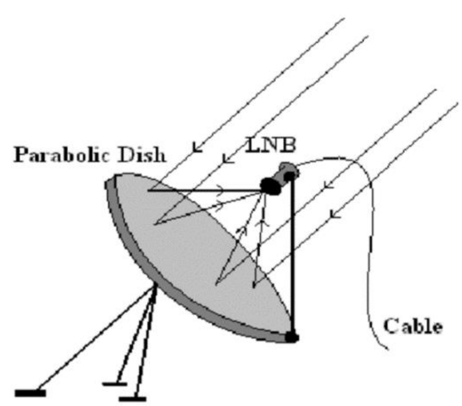
A horn antenna is very similar to the loudspeaker we see at rallies. It has a conical or pyramidal protruding part stuck at the top of a cuboid-based structure. In this way it looks like a megaphone. The horn antennas have been outdated for some time now although modifications have come fast and they are still used in applications requiring moderate gains of around 20 db. These are used above 300 MHz in the SHF range and are used as a threshold to compare other antennas to.



They have notably low VSWR and are broad bandwidth devices. They have low directivity and the spherical beam shot out cannot be used as a focused beam. The flare angle or the angle between the cuboid part and the protruding portion ultimately decides the directivity and there is a huge tradeoff between the directivity and gain here.

3. Parabolic antennas:

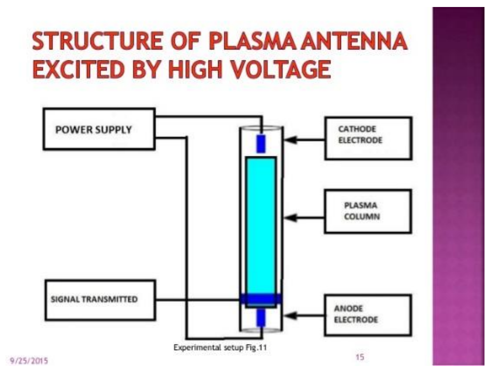
This antenna is basically the humongous ones we see that are employed by SETI and DSN of NASA. It is also used in general satellite communication and TV links. It has very high gains with narrow beamwidths making its directivity quite huge as well. This makes it a good



antenna with strong focusing properties. It enables a precise beam and behaves akin to how a concave mirror works with a beam of light.
However due to its huge size and large costs, the antenna needs to be manufactured with appropriate help. It also needs a reflector and driving element making the system more complex. These antennas are also used extensively for RADAR based work.

4. Plasma antennas:

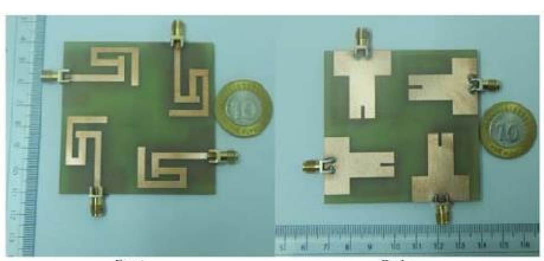
This antenna is novel in the way that it uses plasma instead of normal metallic elements for device development. Plasma antennas might seem very new but the first idea for its development came as far back as the early 20th century. However due to recent strides in technology, it has been only recently considered as a practical device. They are quite versatile



as they are invariant to EM pulse attacks and are invisible to RADARs when switched off. They also have low noise levels and have almost no mechanical parts. Furthermore, their most important property is that they can be dynamically reconfigured to change resonant frequency, gain etc.

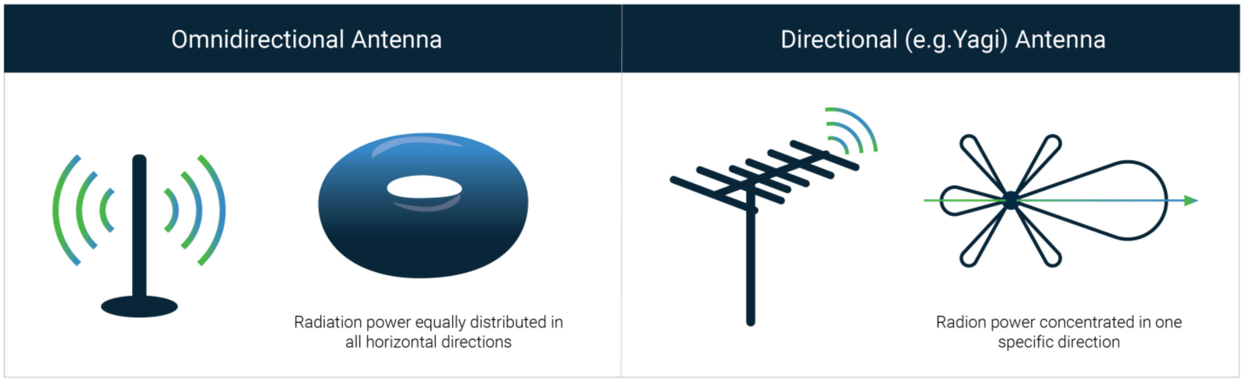
5. MIMO antennas:

MIMO means Multiple Input Multiple Output. This antenna topology is the best in the business. Here the data is propagated after duplication via multiple antenna systems and this increases the data rate by large amounts. It can allow for high transmission efficiency even without LoS visibility. The throughput is obviously much greater and data loss is extremely low.



6. Omnidirectional antennas

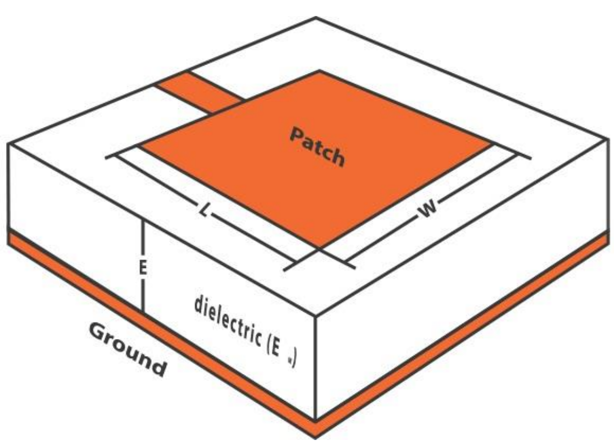
As the name suggests, these antennas are omnidirectional. They transmit and receive data from all directions and therefore have very low directivity. These are useful for wide area coverage networks.



Now we know all of these varying categories of antennas. We chose 6 antennas that encompass both simplistic and complex designs. In the project we studied two microstrip patch antennas, one UWB microstrip antenna, the antipodal Vivaldi antenna, modified antipodal Vivaldi with slots and the printed lotus shaped Quasi Yagi antenna. In the subsequent sections we detail the information about these antennas as well as their mathematical modelling.

RECTANGULAR PATCH ANTENNA

The rectangular microstrip antenna has a transmission line of low impedance and length L. Due to Fringing effect, the effective length of the antenna is increased electrically. Therefore, by this effect, the antenna appears bigger than the actual physical dimensions of the antenna. The resonant frequency depends on the dielectric constant of the substrate and on the physical dimensions such as the length and the width. Fringing account is one important phenomenon why the antenna radiates and the transmission line does not. Therefore, it becomes necessary to take its effect into account.



For this purpose, an effective dielectric constant is calculated for the electric field above the microstrip, in the air above the substrate. Effective dielectric constant is between 1 and the relative permittivity. But as most electric field lines are within the substrate, between the patch and the ground, the effective dielectric constant tends to be closer to the relative permittivity of the substrate. Ereff → Er as the frequency increases and the electric field concentrates in the substrate. The antenna comprises a radiating patch, a dielectric substrate and ground on the other side. Out of all the shapes available, rectangular patch is commonly used due to its wide applications.

The design procedure of the rectangular microstrip patch antenna starts with specifying the dielectric constant and height of the substrate along with the resonant frequency and the impedance of the feeding transmission line. The width can be calculated by the equation: -

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

The patch width should be less than the length for the antenna to be in the TEM 010 mode. Then the effective dielectric constant is calculated because of the fringing effect.

$$\varepsilon_{\mathrm{r,eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5}$$

Then the next step is to calculate the change in length, the effective length and the guided wavelength using these equations.

$$\Delta L = 0.412h\frac{\left(\varepsilon_{\mathrm{r,eff}} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{\mathrm{r,eff}} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

;

$$L_{\mathrm{eff}} = \frac{c}{2f_r\sqrt{\varepsilon_{\mathrm{r,eff}}}} \text{ and}$$

$$\lambda = 2L_{\mathrm{eff}}$$

Then the patch length is calculated using the equation: -

$$L = L_{\mathrm{eff}} - 2\Delta L = \frac{\lambda}{2} - 2\Delta L$$

The next step is to calculate G1, G2, B1, B2.

$$G_{1,\mathrm{est}} = \frac{W}{120\lambda_0}\left[1 - \frac{1}{24}\left(k_0 h\right)^2\right] \quad \text{for } \frac{h}{\lambda_0} < \frac{1}{10}$$

$$B_{1,\mathrm{est}} = \frac{W}{120\lambda_0}\left[1 - 0.636\ln\left(k_0 h\right)\right] \quad \text{for } \frac{h}{\lambda_0} < \frac{1}{10}$$

Where K0 is the free wave number.

