Analysis of Soil Using Microstrip Patch Antenna as a Sensor

B.E. Dissertation

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by

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is a bonafide work done by

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to the
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Guide

Project Coordinator

Head of Department

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Certificate of Approval by Examiners

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Abstract

This paper proposes a four-shaped MSPA which can be used for the analysis of soil fertility. The proposed antenna has a resonant frequency of 1.5GHz with S11-22dB. It has been designed with FR4 epoxy having dielectric constant 4.4(the soil will act as superstrate). The resonant frequency is inversely proportional to the dielectric constant. It has been noticed that as the percentage of fertilizer in the soil increases, its Fr decreases hence, its dielectric constant increases. Thus, the resonant frequency of the MSA will change if there is any change in the fertility of soil. This device is cheap and small in size and can be easily used.

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Chapter 1

Introduction

1.1 Background

In the last 40 years, it has been reported that 33 % of arable land on the Earth has been lost. This coupled with the rapidly increasing population can lead to shortage of food production. Hence, it is important to maintain the fertility of soil. Soil fertility can be increased by increasing the soil organic matter (SOM). SOM mainly consists of oxygen, hydrogen other nutrients. High level of soil fertility is vital for ensuring good yield of crops. Soil rarely have sufficient nutrients required for crops. There are different inorganic and organic carbon fertilizers. However, even if organic fertilizers are used excessively, it can damage crops. It reduces crops ability to hold water. Hence it is important to use fertilizer according to the need of crops. The proposed antenna will analyze soil fertility which can be used for determining the optimum quantity of fertilizer required for good agricultural production.

1.2 An Introduction to Microstrip Antennas:

Microstrip antenna in their simplest form consist of a conducting radiating patch on one side of the substrate and a conducting ground plane on the other side. The electromagnetic waves areradiated through radiating patch to which electrical signal is feed. The top view and side view of rectangular microstrip antenna is shown in Figure1.1. The top layer is conducting patch and the bottom layer is conducting ground plane. In middle there is a substrate with permittivity or dielectric constant r. The microstrip antenna radiates at a particular resonant frequency and has narrow bandwidth. Due to its size, weight, ease of

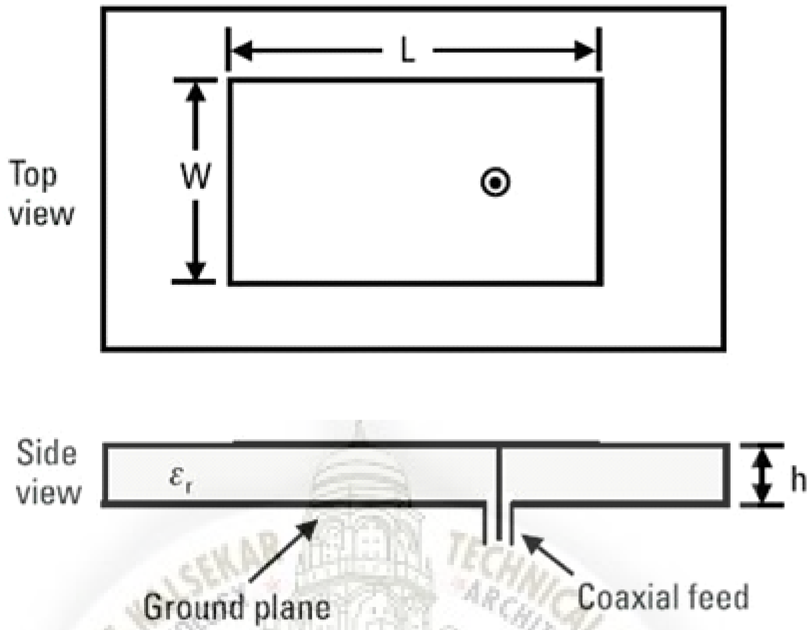


Figure 1.1: Front and Side view of MSA

manufacturing it is used in various fields such as aerospace, defence, telecommunication, etc. Besides communication, recent researches shows that the microstrip antennas can also be used as a sensor for detection of temperature, strain, dielectric, etc.

1.2.1 Types of Microstrip Antenna

Microstrip antennas has different shapes of patch, most commonly used patch is rectangular. Circular and triangular patches also used widely. Microstrip antennas can be classified according to the shape of their patch. Different shapes of microstrip patches is shown in Figure1.2.

When the patch of microstrip antenna is shorted to the ground plane it size reduces to 50 %. Now the microstrip antenna becomes Planer Inverted-F Antenna (PIFA). PIFA is used in mobile phones because of its compactness. The Planer Inverted-F Antenna (PIFA) are printed Inverted-F Antenna which monopole antenna running parallel to ground and shorted to ground at the end. It is a quarter wavelength shorted patch with limited ground plane and dielectric substrate in between. The PIFA design is shown in Figure1.3.

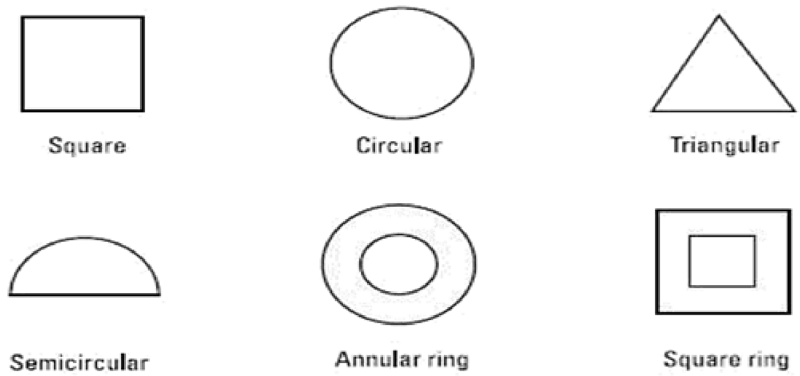


Figure 1.2: Different shape of patches

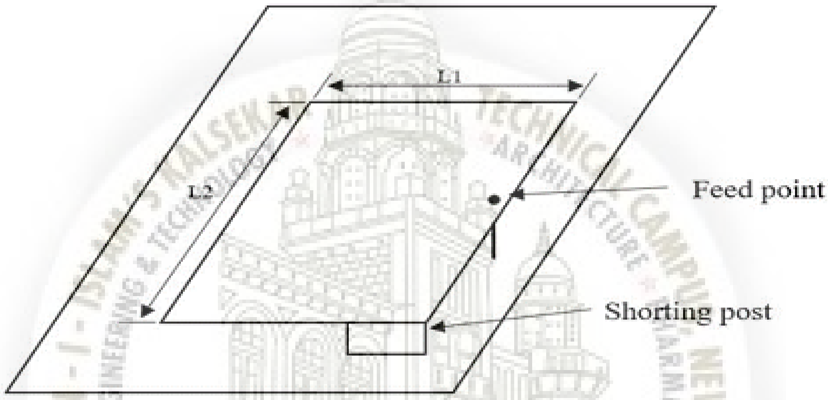


Figure 1.3: PIFA

Advantages:

- They are lightweight and have a small volume and a low-profile planar configuration.
- They can be made conformal to the host surface.
- Their ease of mass production using printed-circuit technology leads to a low fabrication cost.
- They are easier to integrate with other MICs on the same substrate.
- They allow both linear polarization and CP.
- They can be made compact for use in personal mobile communication

Disadvantages:

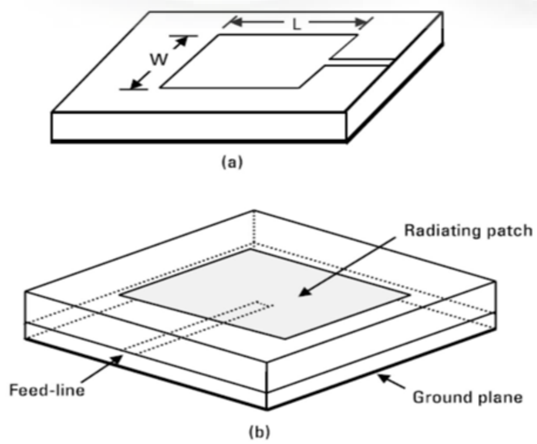
- Narrow BW.

- Lower gain.
- Low power-handling capability.

1.2.2 Feeding Techniques

The MSA can be excited directly either by a coaxial probe or by a microstrip line. It can also be excited indirectly using electromagnetic coupling or aperture coupling and a coplanar waveguide feed, in which case there is no direct metallic contact between the feed line and the patch. Feeding technique influences the input impedance and characteristics of the antenna, and is an important design parameters.The coaxial or probe feed arrangement is shown in Figure1.1. The centre conductor of the coaxial connector is soldered to the patch. The main advantage of this feed is that it can be placed at any desired location inside the patch to match with its input impedance. The disadvantages are that the hole has to be drilled in the substrate and that the connector protrudes outside the bottom ground plane, so that it is not completely planar. Also, this feeding arrangement makes the configuration asymmetrical.

A patch excited by microstrip line feed is shown in Figure 1.4(a). This feed arrangement has the advantage that it can be etched on the same substrate, so the total structure remains planar. The drawback is the radiation from the feed line, which leads to an increase in the cross-polar level. Also, in the millimeter-wave range, the size of the feed line is comparable to the patch size, leading to increased undesired radiation.



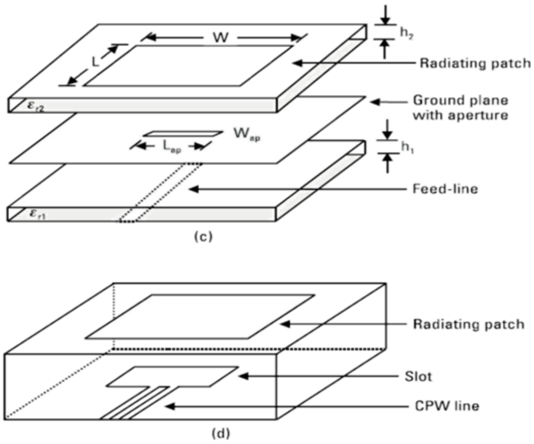


Figure 1.4: Rectangular MSA fed by (a) microstrip line, (b) electromagnetic coupling,(c) aperture coupling and (d) coplanar waveguide (CPW)

For thick substrates, which are generally employed to achieve broad BW, both the above methods of direct feeding the MSA have problems. In the case of a coaxial feed, increased probe length makes the input impedance more inductive, leading to the matching problem. For the microstrip feed, an increase in the substrate thickness increases its width, which in turn increases the undesired feed radiation. The indirect feed, discussed below, solves these problems. An electromagnetically coupled RMSA is shown in Figure 1.4(b). The electromagnetic coupling is also known as proximity coupling. The feed line is placed between the patch and the ground plane, which is separated by two dielectric media. The advantages of this feed configuration include the elimination of spurious feed-network radiation; the choice between two different dielectric media, one for the patch and the other for the feed line to optimize the individual performances; and an increase in the BW due to the increase in the overall substrate thickness of the MSA. The disadvantages are that the two layers need to be aligned properly and that the overall thickness of the antenna increases.

Another method for indirectly exciting a patch employs aperture coupling. In the aperture-coupled MSA configuration, the field is coupled from the microstrip line feed to the radiating patch through an electrically small aperture or slot cut in the ground plane, as shown in Figure 1.4(c).

The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The shape, size, and location of the aperture decide the amount of coupling from the feed line to the patch. The slot aperture can be either resonant or nonresonant.The resonant slot provides another resonance in addition to the patch resonance thereby increasing the BW at the expense of an increase in back radiation. As a result, a non-resonant aperture is normally used. The performance is relatively insensitive to small errors in the alignment of the different layers. Similar to the electromagnetic coupling method, the substrate parameters of the two layers can be chosen separately for optimum antenna performance. This feeding method gives increased BW.

The coplanar waveguide feed, shown in Figure 1.4(d), has also been used to excite the MSA. In this method, the coplanar waveguide is etched on the ground plane of the MSA. The line is excited by a coaxial feed and is terminated by a slot, whose length is chosen to be between 0.25 and 0.29 of the slot wavelength. The main disadvantage of this method is the high radiation from the rather longer slot, leading to the poor front-to-back ratio. The front-to-back ratio is improved by reducing the slot dimension and modifying its shape in the form of a loop.

1.2.3 Miniaturization of Microstrip Antenna

There are many techniques for the miniaturization of microstrip antenna which is used to reduce the size of the antenna. Some of them are shortening of the radiating patch with ground plane, meandering of patch, making slots on the patch, defective ground plane, use of meta material, etc. As this project uses one of the miniaturization techniques among these i.e. use of shortening of patch with ground plane and meandering of patch, some details of these techniques are given below.

The size of the microstrip antenna can be reduced by shorting the radiating patch of the antenna which is the top layer with the ground plane. The patch is shorted to ground plane either by shorting pin or a plane. Series of shorting pins are also used . By implementing shorting post the size of the microstrip antenna is reduced up to 50% . When the microstrip antenna uses coaxial feeding technique and it is miniaturized by using shorting plane or post between the patch and ground plane it becomes PIFA (Planer Inverted-F Antenna). As this project also uses the coaxial feed technique and shorting

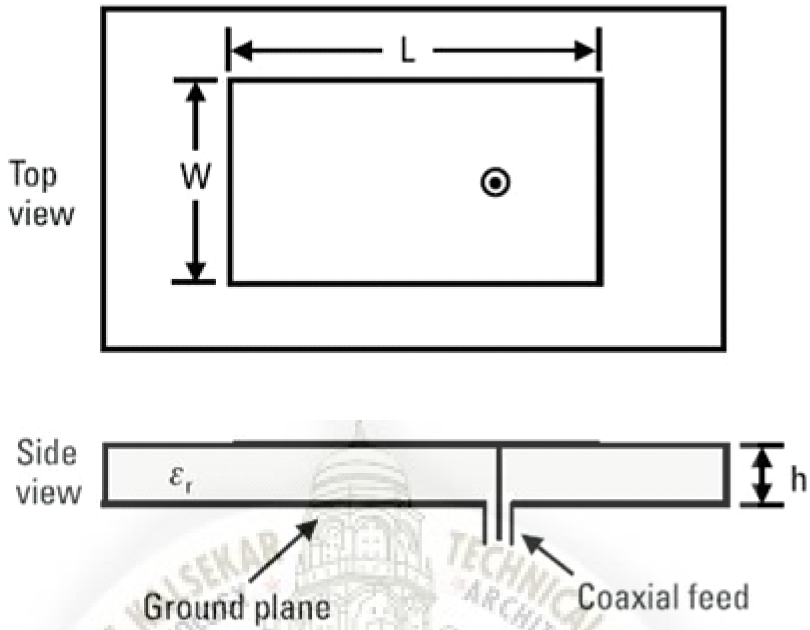


Figure 1.5: Miniaturization with shorting pin

post the microstrip antenna used in the project had taken the form of PIFA (Planer Inverted-F Antenna).