Then, we need to calculate characteristic impedance and admittance. Lastly, determine the width of the feeding microstrip transmission line based on desired zo and the dielectric substrate. The final step is to select the notch width n in the range $0.2W0 < n < 0.5W0$.

The rectangular patch antenna has various applications. The most important use of the rectangular patch is its application in Global Positioning System (GPS). GPS is a widely deployed technique used for locating a cell phone/PDA. RFID is another application where patch antenna is used as it is extremely economical and low weight. RFID has humongous application domains ranging from generic attendance systems to complex navigation systems. The rectangular patch antenna is also utilised in mobile communications and the healthcare industry as an IoT tool. IoMT or Internet of Medical Technologies has been a good application domain for these small patch antennas.

CIRCULAR PATCH ANTENNA

Microstrip antennas have found applications in almost every domain. Their diverse uses are mainly due to the small size and weight and their cost-effective fabrication. A circular microstrip patch antenna takes the ease of construction to the next level. It allows only one degree of freedom and therefore confines the parameters that need to be calculated for efficient working. Although these antennas suffer from narrow bandwidth and relatively low efficiency, they are optimal for low power, low-cost applications. This antenna mainly supports the TMz modes of propagation where z is the axis normal to the patch or parallel to the area vector. It is employed in cognitive radio systems, missile communication and satellite systems. These patch antennas can even be conformed to a shape to create a conformal antenna. These antennas have extremely high Q which is traded off with quite low efficiency.

The circular microstrip enjoys versatility as well due to its low power, and small size properties. It is able to encompass a wide range of frequencies, polarisation patterns and impedances while containing only one degree of freedom i.e. the radius of the patch itself. This simplistic model allows it to be utilized in security systems with narrow bandwidth requirements.

One of the most important issues in circular microstrip antennas is the creation of the feed line. As mentioned earlier, coaxial probes and aperture coupling can be used here but microstrip lines are preferred. The RF power is thus directly fed to the antenna patch using the microstrip line and ht inset of the feed line can be calculated very easily using design equations. The most important part of the inset mechanism creation is the need to reduce input impedance since these antennas usually have a high amount of Zin. This can be done by reducing the distance of the feed line from the center. In this situation a microstrip line with thickness much less than that of the patch is followed close to the center with Zin being affected as the square of cosine of factor of inset distance R.

$$\text{Circular patch radius } a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}}}$$

where

$$F = \frac{9.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}$$

ε_r -Dielectric constant of substrate
h- Height of substrate
a- Radius of the patch
f_r - Resonant frequency

For a circular patch antenna, the sweet spot for the inset feed line is usually 1/3rd distance from the center of the patch. The patch is designed for working at 2.4 Ghz. This band is extremely important as it is used for diverse applications in the radio frequency world. Majority of baby monitors operate at this 2.4 Ghz ISM band. Bluetooth and wireless protocols such as 802.11n also occupy the same frequency band. Even our WiFi operates on a narrow band centered around this frequency. Although this frequency is more prone to dispersion, fundamentally important tools such as Microwave ovens, radars, car alarms, toys, etc also use this frequency for working.

UWB MICROSTRIP ANTENNA

The UWB microstrip antenna is constructed using a semicircular patch and by manipulating the parameters to achieve a wideband frequency range. High data transmission rate is achieved with low power at a short distance with precision. Antenna design, channel model and interference are some of the issues involved in modelling of the ultra-wide band antennas.

The Design has a half circular extended to an extra length. The antenna uses FR4 substrate with appropriate dimension, εr=4.4 and a loss tangent of 0.02. 50 ohms characteristic impedance is achieved by having a proper width of the microstrip fed line, connected to the external circular patch. According to the simulations done on HFSS, the results show wideband frequencies. In the return loss curve given by s11, there is a drastic improvement when an elliptical notch behind the feed line in the ground plane and narrow rectangular slit is used. The microstrip UWB antennas finds extensive importance radar applications. It has various advantages such as ease of fabrication, simple structure, easy integration with microwave integrated circuits.

ANTIPODAL VIVALDI ANTENNA

One great benefit of the Vivaldi antenna is in GPR. GPR or ground penetrating radar is an important application of the antipodal Vivaldi antenna. GPR is basically used to detect buried objects such as landmines, etc. It normally requires the lifting of the antenna. UWB and other antennas are unable to be used here because of a significant drop in energy when the antennas are lifted from the ground. Thus, there is a need for new antennas. The two major antennas that can be used for these applications other than the Vivaldi antenna itself are the Horn antenna and the tapered slot antenna. However, these both suffer from various problems. The issue of the Horn antenna is the fact that its size is too large. Whereas the Tapered slot antenna has a very large axial length for similar frequencies to which the Vivaldi antenna is designed on. Vivaldi antennas can be used for Broadband and ECM (Electronic Countermeasure) applications.

The antenna can be designed using the FDTD method. FDTD or Finite difference time domain is an important tool for the design of these complex planar antennas. FDTD creates movies of the field and we can visualize the EM field in the time domain. According to the resonant frequencies we can easily create the optimal length and width parameters for the design of our operation. So basically, we have complete control of the o/p and i/p shaping in a way unusual to other designs.

Vivaldi antenna is also quite cheap to fabricate, has decently high directivity, and has a respectable bandwidth. The antipodal Vivaldi antenna arose out of the need for an antenna with the characteristics of a normal Vivaldi antenna with certain less restrictions on the operating frequency bandwidth. The feeding line to the slot creates a limit to the actual frequency response of the antenna.

The antipodal Vivaldi antenna's microstrip feed line can be easily designed using design equations. For the design of the antenna, we have used RT Duroid with dielectric constant 2.3 as the substrate. RT Duroid is a PTFE composite laminate that can be easily used as a FR4 replacement as it has a lower loss tangent. In addition to having low electrical loss and minimal moisture absorption, it also has a constant K over a large frequency gap.

$$\frac{W_s}{h} = \frac{8\exp H_e}{\exp(2H_e) - 2}$$

where

$$H_e = \frac{Z_0\sqrt{2(\varepsilon_r + 1)}}{120} + \frac{1}{2}\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}\ln\frac{4}{\pi}\right)$$

Using QFDTD90 software, we use parameters as : dx=1.5mm, dy=1.3mm, dz=1.2mm.

$$s(t) = \exp\left(-\frac{t-t_0}{t_w}\right)^2 \sin\left[2\pi f_0(t-t_0)\right]$$

A gaussian sinusoidal pulse has been utilized in the FDTD software for excitation. These results were used as a benchmark for HFSS results we simulated later in the paper. Vivaldi has strong applications in UWB ranges. The old antennas such as the horn antenna usually don't transmit short pulses well and the Vivaldi antenna triumphs here. A directional antenna with good gain characteristics is important in UWB applications ranging from 3 to 10 Ghz and the Vivaldi antenna is perfect for these. The exponential taper of the antipodal Vivaldi antenna offers great performance with shorter length than its competitors. Vivaldi antennas can offer good consistent group delays and a narrow pulse duration. They also offer simple impedance matching that makes it advantageous to use. However, they also have some major drawbacks. Probably the greatest limitation is that despite its great gain characteristics, it still falls short of having extremely high gain. Aperture coupling or balun feeding can further add to the complexity of this relatively simple antenna. The antipodal Vivaldi antenna's impedance matching can be done easily but it increases cross polarized radiation. This can be prevented by adding a dielectric sheet on top of the symmetric structure. However, this increases the cost scaling.

MODIFIED VIVALDI ANTENNA WITH SLOTS

This is an improved version of the earlier mentioned antipodal Vivaldi antenna, having a high radiation gain. The design is done on the dielectric substrate ASTRA®MT77, which is a metamaterial. This is a novel attempt because of the fact that earlier antennas were made from substrates like FR4 and RT duroid. It improves the performance because of its good electrical and non-electrical properties like resistivity, conductivity, temperature coefficient and dielectric strength. This model is constructed with a square microstrip patch with a microstrip transmission line mounted on a dielectric substrate. A balun is created as the radiating element is a balanced structure, which provides a match between 50-ohm feed line and the antenna. The final antenna is achieved by introducing and placing slots on front and back side of the AVA. The exponentially tapered edge is defined by two things. First the opening rate and second the two points representing the centre of the chamfer edge of radius r1 and r2 respectively. Such a curve can be constructed on a planar surface by using the mathematical equations of the curve on CST studio.

$$y = c_1 e^{Rx} + c_2 \quad ; \quad c_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}}, \quad c_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}}.$$

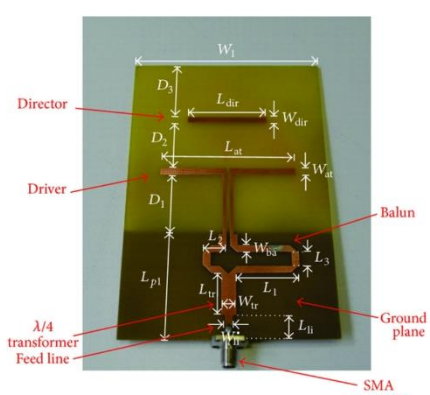
For the antipodal Vivaldi antenna, if the inner edge is sharply tapered, the length of the inner notch decreases and the travelling wave property and the radiation properties decreases. Therefore the tapering must be gradual in nature. Further the properties can also be affected by thickness and dielectric constant of the substrate.