Advantages:

- They are lightweight and have a small volume and a low-profile planar configuration.
- They can be made conformal to the host surface.
- Their ease of mass production using printed-circuit technology leads to a low fabrication cost.
- They are easier to integrate with other MICs on the same substrate.
- They allow both linear polarization and CP.
- They can be made compact for use in personal mobile communication

Disadvantages:

- Narrow BW;

- Lower gain;
- Low power-handling capability.

1.3 S11-Parameter

S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network.

A port can be loosely defined as any place where we can deliver voltage and current. So, if we have a communication system with two radios (radio 1 and radio 2), then the radio terminals (which deliver power to the two antennas) would be the two ports. S11 then would be the reflected power radio 1 is trying to deliver to antenna 1. S22 would be the reflected power radio 2 is attempting to deliver to antenna 2. And S12 is the power from radio 2 that is delivered through antenna 1 to radio 1. Note that in general S-parameters are a function of frequency (i.e. vary with frequency).

Figure 1.6: Two-port network

In the above Figure, S21 represents the power received at antenna 2 relative to the power input to antenna 1. For instance, S21=0 dB implies that all the power delivered to antenna 1 ends up at the terminals of antenna 2. If S21=-10 dB, then if 1 Watt (or 0 dB) is delivered to antenna 1, then -10 dB (0.1 Watts) of power is received at antenna 2.

If an amplifier exists in the circuitry, then S21 can show gain (i.e. S21 ¿ 0 dB). This means that for 1 W of power delivered to Port 1, more than 1 W of power is received at

Port 2.

In practice, the most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the reflection coefficient (sometimes written as gamma: or return loss. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The remainder of the power was "accepted by" or delivered to the antenna. This accepted power is either radiated or absorbed as losses within the antenna. Since antennas are typically designed to be low loss, ideally the majority of the power delivered to the antenna is radiated. See also VSWR, which is directly related to S11.

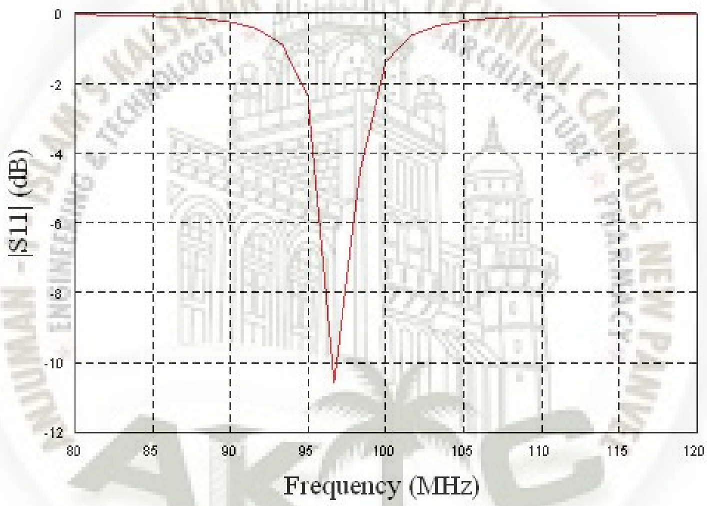


Figure 1.7: S11 plot

The above would typically be measured using a Vector Network Analyzer (VNA), which can plot S11. The above figure implies that the antenna radiates best at 2.5 GHz, where S11=-10 dB. Further, at 1.5 GHz the antenna will radiate virtually nothing, as S11 is close to 0 dB (so all the power is reflected). The antenna bandwidth can also be determined from the above figure. If the bandwidth is defined as the frequency range where S11 is to be less than -6 dB, then the bandwidth would be roughly 1 GHz, with 3 GHz the high end and 2 GHz the low end of the frequency band.

1.4 Superstrate

1.4.1 What is Organic Matter?

On the basis of organic matter content, soils are characterized as mineral or organic. Mineral soils form most of the worlds cultivated land and may contain from a trace to 30 % organic matter. Organic soils are naturally rich in organic matter principally for climatic reasons. Although they contain more than 30 percent organic matter, it is precisely for this reason that they are not vital cropping soils.

This soils bulletin concentrates on the organic matter dynamics of cropping soils. In brief, it discusses circumstances that deplete organic matter and the negative outcomes of this. The bulletin then moves on to more proactive solutions. It reviews a basket of practices in order to show how they can increase organic matter content and discusses the land and cropping benefits that then accrue.Soil organic matter is any material produced originally by living organisms (plant or animal) that is returned to the soil and goes through the decomposition process (Plate 1). At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus.

Figure 1.8: Humus

Most soil organic matter originates from plant tissue. Plant residues contain 60-90 % moisture. The remaining dry matter consists of carbon (C), oxygen, hydrogen (H) and small amounts of sulphur (S), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Although present in small amounts, these nutrients are very important from the viewpoint of soil fertility management.

Soil organic matter consists of a variety of components. These include, in varying proportions and many intermediate stages, an active organic fraction including microorganisms (10-40 percent), and resistant or stable organic matter (40-60 percent), also referred to as humus.

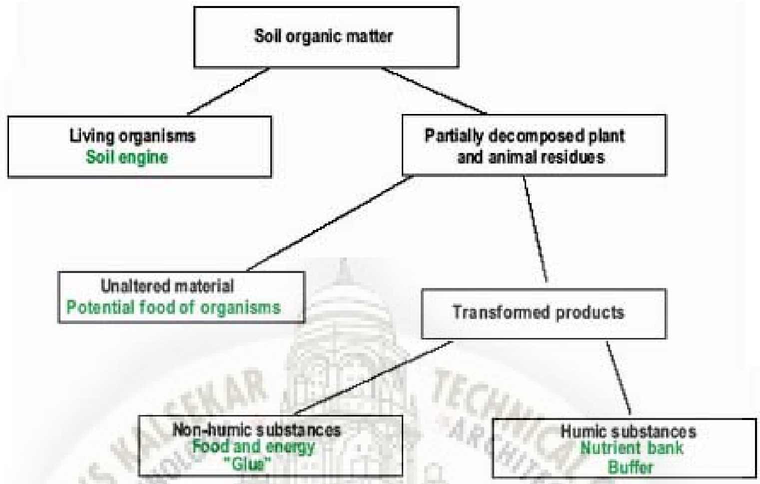


Figure 1.9: Classification of Soil organic matter

Forms and classification of soil organic matter have been described by Tate (1987) and Theng (1987). For practical purposes, organic matter may be divided into above ground and below ground fractions. Above ground organic matter comprises plant residues and animal residues; below ground organic matter consists of living soil fauna and microflora, partially decomposed plant and animal residues, and humid substances. The C:N ratio is also used to indicate the type of material and ease of decomposition; hard woody materials with a high C:N ratio being more resilient than soft leafy materials with a low C:N ratio. Although soil organic matter can be partitioned conveniently into different fractions, these do not represent static end products. Instead, the amounts present reflect a dynamic equilibrium. The total amount and partitioning of organic matter in the soil is influenced by soil properties and by the quantity of annual inputs of plant and animal residues to the ecosystem. For example, in a given soil ecosystem, the rate of decomposition and accumulation of soil organic matter is determined by such soil properties as texture, pH, temperature, moisture, aeration, clay mineralogy and soil biological activities. A complication is that soil organic matter in turn influences or modifies many of these same soil properties. Although soil organic matter can be partitioned conveniently into different fractions, these do not represent static end products. Instead, the amounts present reflect a dynamic equilibrium. The total amount and partitioning of organic matter in the soil is influenced by soil properties and by the quantity of annual inputs of plant and animal residues to the ecosystem.For example, in a given soil ecosystem, the rate of decomposition and accumulation of soil organic matter is determined by such soil properties as texture, pH, temperature, moisture, aeration, clay mineralogy and soil biological activities. A complication is that soil organic matter in turn influences or modifies many of these same soil properties.

Organic matter existing on the soil surface as raw plant residues helps protect the soil from the effect of rainfall, wind and sun. Removal, incorporation or burning of residues exposes the soil to negative climatic impacts, and removal or burning deprives the soil organisms of their primary energy source. Organic matter within the soil serves several functions. From a practical agricultural standpoint, it is important for two main reasons: (i) as a revolving nutrient fund; and (ii) as an agent to improve soil structure, maintain tilth and minimize erosion. As a revolving nutrient fund, organic matter serves two main functions:

- As soil organic matter is derived mainly from plant residues, it contains all of the essential plant nutrients. Therefore, accumulated organic matter is a storehouse of plant nutrients.
- The stable organic fraction (humus) adsorbs and holds nutrients in a plant-available form.

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1.4.2 What is Soil Organic Carbon?

Organic matter makes up just 210 % of the soils mass but has a critical role in the physical, chemical and biological function of agricultural soils. Carbon is a measurable component of soil organic matter. Organic matter contributes to nutrient turnover and cation exchange capacity, soil structure, moisture retention and availability, degradation of pollutants, greenhouse gas emissions and soil buffering.

1.4.3 Background to Soil Organic Matter and Soil Carbon

- Soil carbon, or soil organic carbon as it is more accurately known, is the carbon stored within soil
- Carbon makes up approximately 60 % of the soil organic matter (SOM), with the remaining 40 % of SOM containing other important elements such as calcium, hydrogen, oxygen, and nitrogen
- SOM is commonly, but incorrectly used interchangeably with SOC
- Soil carbon enters the soil as soil organic matter
- Soil organic matter is made up of plant and animal materials in various stages of decay
- Un-decomposed materials on the surface of the soil, such as leaf litter, are not part of the organic matter until they start to decompose
- SOM makes up only a small fraction of the soil (normally 2 to 10 % - compared to minerals which make up the bulk of soil), but plays a very important role
- SOM and SOC are a very diverse collection of materials that decay at different rates
- SOM retains moisture (humus holds up to 90 % of its weight in water), and is able to absorb and store nutrients
- A typical agricultural soil has 1 % to 6 % organic matter

1.4.4 How much Organic Matter is enough?

As mentioned earlier, soils with higher levels of fine silt and clay usually have higher levels of organic matter than those with a sandier texture. However, unlike plant nutrients or pH levels, there are few accepted guidelines for adequate organic matter content in particular agricultural soils. We do know some general guidelines. For example, 2% organic matter in a sandy soil is very good and difficult to reach, but in a clay soil 2% indicates a greatly depleted situation. The complexity of soil organic matter composition, including biological diversity of organisms, as well as the actual organic chemicals present, means that there is no simple interpretation for total soil organic matter tests. We also know that soils higher in silt and clay need more organic matter to produce sufficient water-stable aggregates to protect soil from erosion and compaction.

For example, to have an aggregation similar to that of a soil with 16% clay and 2% organic matter, a soil with close to 50% clay may need around 6% organic matter. Organic matter accumulation takes place slowly and is difficult to detect in the short term by measurements of total soil organic matter. However, even if you do not greatly increase soil organic matter (and it might take years to know how much of an effect is occurring), improved management practices such as adding organic materials, creating better rotations, and reducing tillage will help maintain the levels currently in the soil. And, perhaps more important, continuously adding a variety of residues results in plentiful supplies of dead organic matterthe relatively fresh particulate organic matter that helps maintain soil health by providing food for soil organisms and promoting the formation of soil aggregates. A recently developed soil test that oxidizes part of the organic matter is thought to provide a measure of active carbon. It is more sensitive to soil management than total organic matter and is thereby an earlier indicator for soil health improvement. Interpretation of the test is currently an active research area.

1.4.5 Factors affecting Soil Carbon level

- Determined by factors such as rainfall, temperature, vegetation and soil type
- The main inputs of SOC to soil in rain fed farming systems are from plant material, such as crop residues, plant roots, root exudates and animal manure
- Losses of SOC from soil are from decomposition by microorganisms, erosion of surface soil and off-take in plant and animal production
- Decomposition and SOC:
  1. Occurs when microorganisms use SOC in soil to obtain the carbon, nutrients and energy they need to live
  2. During decomposition, SOC is lost from soil because microorganisms convert about half of the SOC to carbon dioxide gas (CO2). Without continual inputs of SOC, the amount stored in soil will decrease over time because SOC is always being decomposed by microorganisms
- Erosion of surface soil and SOC:
  1. Losses of SOC from erosion of surface soil can have a large impact on the amount of SOC stored in soil
  2. This is because OC is concentrated in the surface soil layer as small particles that are easily eroded
  3. In Australian agriculture, erosion can cause the annual loss of 0.2 t/ha of soil from a pasture, 8 t/ha from a crop and up to 80 t/ha from bare fallow
- Off-take of OC in plant and animal production is also an important loss of OC from soil. Harvested materials such as grain, hay, feed and animal grazing all represent loss of OC (and nutrients) from soil

Chapter 2

Literature review

2.1 Dielectric Behavior of Fertilized Soil at Microwave Frequency

2.1.1 Introduction

An application note by Rajesh Mohan R,S Mridula and P Mohanan, Study and Analysis of Dielectric Behavior of Fertilized Soil at Microwave Frequency, published by European Journal of Advances in Engineering and Technology, 2015, 2(2): 73-79. The variations in dielectric constant of soil with different concentration of various fertilizers like Boric Acid, NPK, Potash and Urea are studied extensively.Measurement has been performed using Vector Network Analyzer (VNA) and antenna/soil sample holder. The sample-mixtures are prepared by mixing different fertilizers in soil according to the statistics.

2.1.2 Dielectric Behavior of Fertilized Soil at Microwave Frequency

Thirteen elements, called nutrients, are essential for plant growth. They are classified as macro- and micro-nutrients, based on the quantity required.nutrients are returned to the soil when plants die and decay. When cultivated plants are harvested, nutrients that the plants extracted from the soil are taken away. To keep the soil productive, it is necessary to replace these nutrients artificially. This is done by applying to the soil substances that contain these nutrients. Nitrogen, phosphorus, and potassium are the major macro-nutrients.Water has a strong influence on the dielectric properties of soil at microwave frequencies.Different levels of fertilizers give rise to a large variation in the dielectric constant. Thus, knowledge of the variation of the dielectric constant of soil with fertilizers is necessary for their efficient use in soil.Dielectric constant represents the ability of a material to store electric energy, while the loss factor represents the loss of electric-field energy in the material.' This trend of decrease in value for increase in er frequency is shown by all the other soil-fertilizer combinations also.' Fertilizers increase the pore space of the soil. Due to more pore space, increases and the fertility er of soil is also increased. The different types of fertilizers have different organic components. Soil is also affected by these different organic components.

2.1.3 Conclusion

The paper explores the relevance of usage of microwave frequencies for the dielectric-property extraction of soil Soil pH and availability and supply of nutrients are interrelated. Through this paper, dielectric constant values of a variety of soil samples, each with varying pH and TSS are measured, both at fixed and varying fertilizer-concentrations at the L, S and C-band frequencies. It has been observed that the dielectric constant of plain soil and soil mixed with fertilizers decreases with increase in frequency in the microwave band.This study on the dielectric properties of dry and fertilized soils is thus useful not only in designing microwave sensors of soil-moisture estimation.

2.2 Dielectric Properties of Soils with Organic and Inorganic Matter at J-Band Microwave Frequency

2.2.1 Introduction

The research paper authored by Harish C. Chaudhari., DIELECTRIC PROPERTIES OF SOILS WITH ORGANIC AND INORGANIC MATTER AT J-BAND MICROWAVE FREQUENCY International Journal of Remote Sensing Geo-science (IJRSG).The real (') and imaginary (") parts of the complex dielectric constant (*) of four soils with increasing percentage of humus and calcium carbonate separately are measured. The J-band microwave bench tuned to 7.0 GHz is used for measurements. The two point method is used for these measurements. The value of and increases with increase in organic as well as with inorganic matter of soils.

2.2.2 Properties of Soils with Organic and Inorganic Matter

The dielectric properties of soil are function of its physical properties such as sand, silt, clay and the chemical properties such as nitrogen, sodium, potassium, iron, magnesium also on the available micro-nutrients.The dielectric constant of dry soils with their physical constituents and naturally available nutrients at C- band microwave frequency 4.5 GHz are presented. The effect of organic matter content of soil with different organic matter level and at a given moisture level on the microwave emissivity is observed. The effect of cow manure on dielectric properties of clay loam soil at microwave frequency have been measured using a vector network analyzer with varied moisture contents in the frequency range 150 MHz to 2.2 GHz. Measurements of complex dielectric permittivity in this frequency range were also carried out for different concentration of cow manure in soil. Dielectric properties of soilorganic matter mixtures using coaxial impedance dielectric reflectometry are measured. Dielectric response of a variable saturated soil contaminated by non-aqueous phase liquids (NAPLs) hydrocarbon contamination in soils

2.2.3 Conclusion

Study of physical properties, chemical properties, dielectric properties of soils with varied organic and inorganic matter is useful in agriculture to predict quality and fertility of soil.

Chapter 3

Design of Microstrip antenna

3.1 Planar Inverted Folded Antenna (PIFA)

The Planar Inverted-F antenna (PIFA) is increasingly used in the mobile phone market.The antenna is resonant at a quarter-wavelength (thus reducing the required space needed on the phone), and also typically has good SAR properties. This antenna resembles an inverted F, which explains the PIFA name.The Planar Inverted-F Antenna is popular because it has a low profile and an omnidirectional pattern.The PIFA is shown from a side view in Figure 3.1

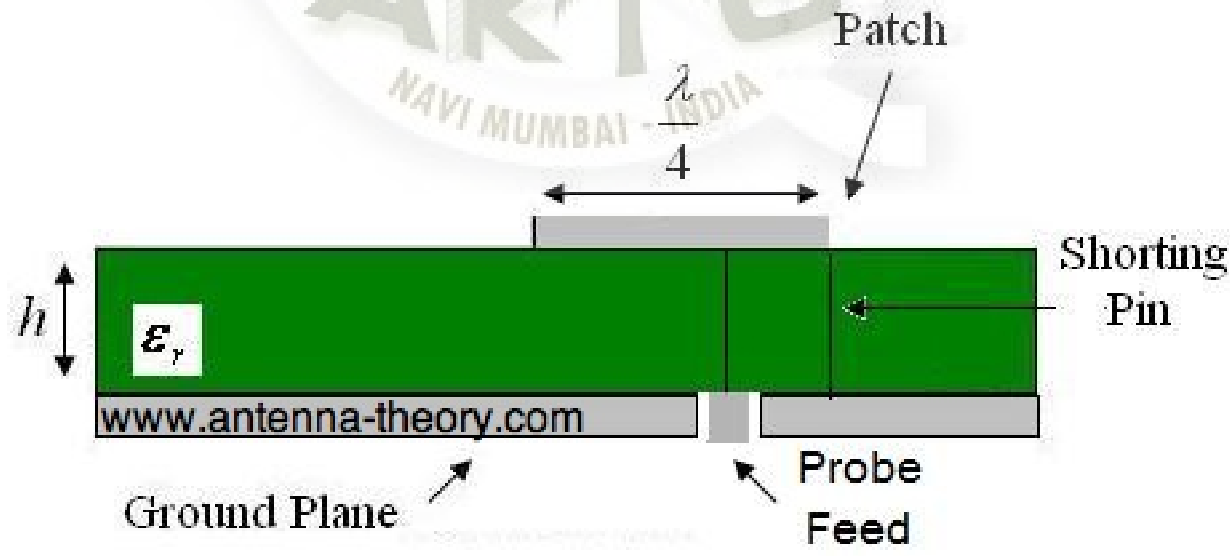


Figure 3.1: Planar Inverted-F Antenna (PIFA)

The PIFA is resonant at a quarter-wavelength due to the shorting pin at the end. We'll see how the resonant length is defined exactly in a minute.The feed is placed between the open and shorted end, and the position controls the input impedance.In PIFAs, the shorting pin can be a plate, as shown in Figure 3.2

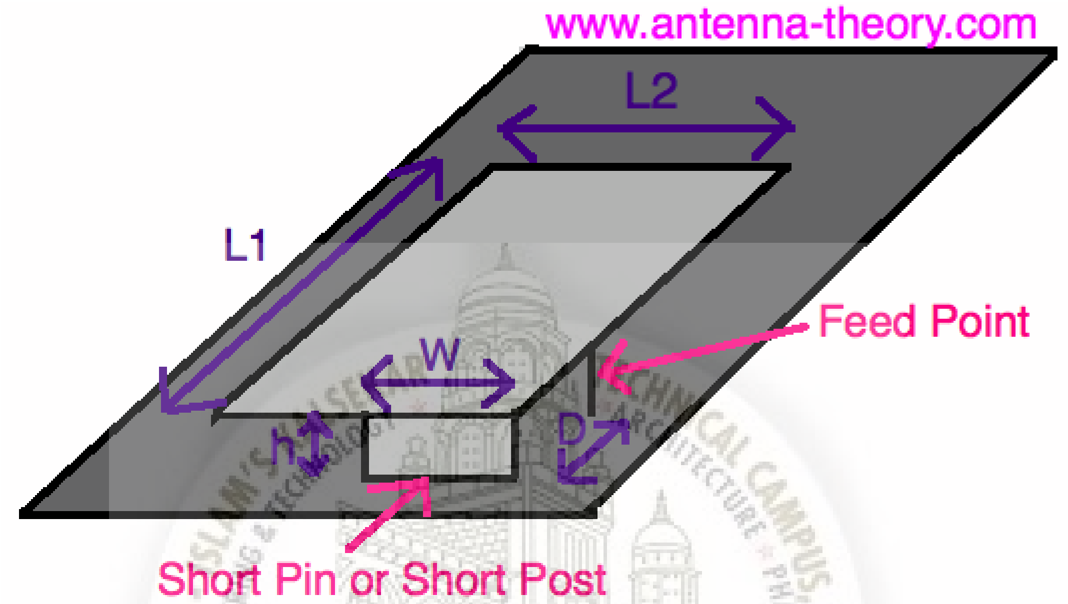


Figure 3.2: The Planar Inverted-F Antenna (PIFA), with a shorting Plane

3.1.1 Designing Calculation

In Figure 3.2, we have a PIFA of length L1, of width L2. The shorting pin (or shorting post) is of width W, and begins at one edge of the PIFA as shown in Figure 3.2. The feed point is along the same edge as shown. The feed is a distance D from the shorting pin. The PIFA is at a height h from the ground plane. The PIFA sits on top of a dielectric with permittivity as with the patch antenna.

The impedance of the PIFA can be controlled via the distance of the feed to the short pin (D).The closer the feed is to the shorting pin, the impedance will decrease; the impedance can be increased by moving it farther from the short edge.The PIFA can have it's impedance tuned with this parameter.

The resonant frequency of the PIFA depends on W. If W=L2, then the shorting pin runs the entire width of the patch. In this case, the PIFA is resonant (has maximum radiation efficiency) when:

$$if, \qquad W = L2 \Rightarrow L1 = \lambda/4 \qquad ....[Equation\ \ 1]$$

Suppose that W=0, so that the short is just a pin (or assume W ¡¡ L2). Then the PIFA is resonant at:

$$if, \qquad W = 0 \Rightarrow L1 + L2 = \lambda/4 \qquad ....[Equation\ \ 2]$$

Why does the resonant length of the PIFA depend on the shorting pin length W? Intuitively, think about how a quarter-wavelength patch antenna radiates. It needs a quarter-wavelength of space between the edge and the shorting area. If W=L2, then the distance from one edge to the short is simply L1, which gives us Equation [1].

What about when W=0? Since it is the fringing fields along the edge that give rise to radiation in microstrip antennas, we see that the length from the open-circuited radiating edge (the far edge in Figure 3.2) to the shorting pin is on average equal to L1+L2. You can convince yourself of this by measuring the distance from any point on the far edge of the PIFA to the shorting pin. The clockwise and counter-clockwise paths always add up to 2*(L1+L2), so on average, resonance will occur when the path length (L1+L2) for a single path is a quarter-wavelength.

In general, we can approximate the resonant length of a PIFA as a function of its parameters as:

$$L1 + L2 - W = \lambda/4 \qquad ....[Equation\ \ 3]$$

To make things concrete, suppose L1=0.1 meters (10cm), L2=0.05 meters (5 cm), W=0.02 meters (2cm), and that =4. Then what is the resonant frequency? The solution can be found in Equation [4]:

$$L1 + L2 - W = \lambda/4$$

$$0.1 + 0.05 - 0.02 = c/[4f\sqrt{\varepsilon_r}]$$

$$0.13 = 3 * 10^8/[4f\sqrt{4}] \Rightarrow f = 3 * 10^8/[4f\sqrt{4(0.13)} = 288.5MHz] \quad ....[Equation\ 4]$$

In Equation [4], note that we used one of the fundamental antenna equations, relating wavelength, speed of light and permittivity:

$$c = \lambda f$$

$$f = \mathcal{C}_0/\lambda\sqrt{\varepsilon_r} = 3 * 10^8/\lambda\sqrt{\varepsilon_r} \quad ....[Equation\ 5]$$

Capacitive Loading in PIFA Antennas Suppose we want to further reduce the length of our PIFA antenna. What can we do? Well, it's common to use capacitive loading in PIFA antennas. In this technique, we add capacitance to the PIFA antenna, between the feed point and the open edge. Why does this work? Well, to the right of the feed in Figure 3.2, we have a short circuit to ground. Short circuits with a small fraction of a wavelength can be viewed as a parallel inductance to ground, as far as the impedance is concerned. Similarly, the open circuit and arm to the left of the feed in Figure 3.2 can be viewed as a capacitor (if this isn't too clear, you might want to check out the transmission line tutorial). The distances from the feed to the shorting pin, or the feed to the open edge of the PIFA determine the inductance and capacitance, respectively. In some sense, the lengths are required such that the inductance and capacitance can be balanced out.

To compensate for this, we add a parallel capacitance, and (from an impedance perspective), everything remains balanced and the PIFA radiates.

This technique works, but be careful: you lose radiation efficiency by using this technique (and the bandwidth of your PIFA will decrease as well). You can't just decrease the size of your PIFA, replace it with capacitance and expect everything to be the same: you can't get something for nothing; antenna engineering is all about trade-offs. The antenna designed is shown below,

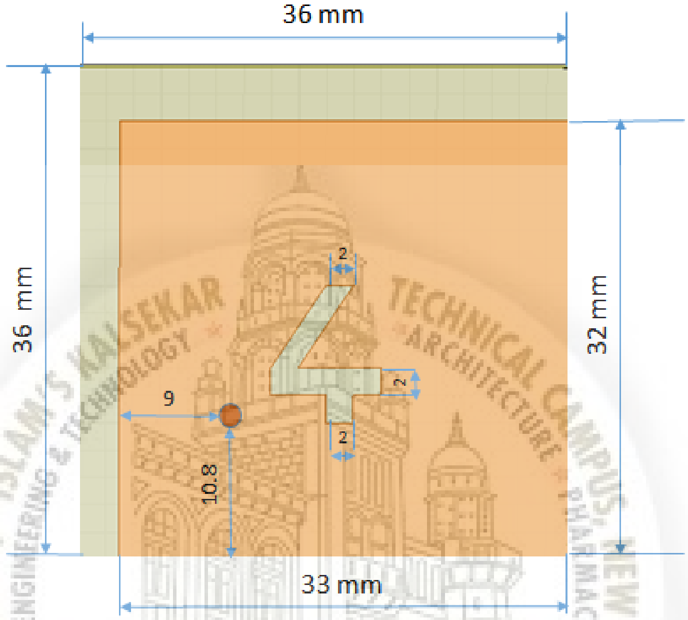


Figure 3.3: Antenna Deign

Chapter 4

Methodology

The design of microstrip antenna sensor for this project include calculation and simulation, sometime in the process of design both calculation and simulation going simultaneously and also iterations are carried out. The software used for simulation is HFSS (High Frequency Simulation Software). The iteration method is carried in the HFSS simulation method to get the expected results. In the proceeding section introduction to HFSS is given which is followed by the simulation procedure in HFSS.

HFSS is an interactive software package for calculating the electromagnetic behaviour of a structure. The software includes post-processing commands for analyzing this behaviour in detail [13]. The work window of HFSS software is shown in Figure 4.1.

Using HFSS, we can compute:

- Basic electromagnetic field quantities and, for open boundary problems, radiated near and far fields.
- Characteristic port impedances and propagation constants.
- Generalized S-parameters and S-parameters renormalized to specific port impedances.
- The eigenmodes, or resonances, of a structure.

We are expected to draw the structure, specify material characteristics for each object, and identify ports and special surface characteristics. HFSS then generates the necessary field solutions and associated port characteristics and S-parameters [13].