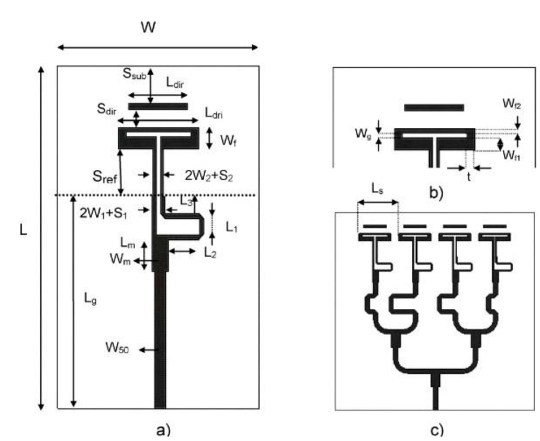
Applications can include transmissions which requires a very high bandwidth. It can prove to be an important facet in radar and wireless communication applications. This can also be widely used in dual polarization applications. Almost infinite bandwidth of this antipodal Vivaldi antenna can further be utilized in ultra-wide band applications, for e.g., where high data rate is required such as in sensing applications.

QUASI YAGI ANTENNA

The Quasi yagi antenna came to existence because of the demand in terms of high bandwidth and good radiation characteristics i.e. beam pattern and low mutual coupling. This antenna is constructed on substrates having relatively very high permittivity and metallization is done on both the sides. On the top side of the metallization, there is a feed(microstrip), a CPS balun and two dipole elements, the second dipole being the parasitic director. On the other side of the antenna, there is a microstrip ground, which is also metallized and acts as the reflector element of the antenna. The parasitic director element acts as an impedance matching element and directs the electromagnetic energy in a particular direction. We can modify the antenna by choosing the parameters appropriately. One, there can be broadband applications with modest gains and two, there can be a narrower bandwidth with high gains above 6db. Other parasitic elements are added in order to improve the performance in gain and bandwidth, but the complexity of the design increases and more care is required as the number of manageable parameters increases.

For broadband performance, FDTD code is used to find the dimensions of the antenna, where the 0.635 mm thick duroid is used, having a dielectric constant of 10.2. The broadband characteristics come by decreasing the size of the director element of the antenna than the conventional yagi-uda antenna. This antenna shows the best results when it comes to planar antennas showing such a wide bandwidth with a compact design. The drawback we can conclude is that the quasi yagi antenna requires a complex feeding network whereas in traditional yagi antennas, it can be directly connected to the coaxial line. The planar quasi yagi antenna has applications in Wi-Fi and Wimax.





MATHEMATICAL MODELLING

1. <u>RECTANGULAR PATCH:</u>

* <u>Rectangular Patch Calculation.</u>

<u>Formulas used</u> :

$$Z_c = \frac{120}{\sqrt{\varepsilon_{r\,eff}}}\left(\frac{W_f}{h} + 1.3 + 0.66\ln\left(\frac{W_f}{h} + 1.4\right)\right)$$

1) $$W = \frac{c}{2f_r}\sqrt{\frac{2}{1+\varepsilon_r}}$$

2) $$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 2h/W}}\right)$$

3) $$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}}$$

4) $$\Delta L = h * 0.412 * \frac{(\varepsilon_{eff} + 0.3)\left(W/h + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(W/h + 0.8\right)}$$

5) $$L = L_{eff} - 2\Delta L$$

Solving for a frequency of 2.4 GHz, the design parameters come out as:

<u>Patch dimensions</u> : L = 38.03 mm W = 29.28 mm.
<u>Ground dimension</u> : L = 50 mm W = 49.5 mm H = 2 mm.
<u>Feed dimensions</u> : L = 11.5 mm. W = 4 mm.

2. CIRCULAR PATCH:

+ Circular Patch Calculation.

In our work we selected FR4 substrate which has relative dielectric constant of 4.4 and substrate thickness to be 1.66 mm.

To calculate radius, we use:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon F}\left(\ln \frac{\pi F}{2h} + 1.7726\right)\right\}^{1/2}}$$

where $F = \frac{8.79 \times 10^9}{f_r \sqrt{\epsilon}}$ Here $a = 14.14$ mm.

For singular patch, optimal feed location is at $1/3^{rd}$ distance from centre of patch. This location is calculated using formula.

$$y_f = \frac{W}{2} \quad \text{and} \quad x_f = \frac{L}{2\sqrt{\epsilon_{reff} L}}.$$

Here at $f = 2.4$ GHz, inited strip has parameters as:

$W = 3$ mm

$L = 29.9$ mm.

Subtracted strip

$W = 5$ mm

$L = 13.7$ m.

3. UWB ANTENNA:

* Ultra Wide band Antenna Calculations.

The antenna has been designed to provide minimal losses at 5 GHz frequency. This U or semi circular patch antenna can be looked at as a modification of circular patch band antenna with wide band considerations.

Circular Patch radius : a = 13 mm.

Formula ⇒
$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon F}\left(\ln \frac{\pi F}{2h} + 1.7726\right)\right\}^{1/2}}$$

United rectangle : L = 13 mm.
W = 3 mm.

Ground size & dimensions : L = 27 mm
W = 11.5 mm

Radiation box dimensions : L = 40 mm.
W = 40 mm
H = 40 mm.

L calculation for notch freq ⇒
$$L = \frac{c}{2 f_{not} \sqrt{\frac{\epsilon_r + 1}{2}}}$$

{FR4 $\epsilon_r = 4.4.$ }

4. ANTIPODAL VIVALDI ANTENNA:

* Antipodal Vivaldi Antenna. Calculation

Creation of two finned antipodal vivaldi antenna operating for minimum return loss at (7 GHz frequency). Careful consideration taken during design of the Vivaldi antenna.

Method used = FDTD method.

Equation of slot → $Z(y) = \pm A e^{Py}$
z = substrate axial direction
y = horizontal direction

W_s (strip width) > h (substrate thickness)

$$\frac{W_s}{h} = \frac{8\exp(K_e)}{\exp(2K_e) - 2} \quad \text{— (i)}$$

$$K_e = \frac{Z_0\sqrt{2(\varepsilon_r+1)}}{120} + \frac{1}{2}\left(\frac{\varepsilon_r-1}{\varepsilon_r+1}\right)\left(\ln \pi/2 + \frac{1}{\varepsilon_r}\ln\left(4/\pi\right)\right)$$

ε_r of material = 2.45.

For optimisation, $W = 7.5$ cm
$L_1 = 6$ cm
$L_2 = 8$ cm
$h = 1.5$ mm.
$\varepsilon_r \approx 2.3$. (RT Duroid)

5. QUASI YAGI ANTENNA:

* Quasi-Yagi Antenna Calculation

Broad band Planar Quasi-Yagi Antenna

Goals. 48% bandwidth
VSWR < 2
front to back ratio better than 12 dB.
3-5 dB absolute gain.

Material: High ε_r 0.635 mm thick Duroid
$\varepsilon_r = 10.2$.

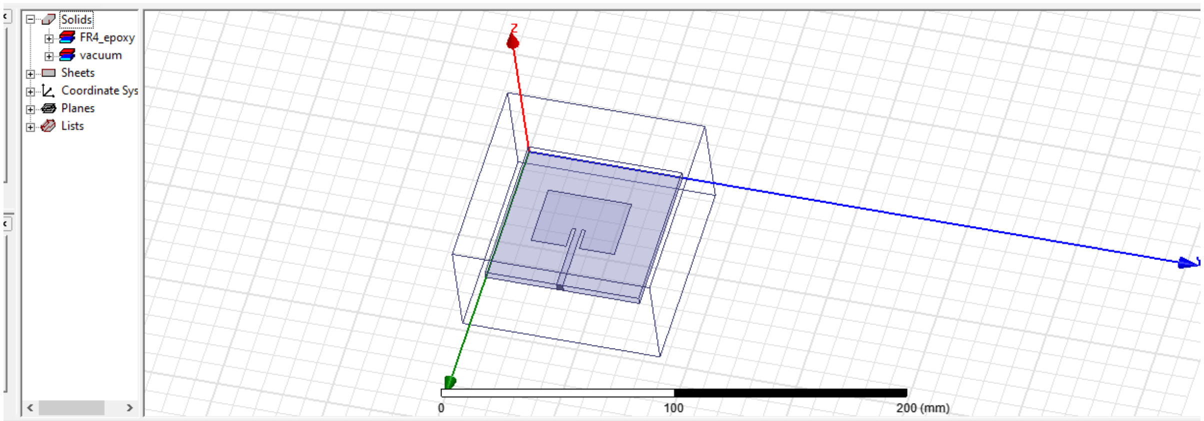
Things to consider. reflector parameters.
driver parameters
director parameters