HFSS uses a numerical technique called the Finite Element Method (FEM). This is a procedure where a structure is subdivided into many smaller subsections called finite elements. The finite elements used by HFSS are tetrahedra, and the entire collection of tetrahedra is called a mesh. A solution is found for the fields within the finite elements, and these fields are interrelated so that Maxwells equations are satisfied across inter-element boundaries. Yielding a field solution for the entire, original, structure. Once the field solution has been found, the generalized S-matrix solution is determined [13].

The six general steps in an HFSS simulation

There are six main steps to creating and solving a proper HFSS simulation [13]. They are:

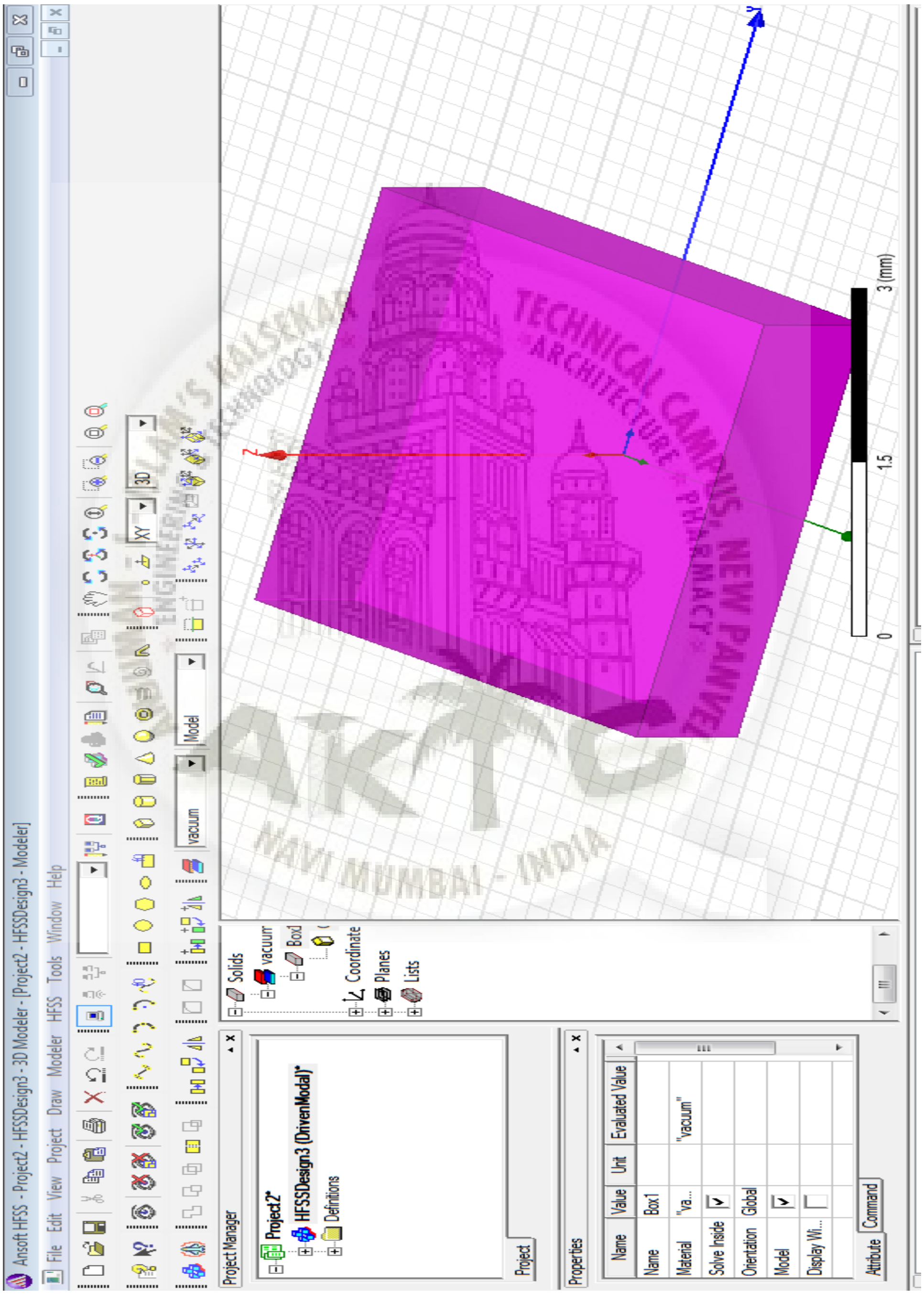
1. Create model/geometry
2. Assign boundaries
3. Assign excitations
4. Set up the solution
5. Solve
6. Post-process the results

First we have to select solution type for our project i.e. *Driven Terminal.*

Go to HFSS → Solution type → Select Driven Terminal → *Ok*.

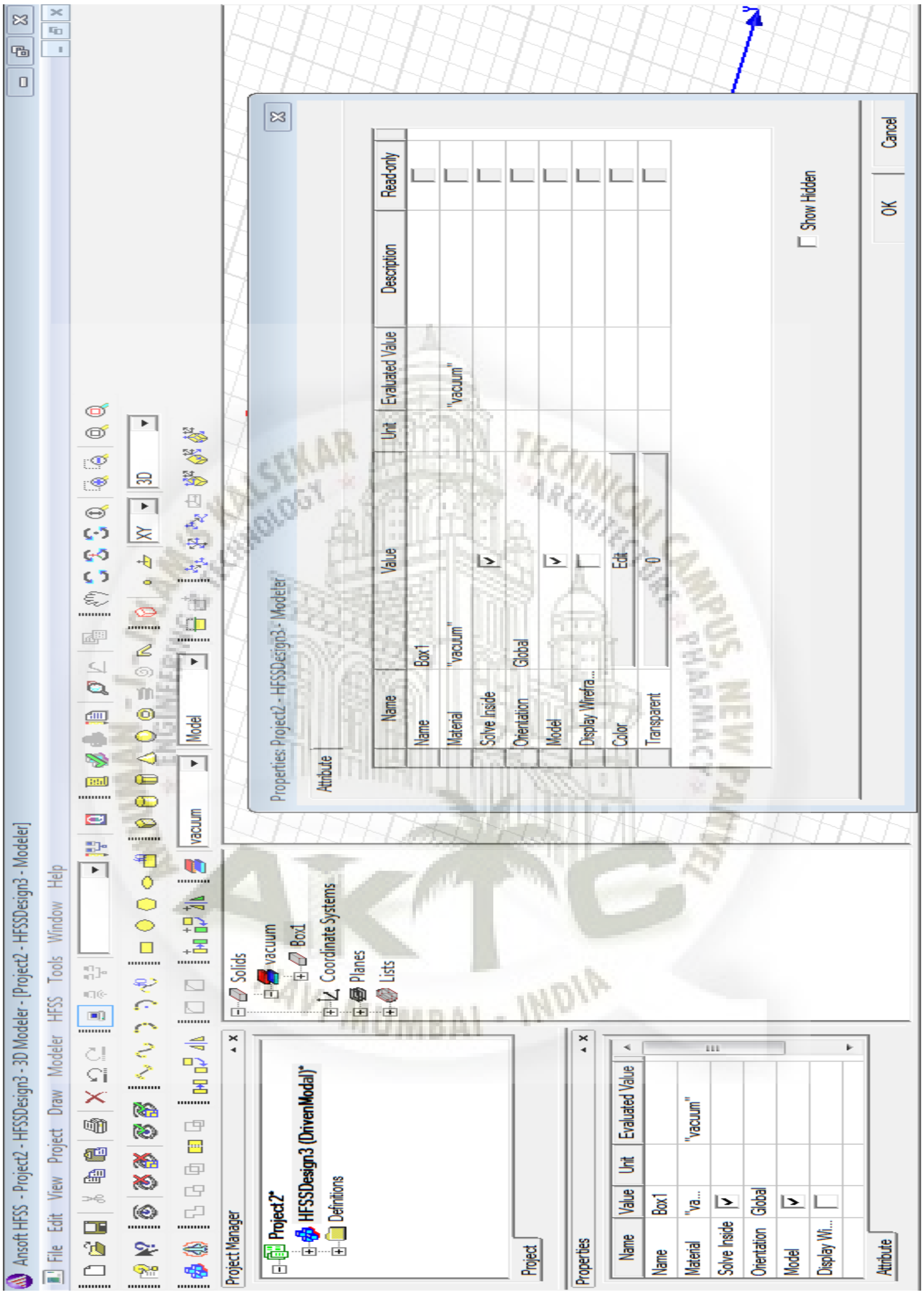
Placing Substrate in the drawing window.

Select Draw box Place in the drawing window

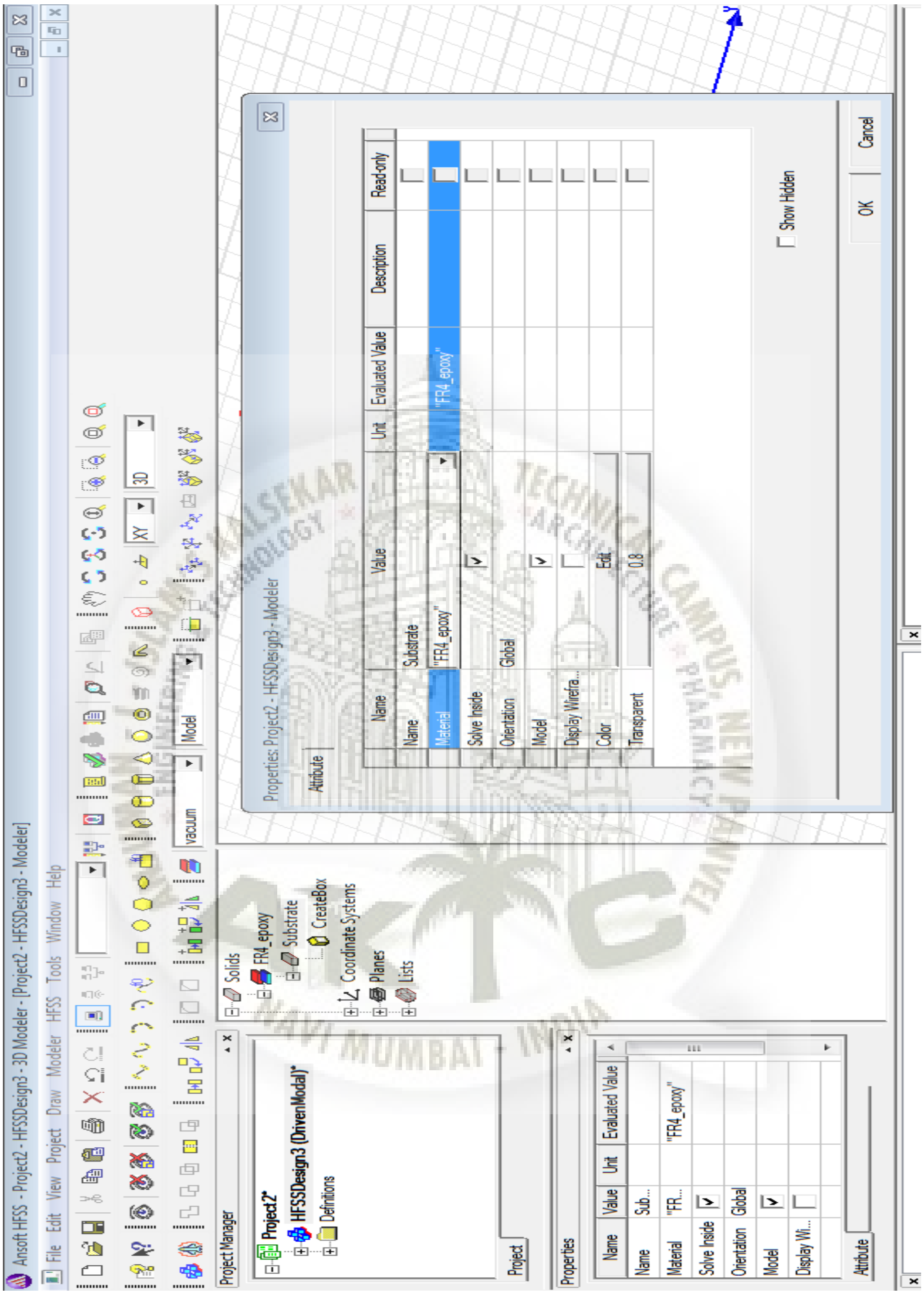


Setting box properties (Name, Material, Color and transparency)

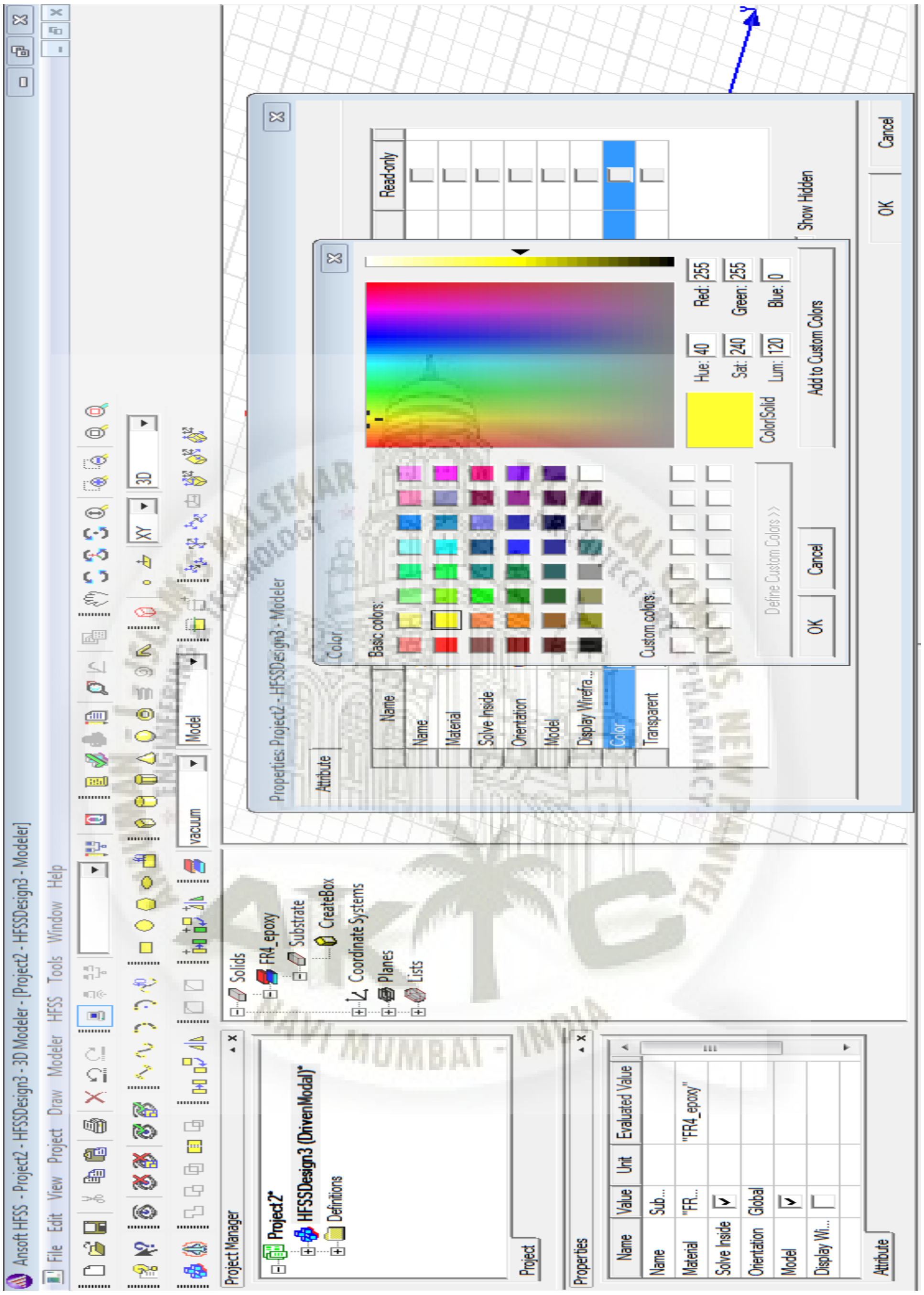
Right click on Box1 $\rightarrow$ *Properties* $\rightarrow$ *Name* $\rightarrow$ *Box*1



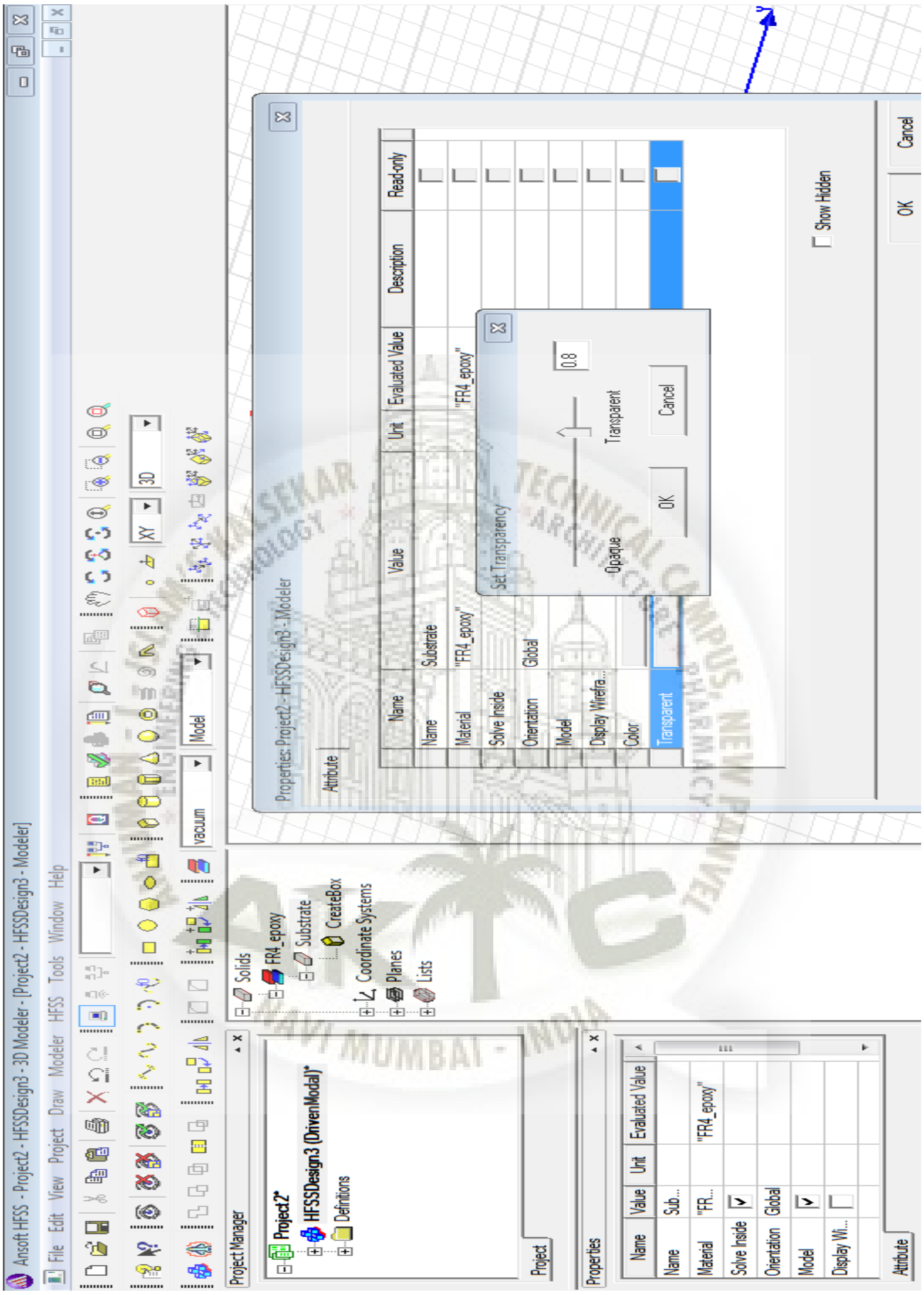
Setting box properties (Name, Material, Color and transparency) Right click on Box1 $\rightarrow Properties \rightarrow Material \rightarrow$FR4$_e poxy \rightarrow Ok.$



Setting box properties (Name, Material, Color and transparency) Right click on Box1 $\rightarrow$ *Properties* $\rightarrow$ Colour Ok.

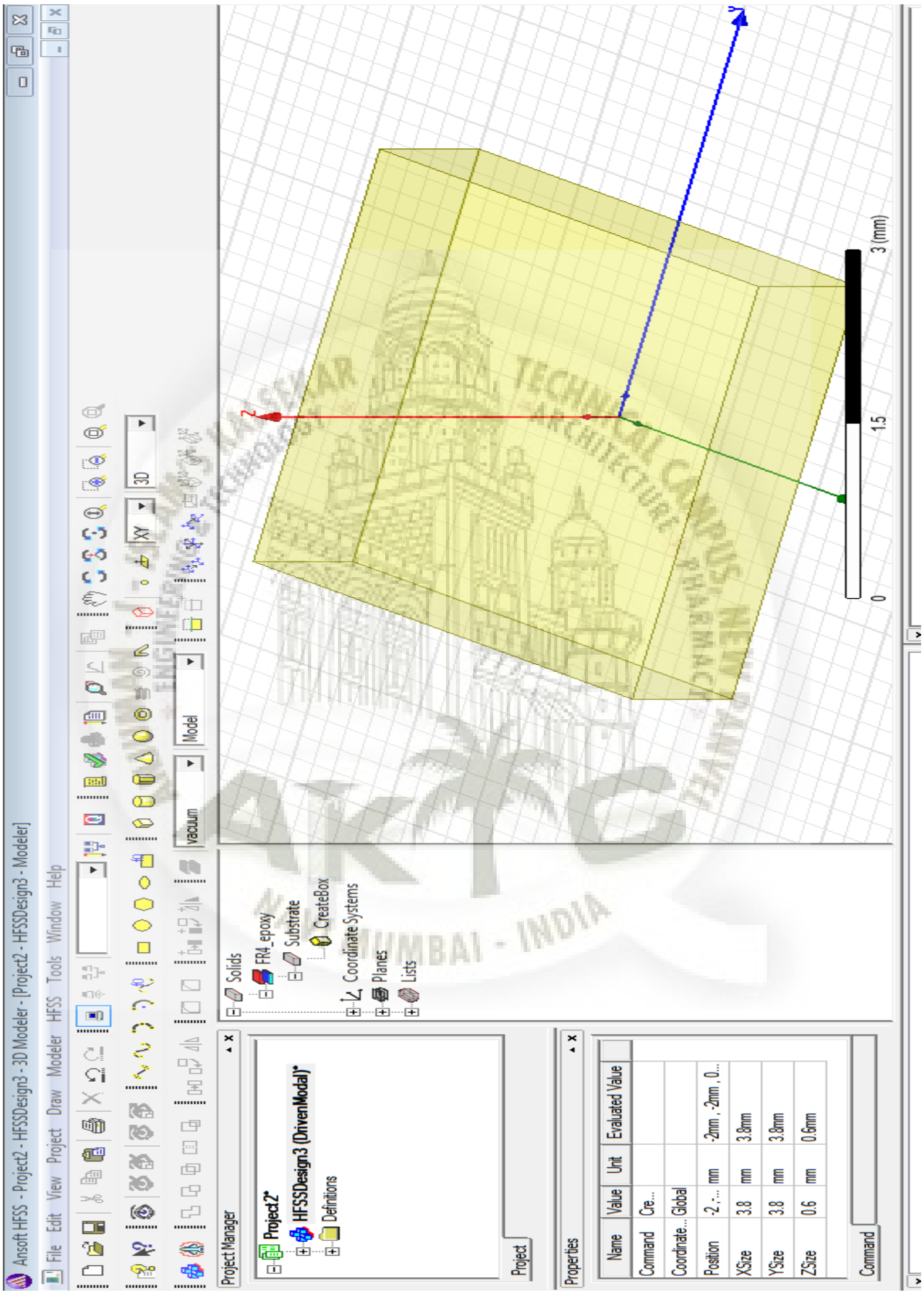


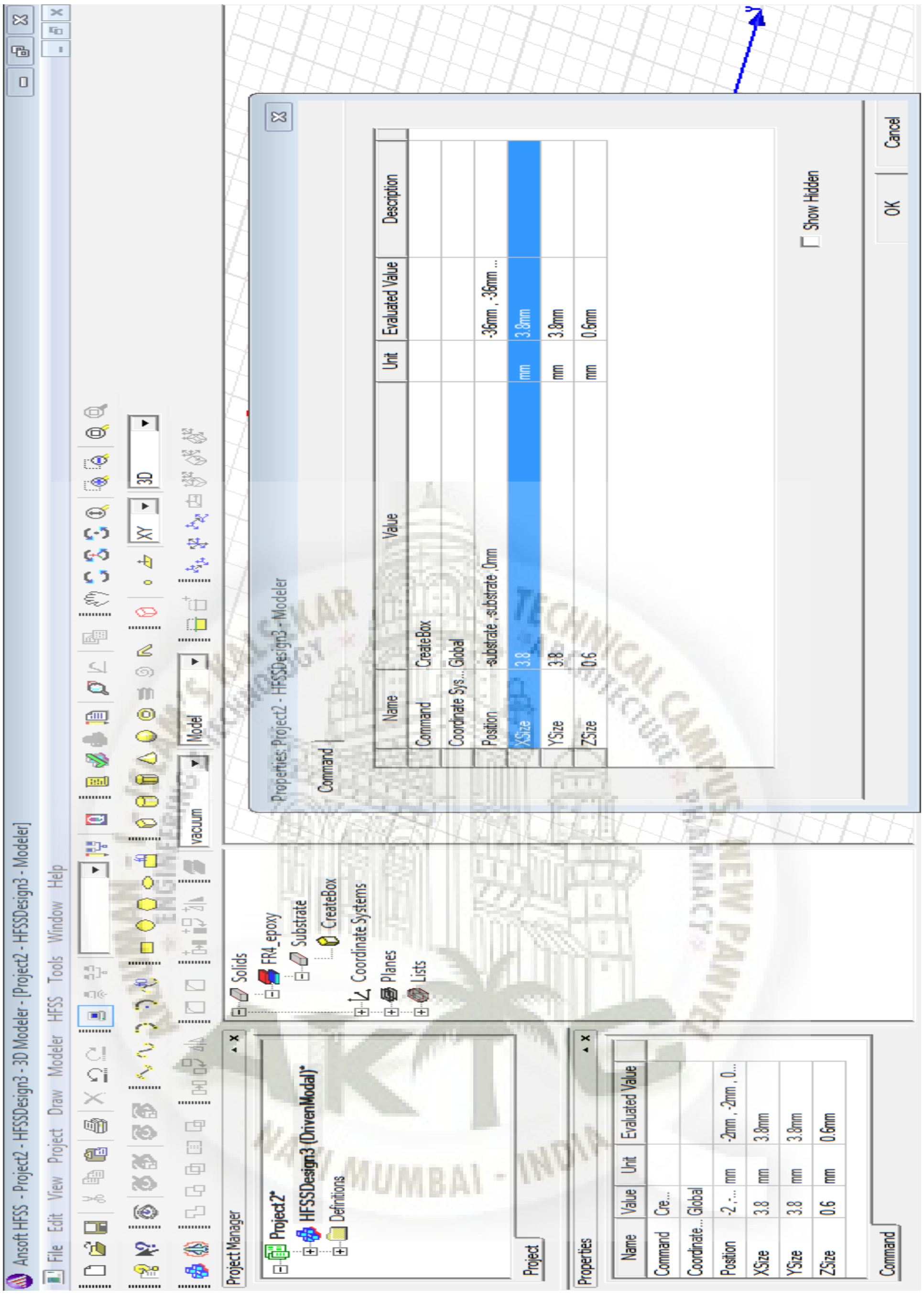
Setting box properties (Name, Material, Color and transparency) Right click on Box1 $\rightarrow$ *Properties* $\rightarrow$ *Transparent* $\rightarrow$ *OK*.