Design Values. $W_1 = W_3 = W_4 = W_5 = W_{dri} = W_{dir} = 0.6$ mm.
$W_2 = 1.2$ mm.
$W_6 = S_5 = S_6 = 0.3$ mm.
$L_1 = 3.3$ mm.
$L_2 = L_5 = 1.5$ mm.
$L_3 = 4.8$ mm.
$L_4 = 1.8$ mm.
(mm) $S_{ref} = 3.9$ $S_{dir} = 3$ $S_{sub} = 1.5$ $L_{dri} = 8.7$ $L_{dir} = 3.3$

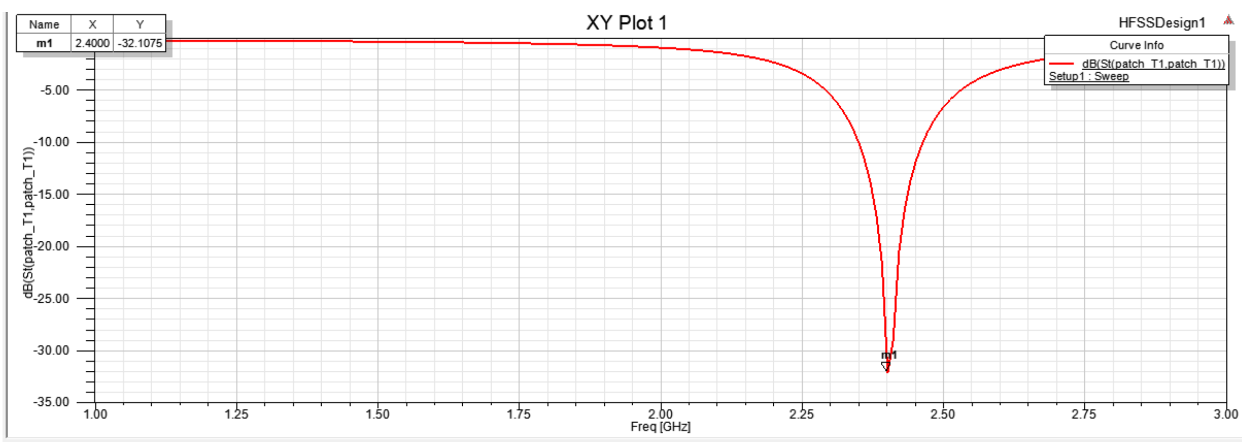
FDTD Method arrives at these parameters.

RESULTS

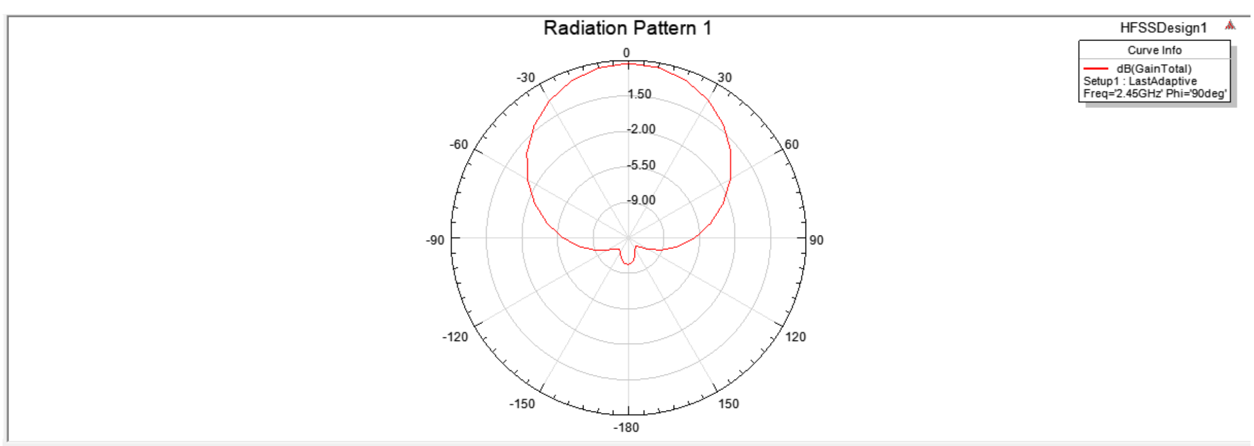
- <u>Rectangular microstrip patch antenna</u>