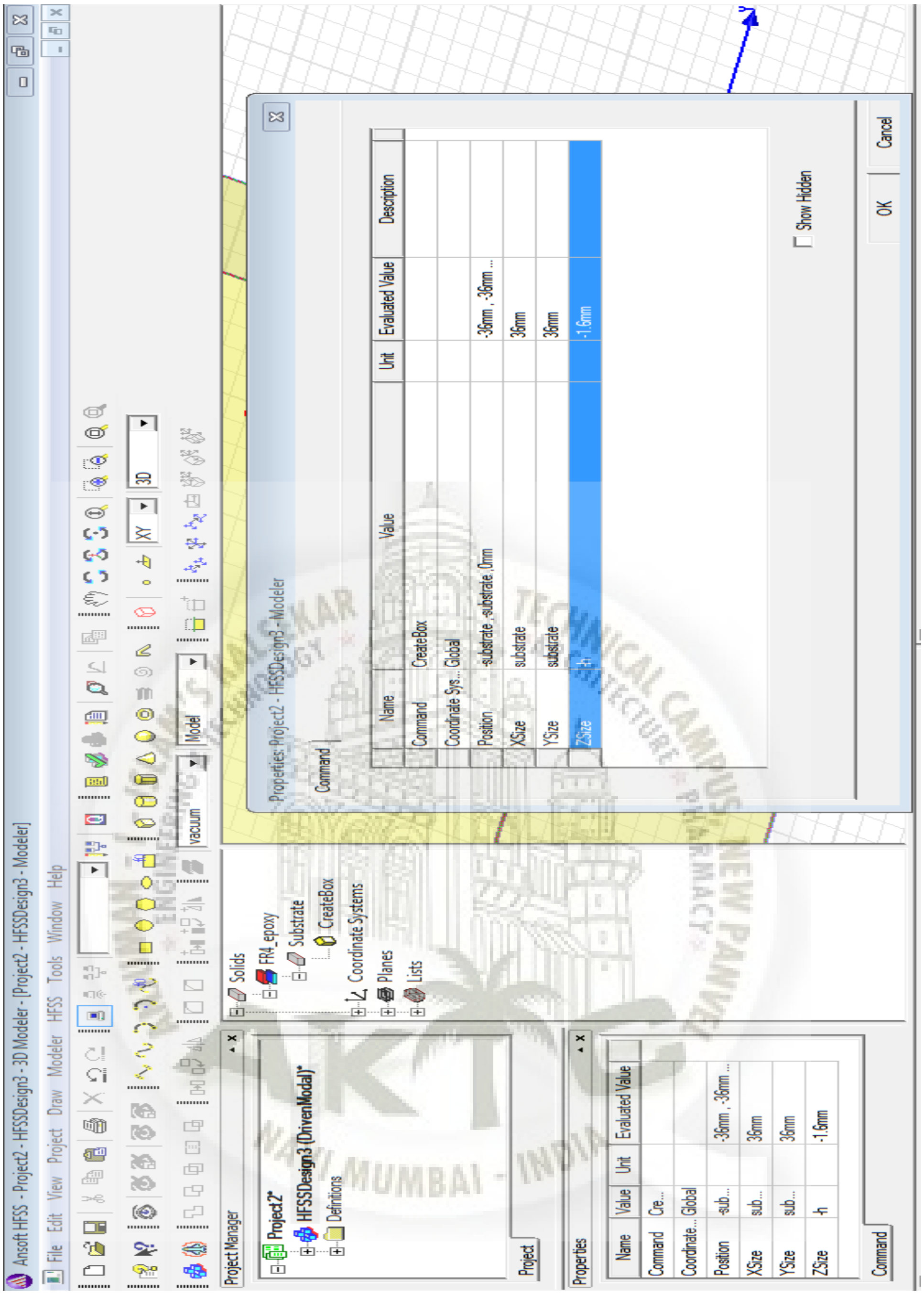


After setting Name, Color and transparency the size and position of the substrate is edited.

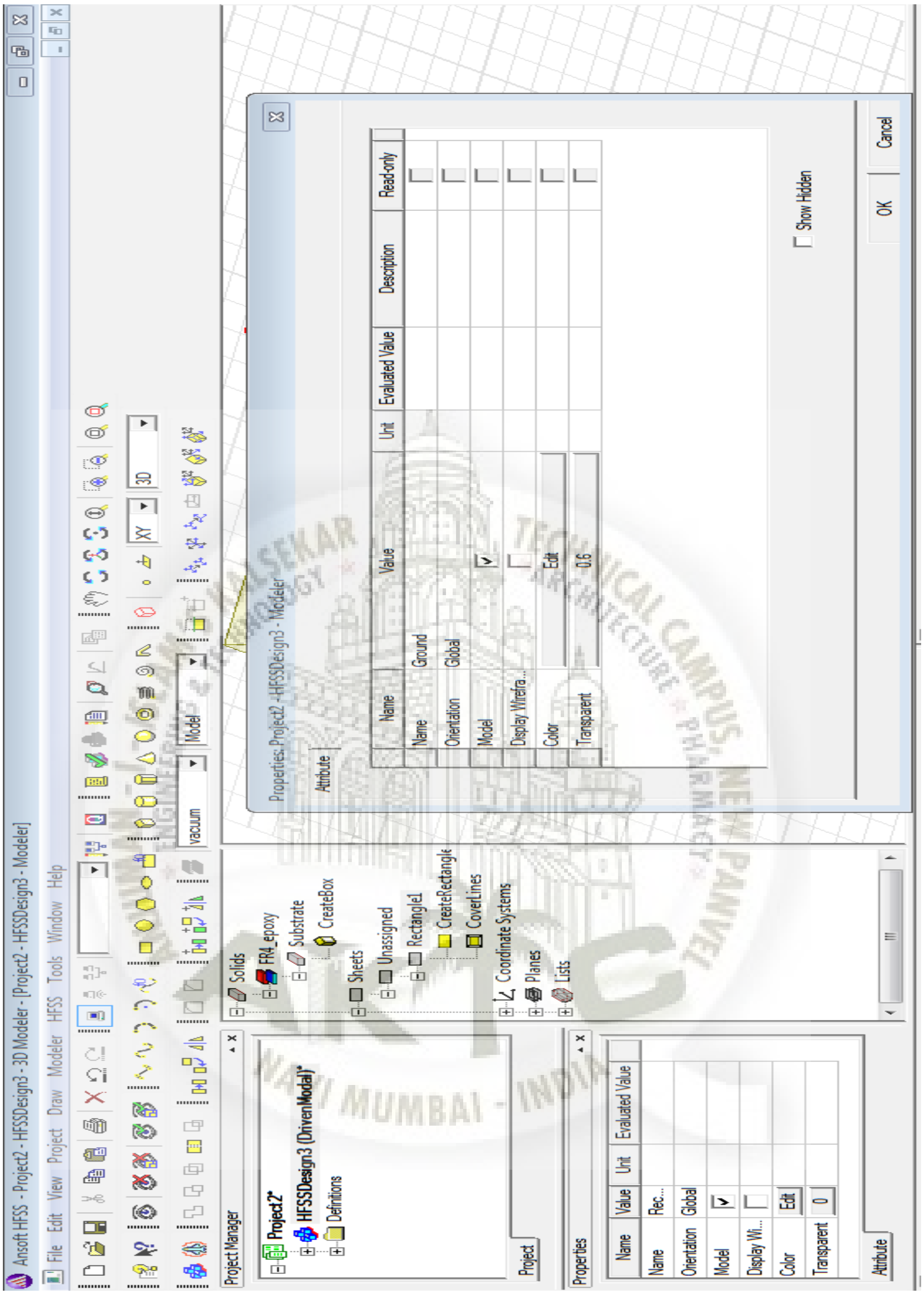
Right click on create box → *Properties* → edit x, y, z position → edit X, Y, Z size → *OK*.



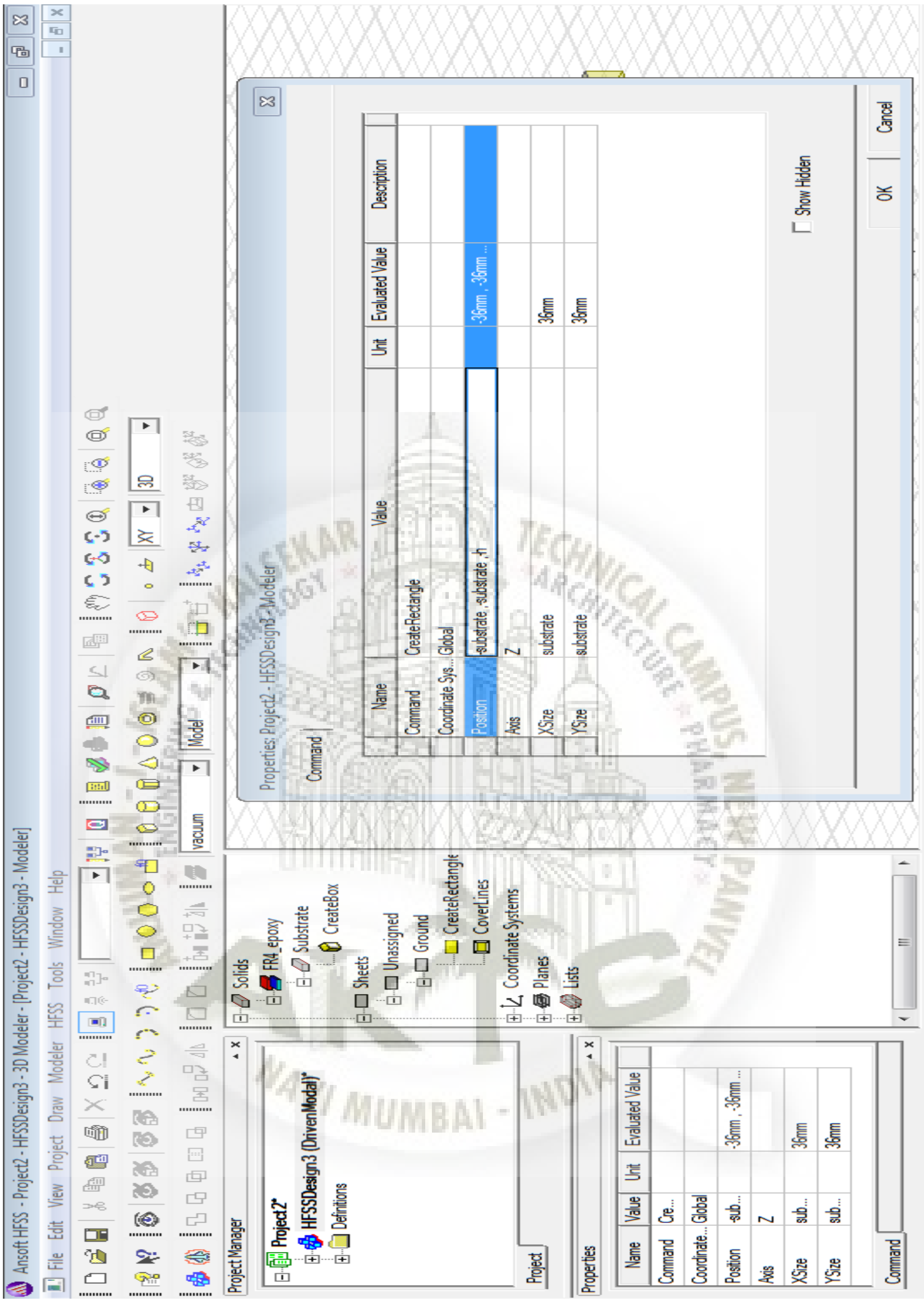

Ansoft HFSS - Project2 - HFSSDesign3 - 3D Modeler - [Project2 - HFSSDesign3 - Modeler]
File Edit View Project Draw Modeler HFSS Tools Window Help
Project Manager
Project2*
HFSSDesign3 (DrivenModal)*
Definitions
Solids
FR4_epoxy
Substrate
CreateBox
Coordinate Systems
Planes
Lists
Properties: Project2 - HFSSDesign3 - Modeler
Command
Name
Value
Unit
Evaluated Value
Description
Command
CreateBox
Coordinate Sys...
Global
Position
-substrate ,-substrate ,0mm
-36mm , -36mm ...
XSize
3.8
mm
3.8mm
YSize
3.8
mm
3.8mm
ZSize
0.6
mm
0.6mm
Show Hidden
OK
Cancel


Ansoft HFSS - Project2 - HFSSDesign3 - 3D Modeler - [Project2 - HFSSDesign3 - Modeler]
Properties: Project2 - HFSSDesign3 - Modeler
Command
Name
Value
Unit
Evaluated Value
Description
Command
CreateBox
Coordinate Sys...
Global
Position
-substrate ,-substrate ,0mm
-36mm , -36mm ...
XSize
substrate
36mm
YSize
substrate
36mm
ZSize
-h
-1.6mm
Show Hidden
OK
Cancel
Project Manager
Project2*
HFSSDesign3 (DrivenModal)*
Definitions
Solids
FR4_epoxy
Substrate
CreateBox
Coordinate Systems
Planes
Lists
Properties

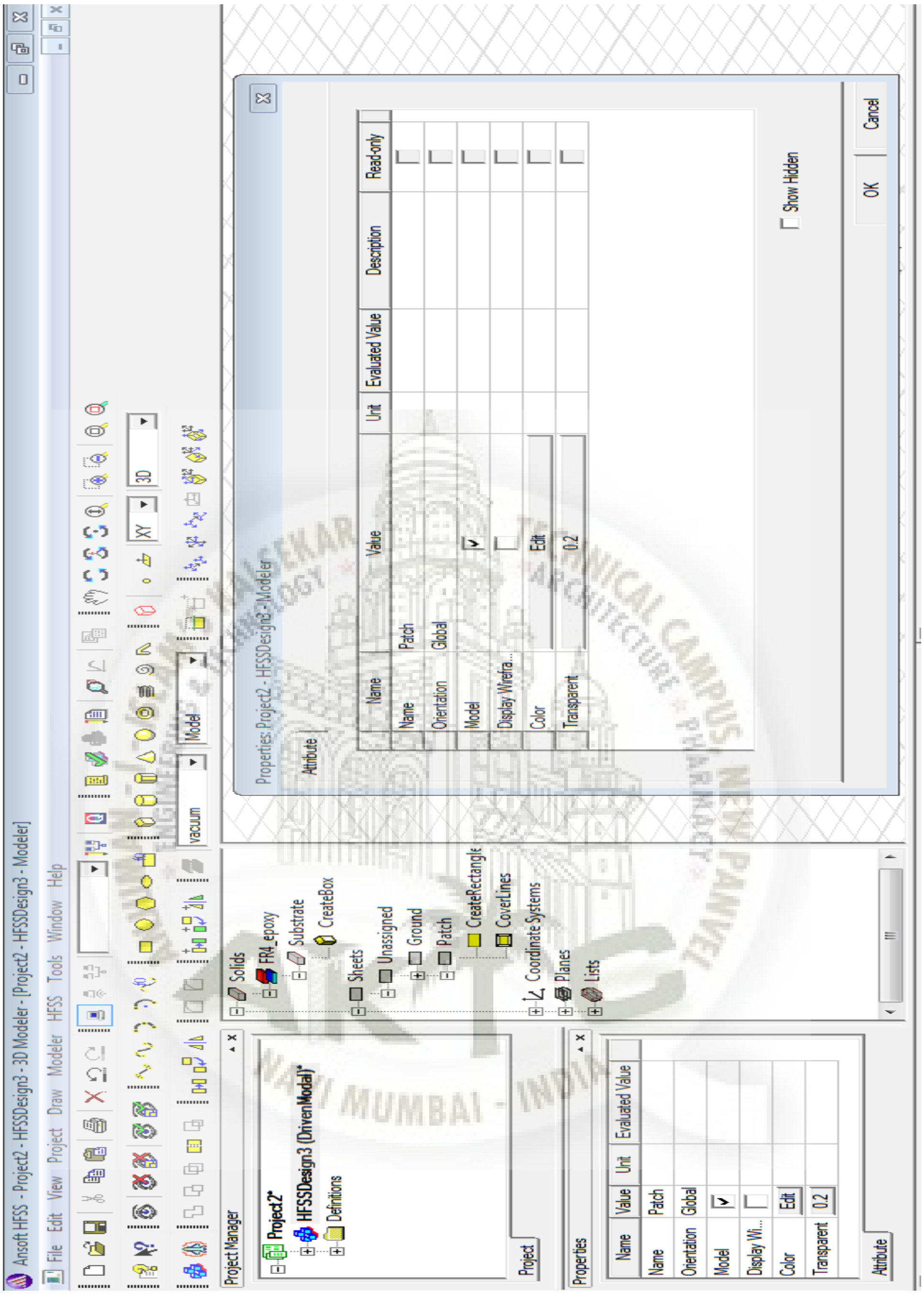
Right click on Rectangle1 → *Properties* → *Name* → *Ground*