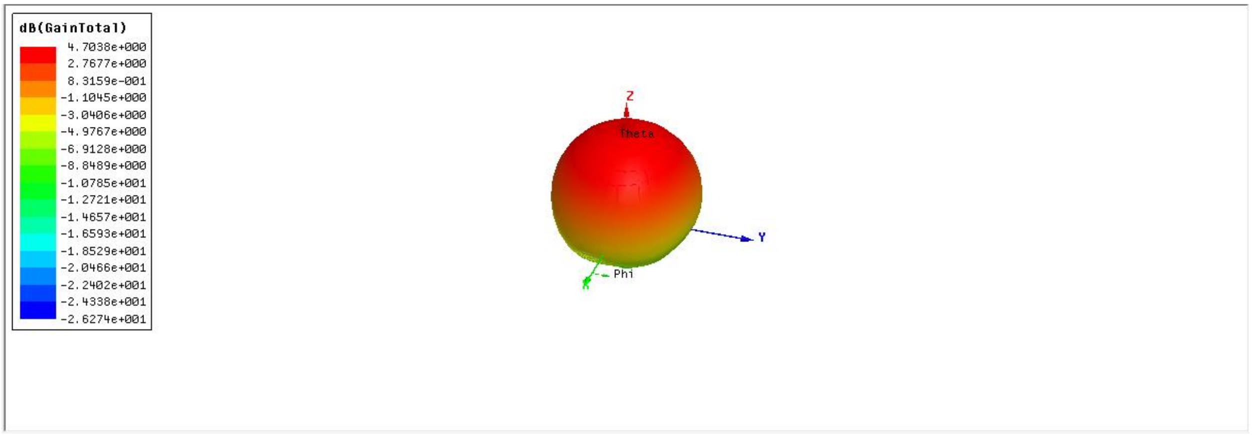
Antenna design



Return loss curve

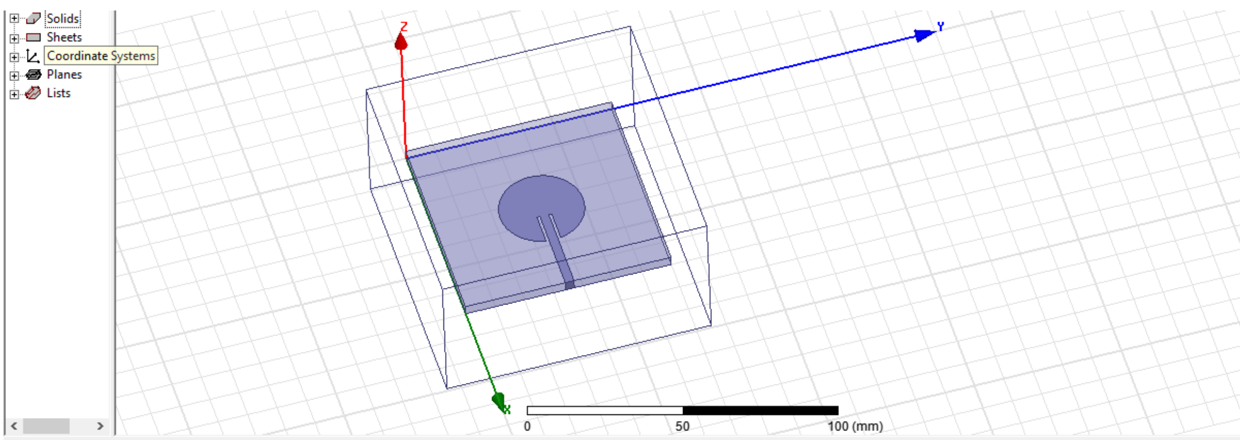


Radiation Pattern

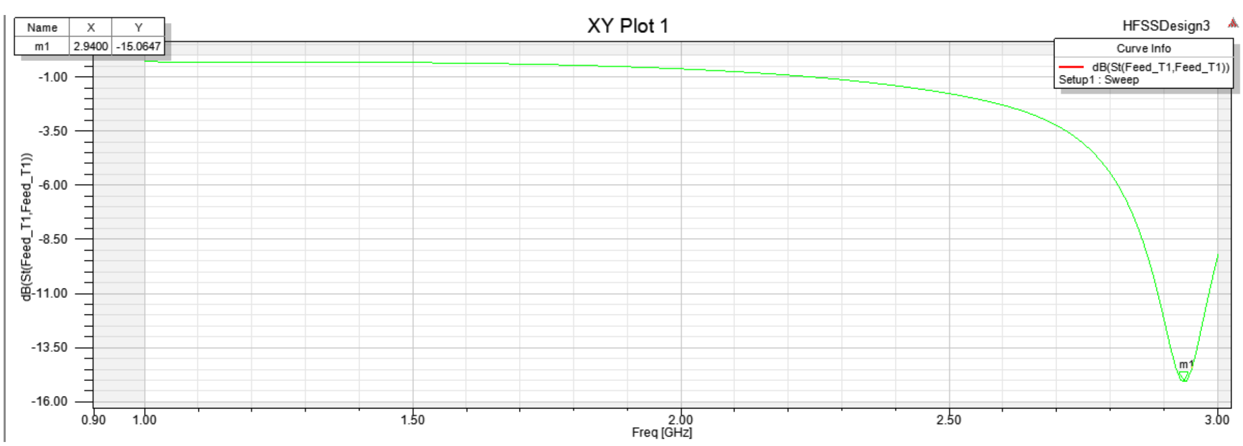


Polar plot

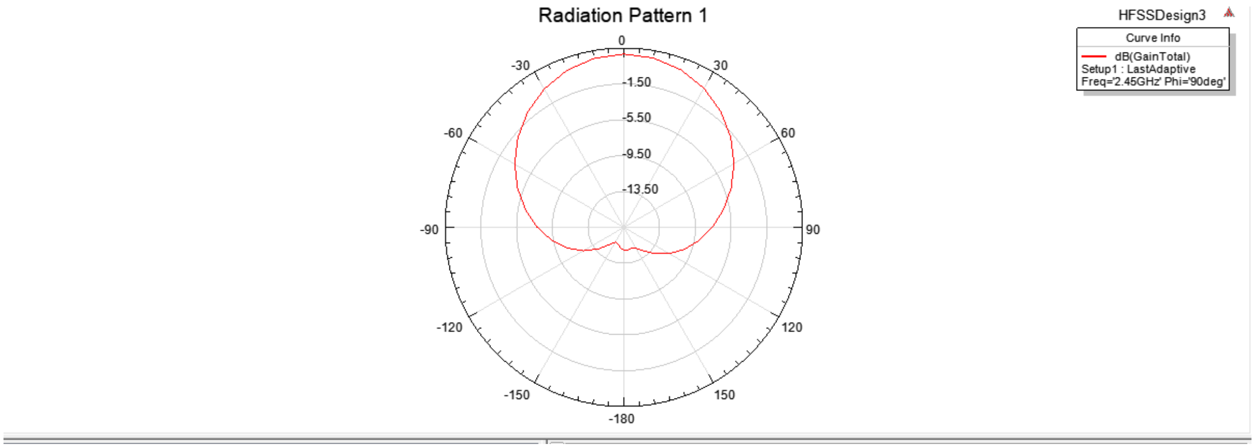
- ♦ <u>Circular patch antenna</u>