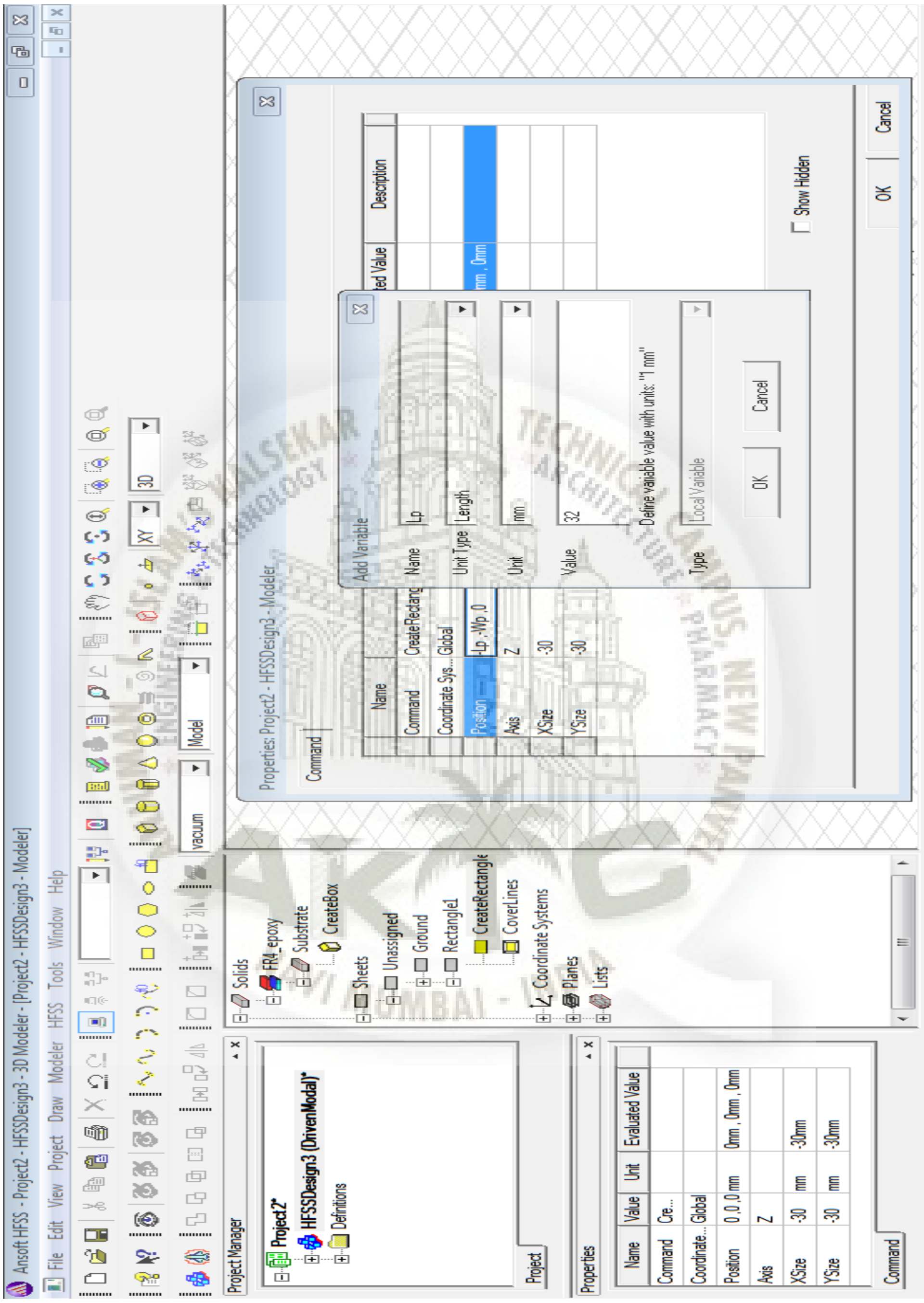
Right click on Create Rectangle1 → *Properties* → dimension of ground → *OK*

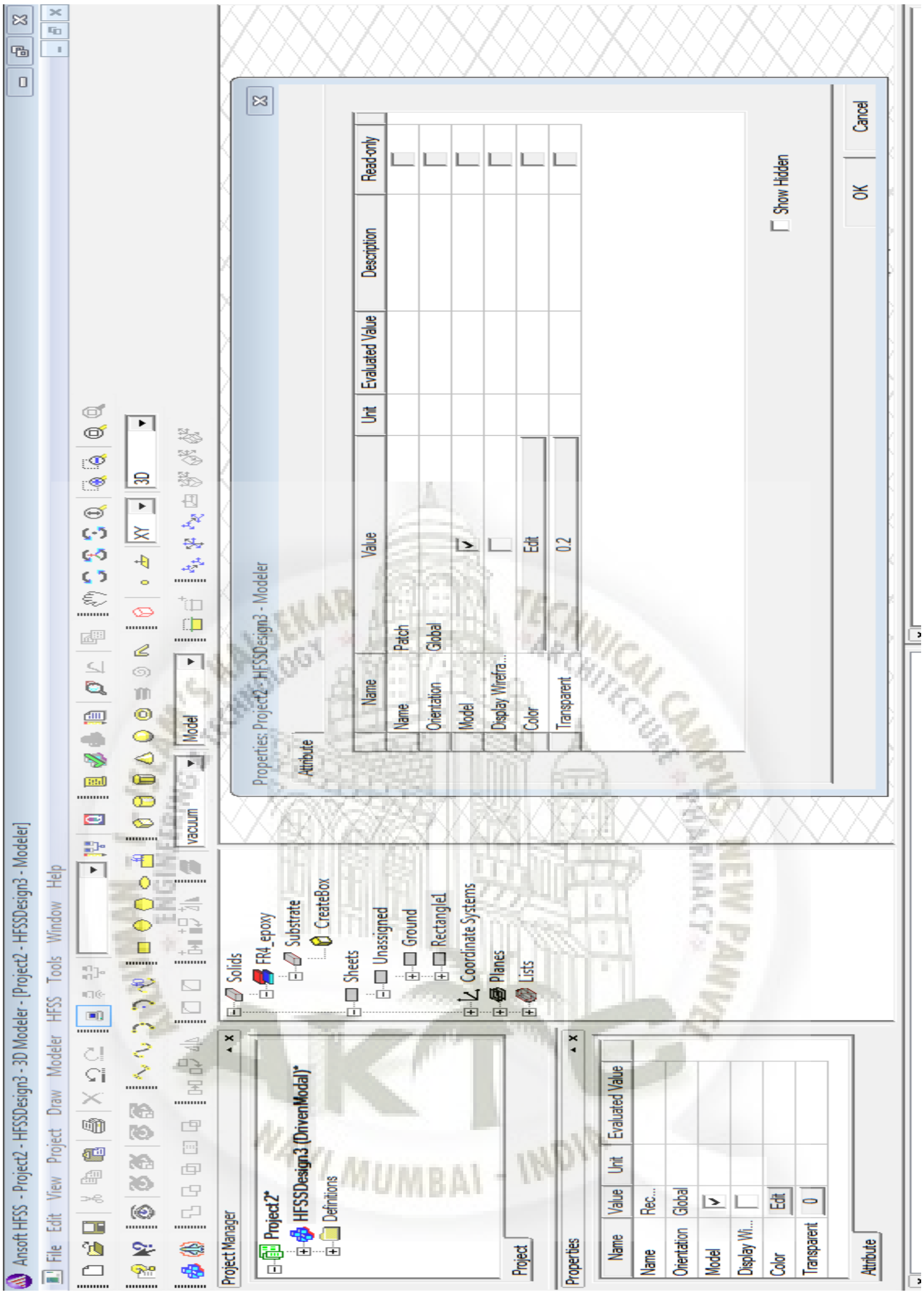


Right click on Rectangle2 → *Properties* → *Name* → *patch*

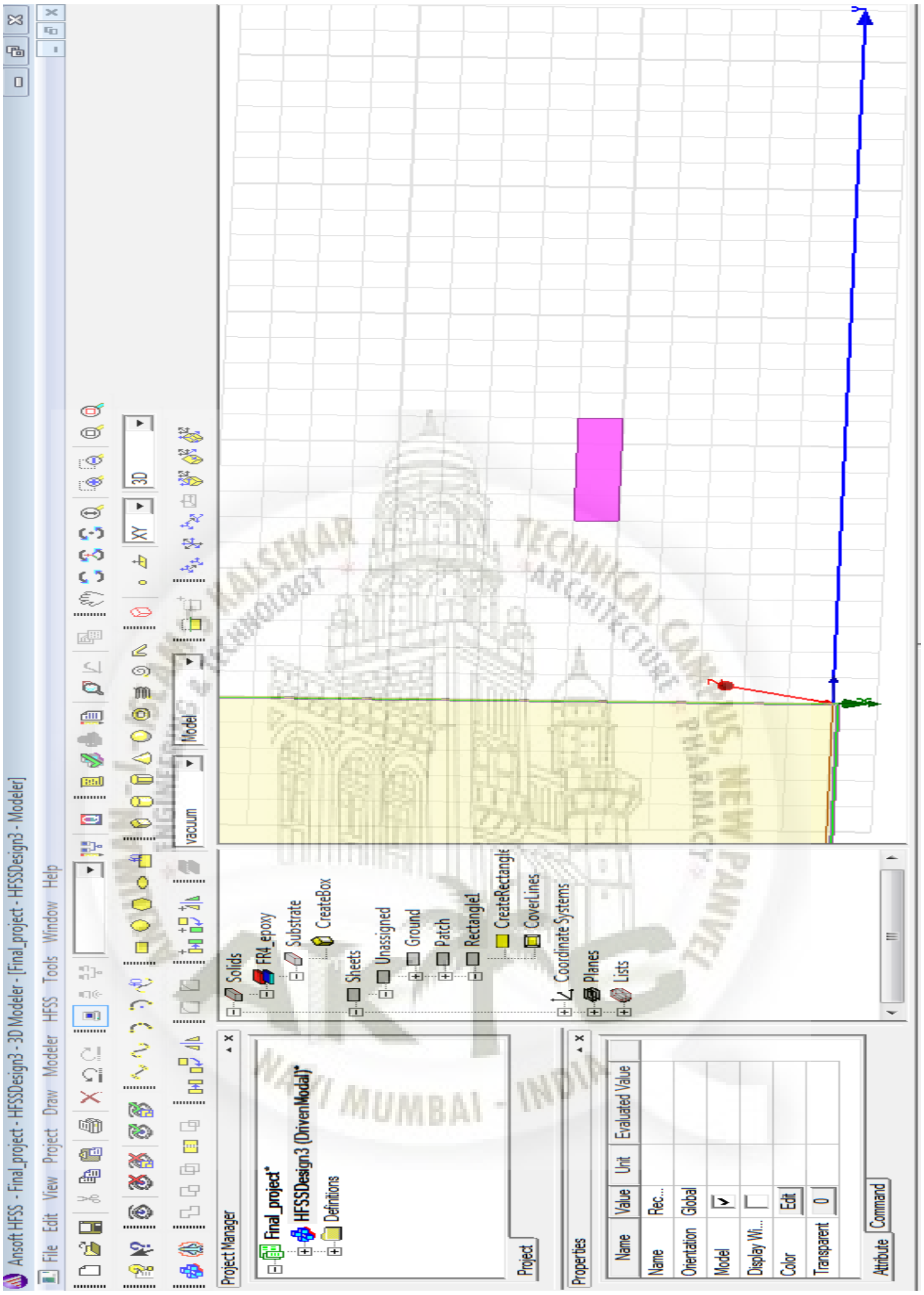


After setting Name, Color and transparency the size and position of the substrate is edited. Right click on create box → Properties → edit Lp, Wp position → give value of Lp ,Wp → *Ok*.