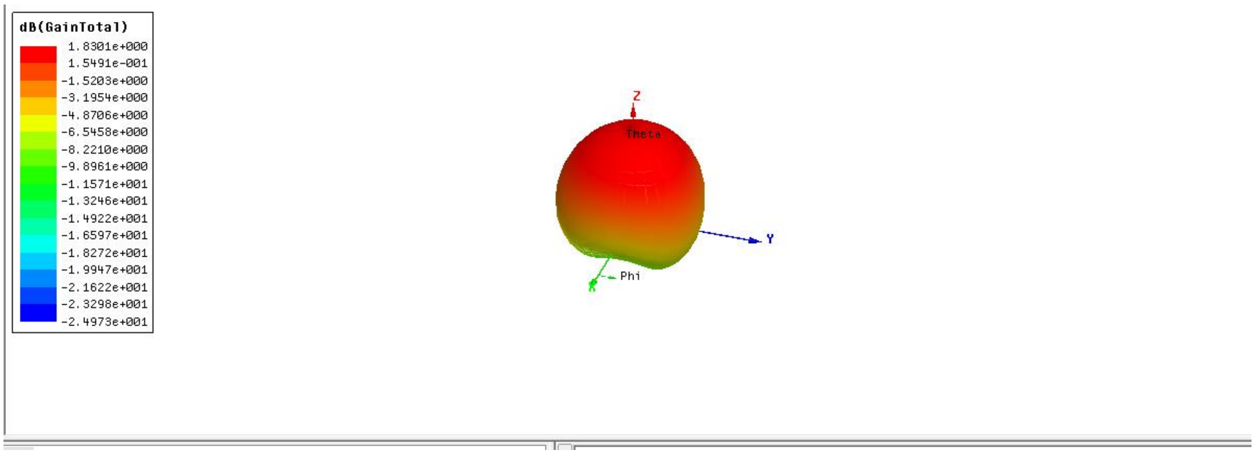
Antenna design



Return loss curve

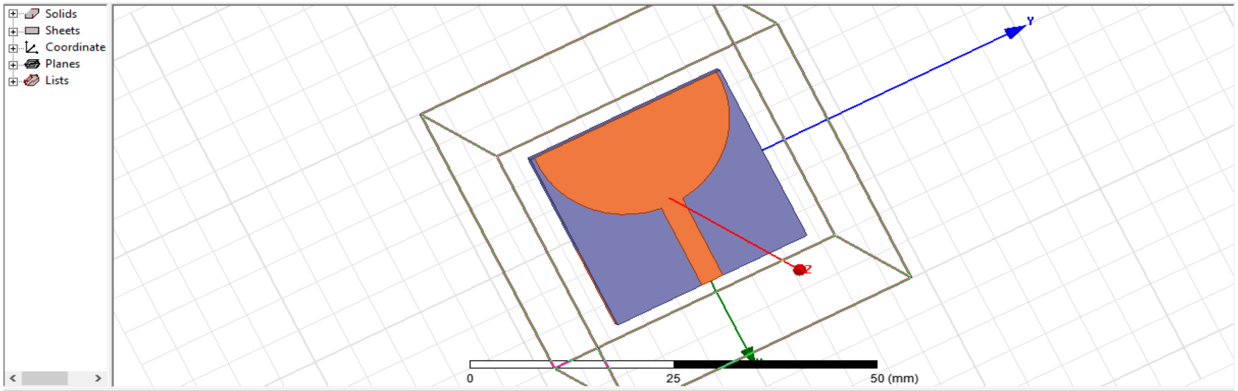


Radiation pattern

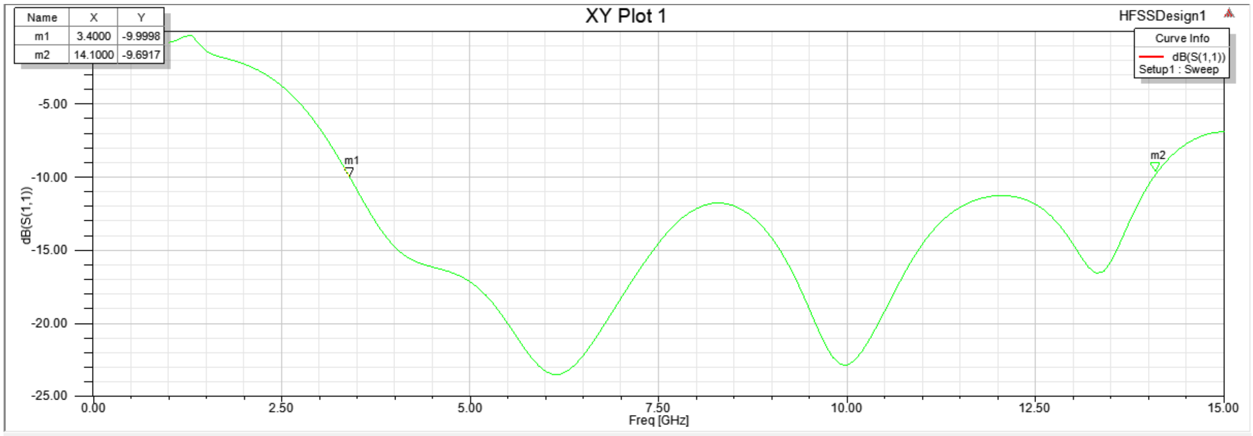


Polar plot

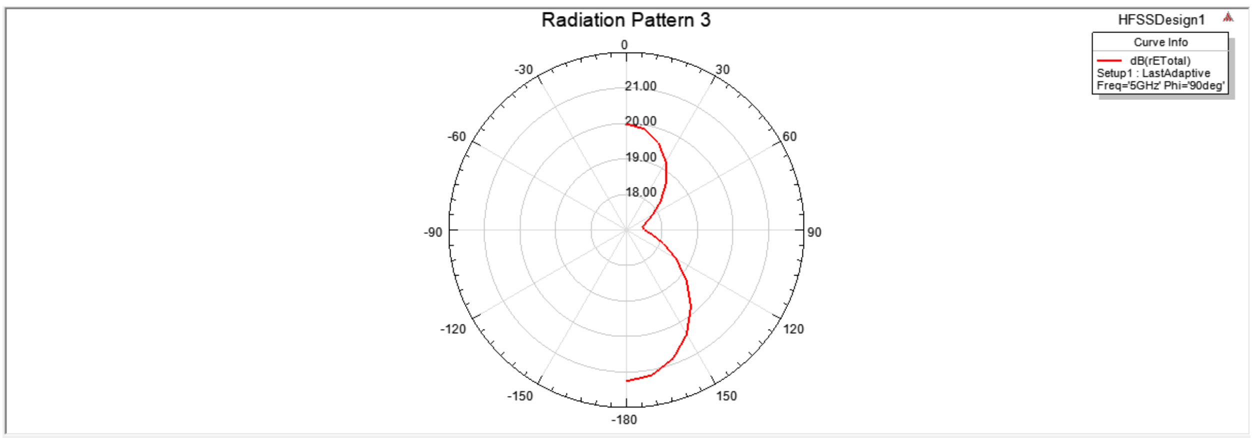
- <u>Ultra-Wideband microstrip antenna</u>



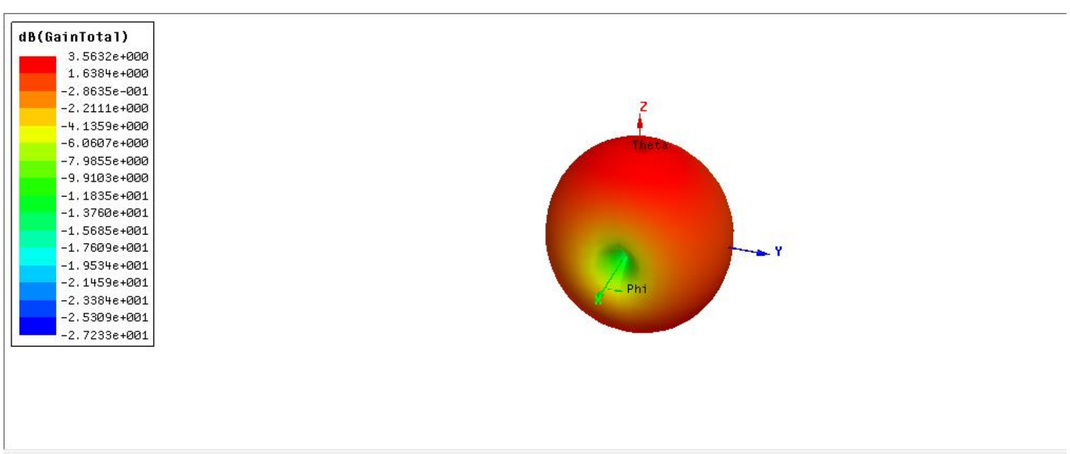
Antenna design



Return loss

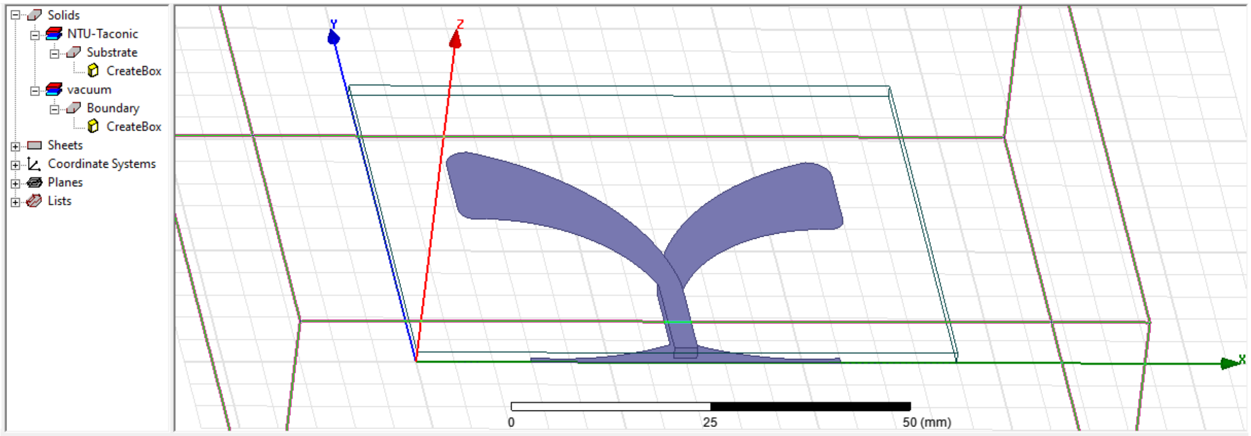


Radiation Pattern

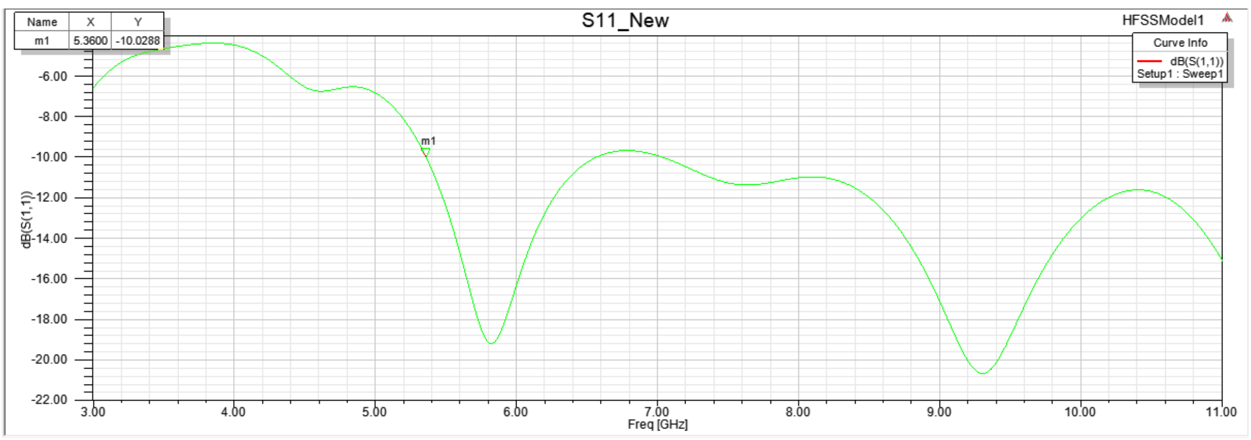


Polar plot

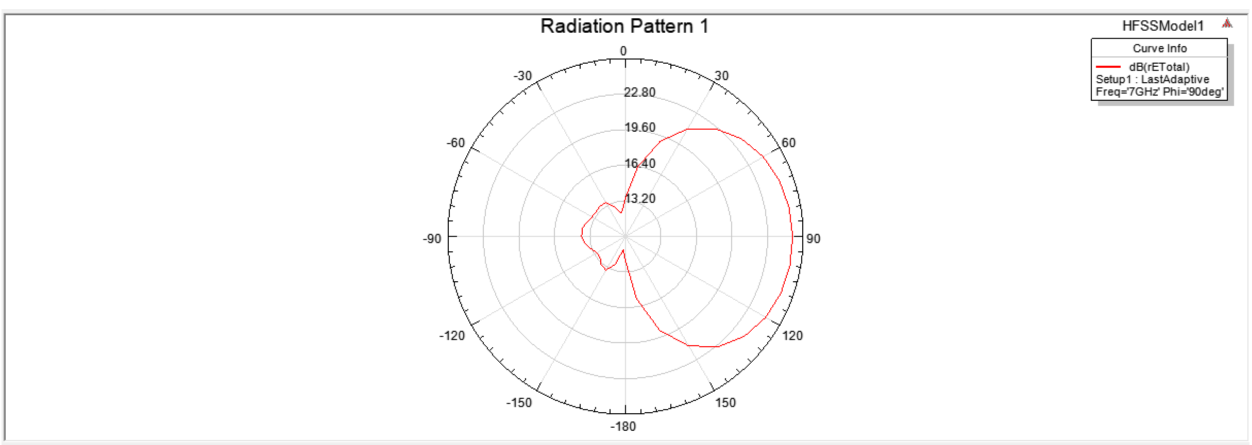
♦ <u>Antipodal Vivaldi antenna</u>



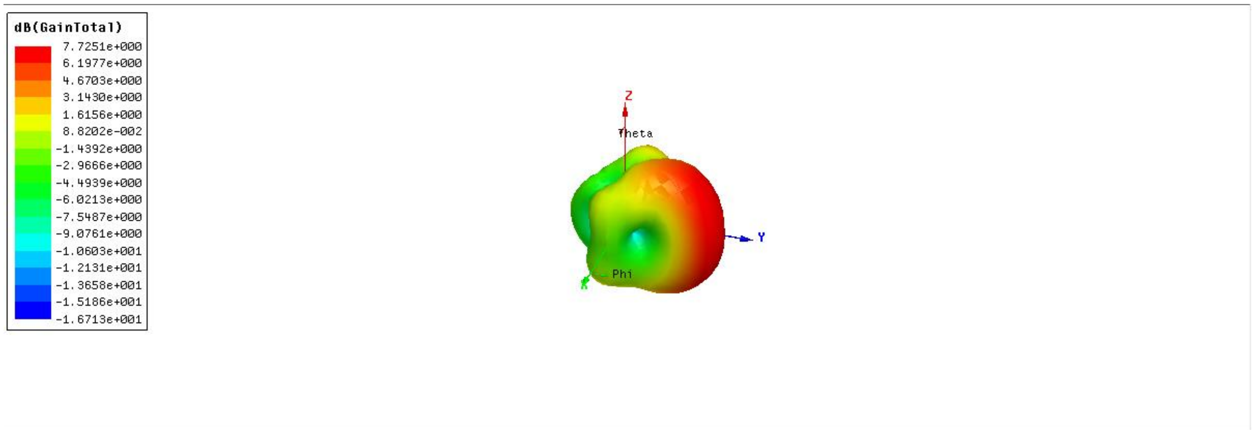
Antenna design



Return loss

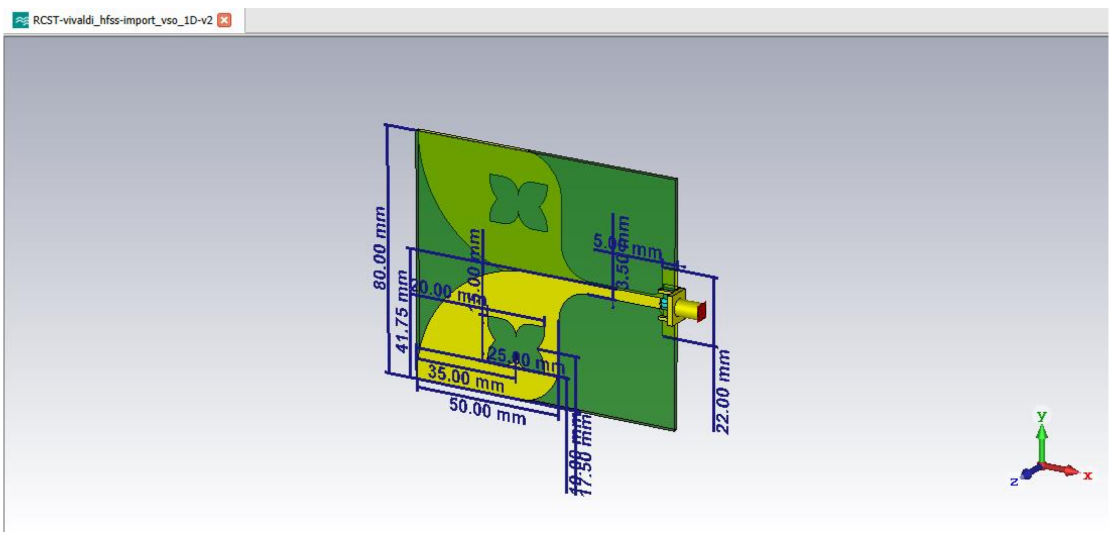


Radiation pattern

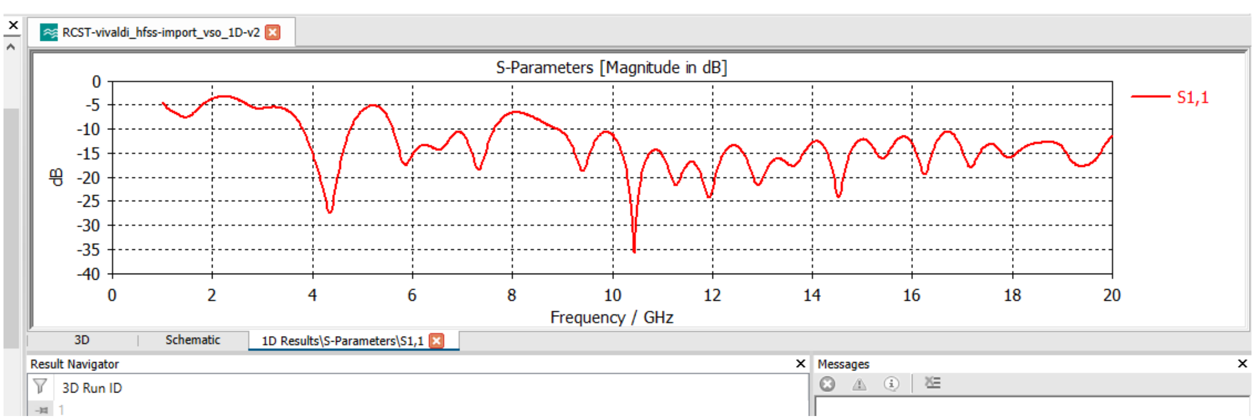


Polar plot

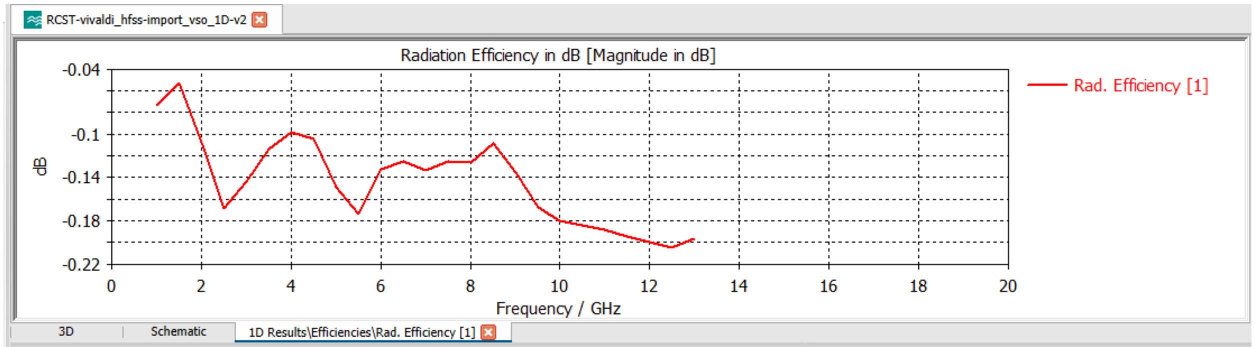
- <u>Antipodal Vivaldi antenna with slots</u>



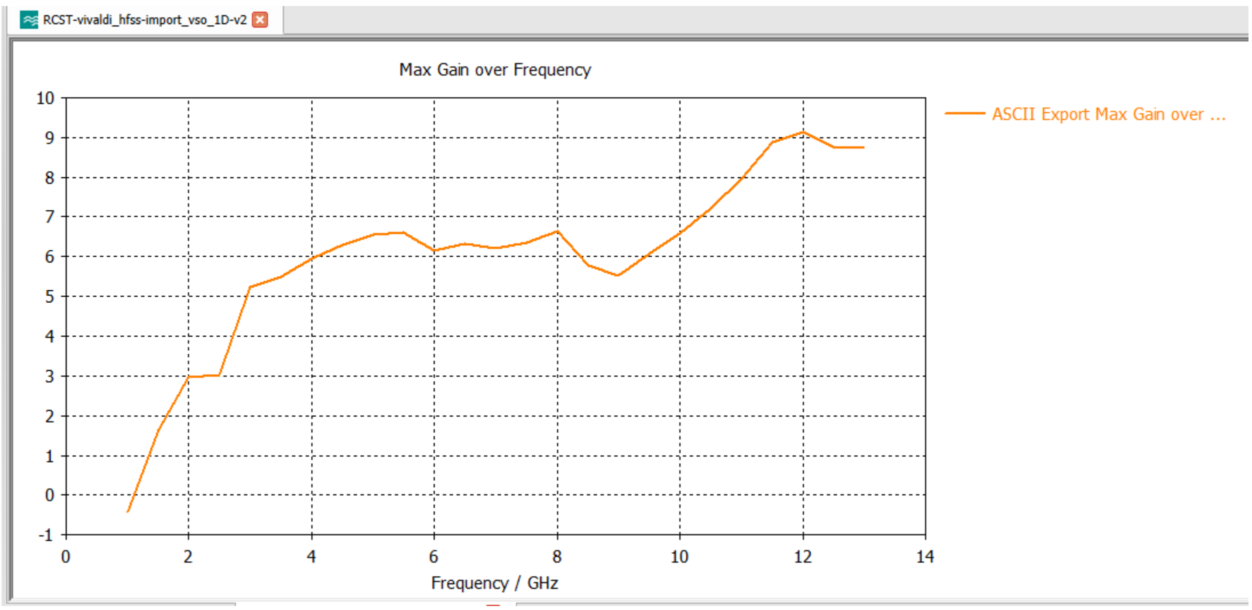
Antenna design



Return loss

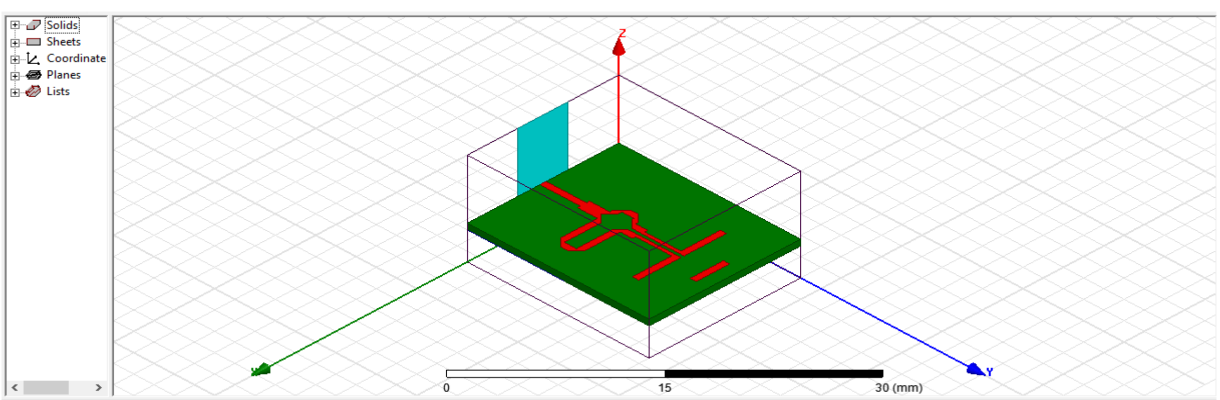


Radiation efficiency v/s frequency

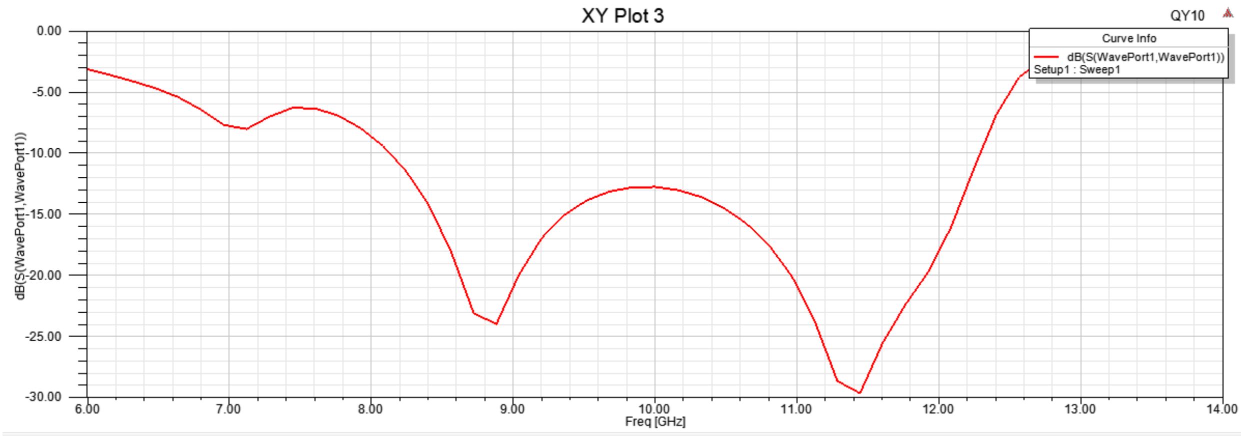


Gain v/s frequency

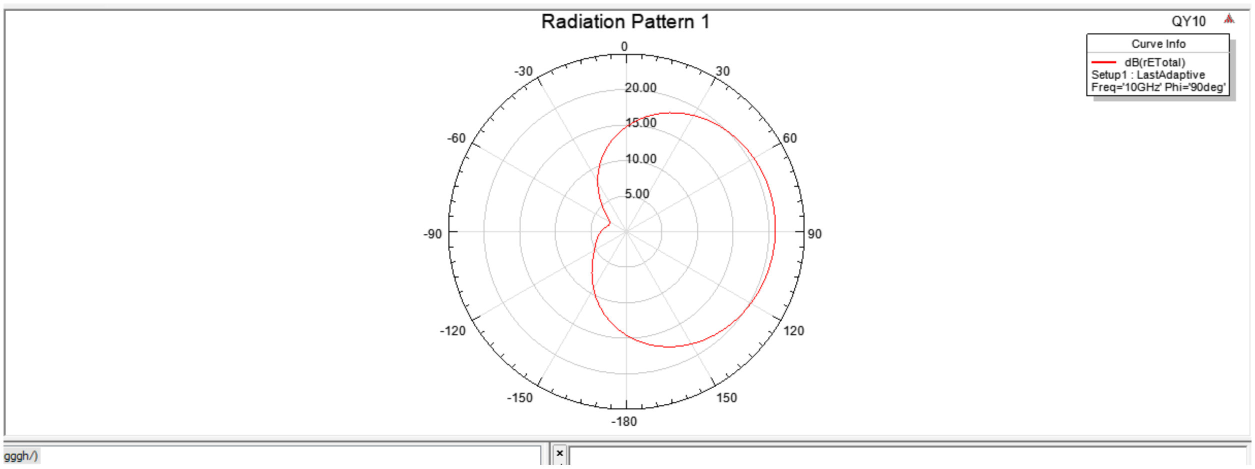
- Quasi Yagi antenna



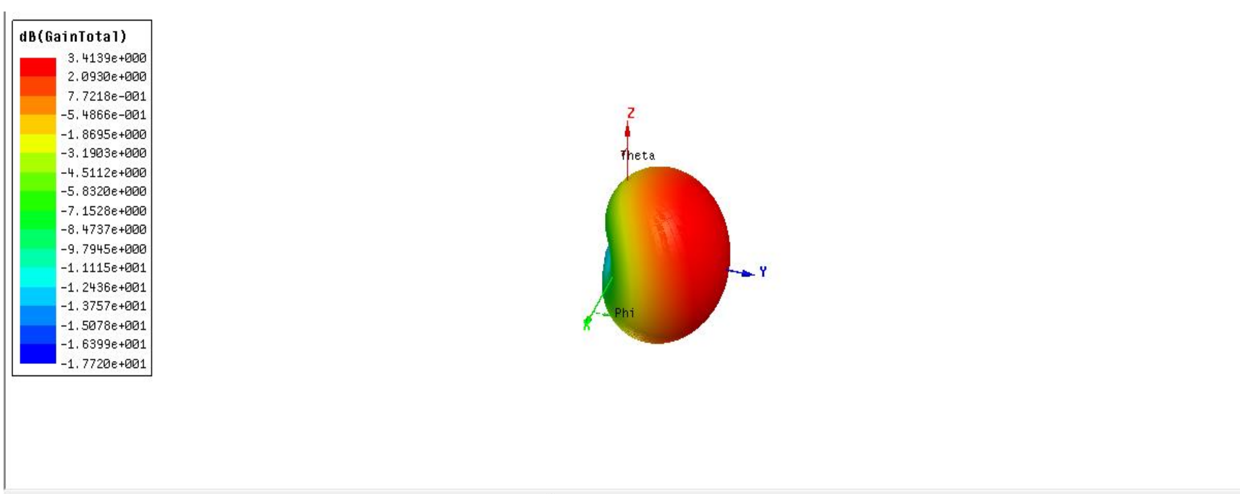
Antenna Design



Return loss



Radiation pattern



Polar plot

COMPARISON MODELLING

	Rectangular Patch	Circular Patch	UWB	Antipodal Vivaldi	Quasi-Yagi
Bandwidth	104 MHz	81 MHz	10 GHz	1.2 GHz	4.1 GHz
Gain (dB)	4.7	1.9	3.56	7.64	3.4
Directivity (dB)	6.7	4.5	3.75	7.72	3.45
Radiation eff.	70.14%	44%	94.9%	98.9%	99%
VSWR	1.05	1.4	1.15	1.2	1.06
Return Loss (dB)	-32	-15.66	-23.48	-20.05	-29.62

ANTIPODAL VIVALDI W/ SLOTS.

Bandwidth	8.2 GHz
Gain (dB)	9.16
Directivity (dB)	9.55
Rdn efficiency	95.92
VSWR	1.054
Return loss (dB)	-35.645

FUTURE SCOPE

Conformal antennas can be constructed using the basic microstrip patch antennas. A conformal antenna is one which conforms to the surface which is governed by considerations other than electromagnetic, for e.g., aerodynamic considerations. It can make use of the geometries available such as a cylinder, sphere and cone. We are looking forward to designing an array of rectangular microstrip antennas on a cylindrical geometry. Arrays are oriented in an axial direction as well as azimuthal direction.

Different Meta materials used as a substrate are recently heavily researched upon and the different electrical and non-electrical properties can give improved results when done on an experimental basis. Antipodal Vivaldi antennas are generally used for ultrawideband applications. The scope for UHF and VHF frequency band applications generally used in FM radios, TVs and Wi-Fi can be researched upon by antipodal Vivaldi antennas, and by using properties of metamaterials, the size can be small as compared to other antennas.

The extension to the development of Vivaldi array antennas can be touched upon. Side lobes and back lobes can be reduced with the help of a feed power divider. Narrow beam width along with high peak gain that can be used on different applications such as ground penetrating radar, radar cross-section reduction in stealth platforms, and phased array applications.

CONCLUSION

A detailed comparison is carried out comparing all the parameters of different antennas with the reference antenna (rectangular microstrip patch antenna) parameters. It is observed that there are changes for each parameter as compared to reference antennas. The circular microstrip patch antenna shows the highest return loss with reduced bandwidth, higher VSWR, low gain and low efficiency, performing the least. The Ultra-wide band antenna with a BW of 10 GHz has a low directivity and a low gain, showing the tradeoff between gain and bandwidth. The antipodal Vivaldi antenna has very high gain and high efficiency, but the Bandwidth is reduced and the VSWR trends on a higher side. The Quasi-Yagi antenna shows a higher bandwidth than the Vivaldi antenna, with an increased radiation frequency, with comparable VSWR with the reference antenna, thus showing the best performance out of all these antennas.

Modified Antipodal Vivaldi > Quasi-Yagi > Antipodal Vivaldi > UWB (application specific) > Rectangular Patch > Circular Patch

The evolution of Antennas is clearly visible through the design of these antennas. All antennas have been self-designed and optimized based upon researched parameters and it is completely novel.

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