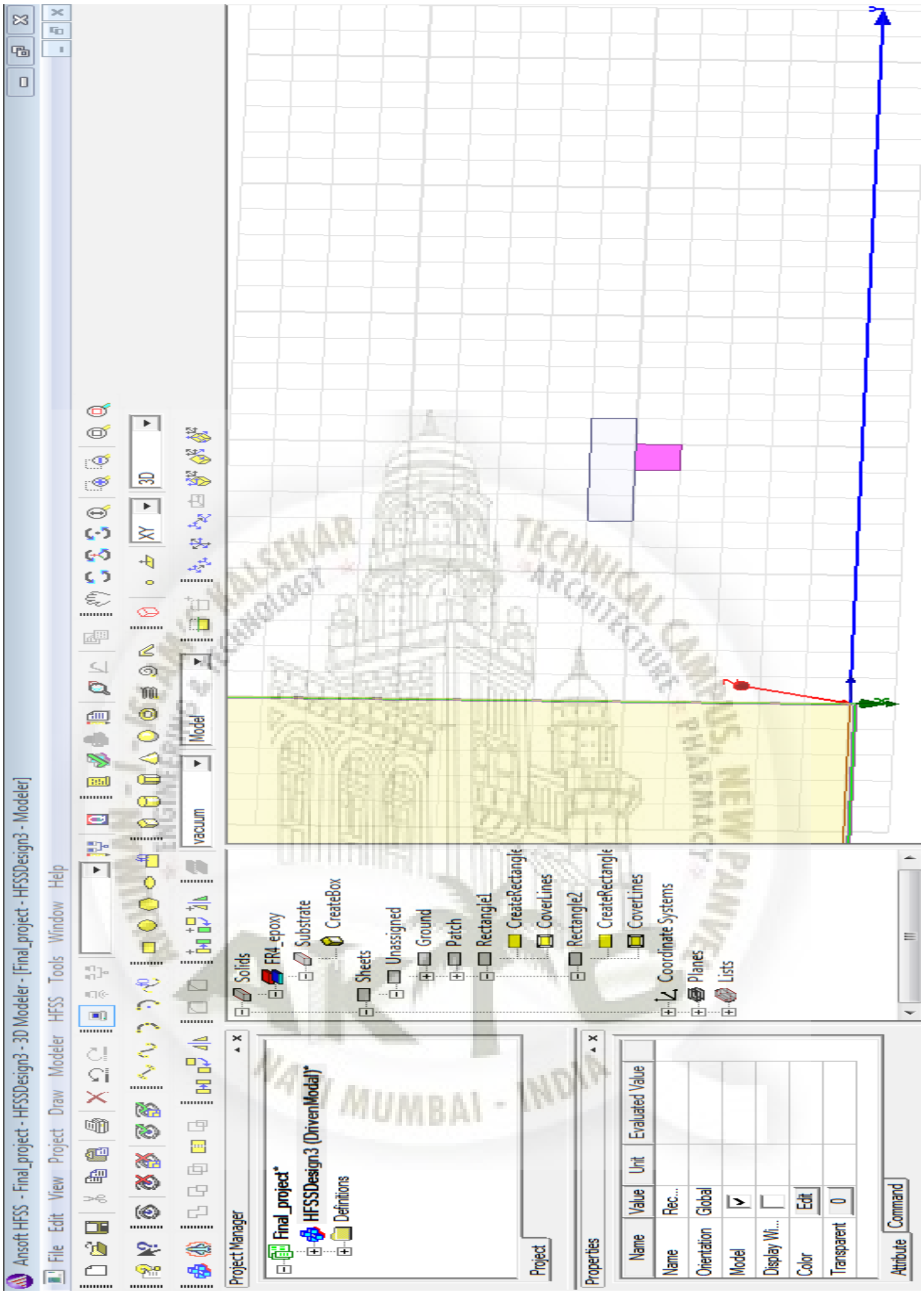



Ansoft HFSS - Project2 - HFSSDesign3 - 3D Modeler - [Project2 - HFSSDesign3 - Modeler]
File Edit View Project Draw Modeler HFSS Tools Window Help
Project Manager
Project2*
HFSSDesign3 (DrivenModal)*
Definitions
Solids
FR4_epoxy
Substrate
CreateBox
Sheets
Unassigned
Ground
Rectangle1
Coordinate Systems
Planes
Lists
Properties: Project2 - HFSSDesign3 - Modeler
Attribute
Name
Value
Unit
Evaluated Value
Description
Read-only
Patch
Orientation
Global
Model
Display Wirefra...
Color
Edit
Transparent
0.2
Show Hidden
OK
Cancel

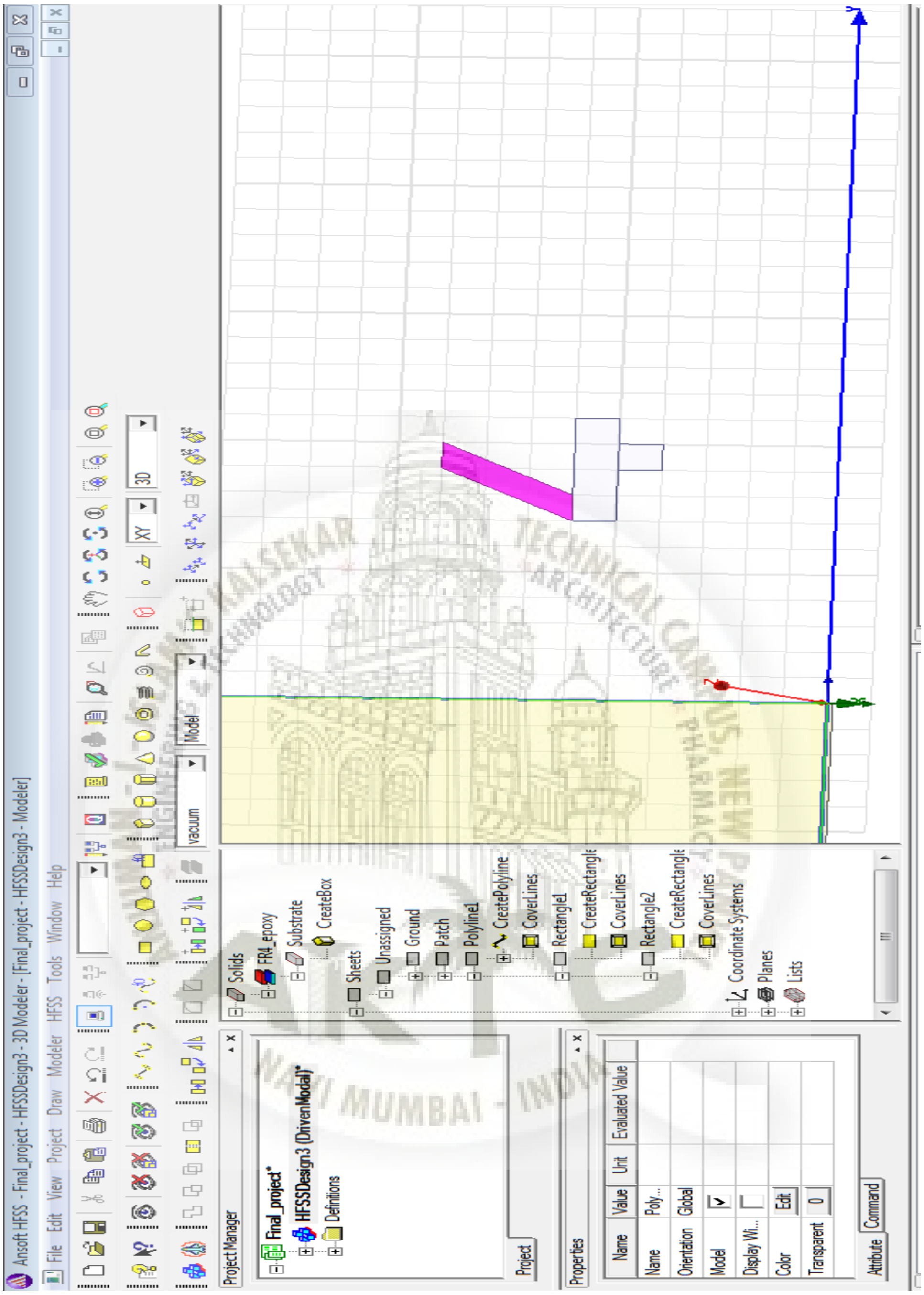
Right click on Rectangle3 → cover lines → *Properties*



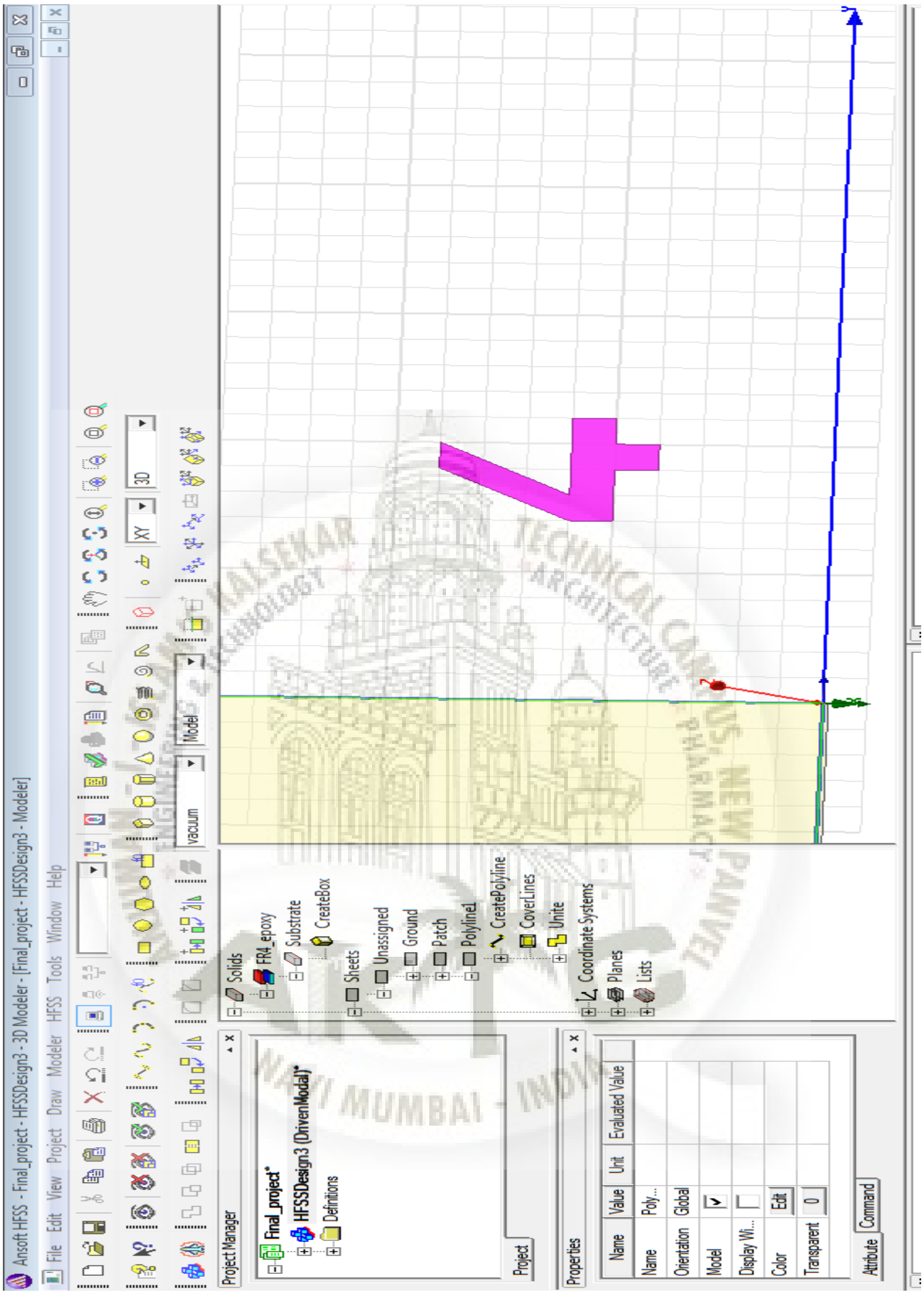
Right click on Rectangle4 → cover lines → *Properties*



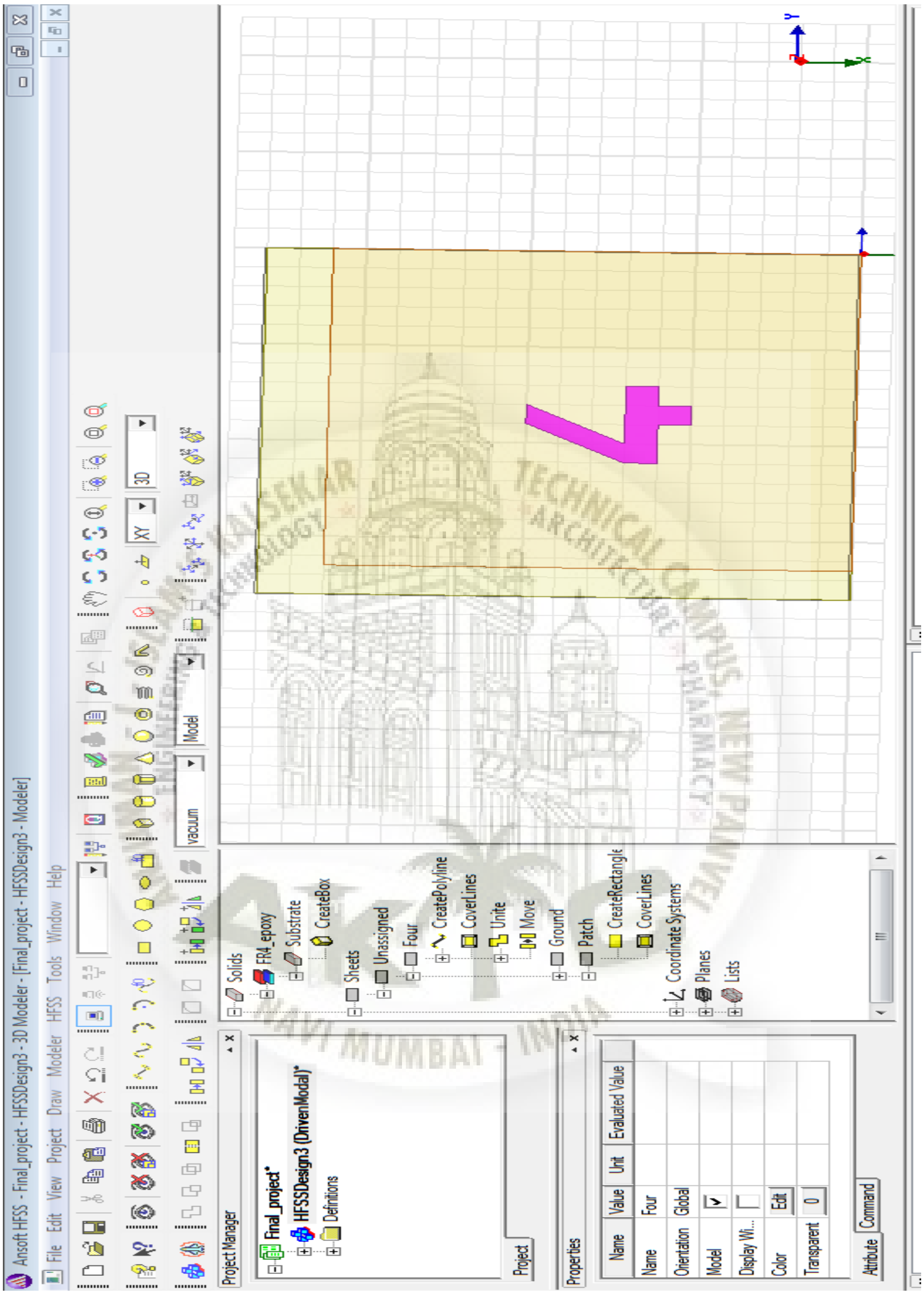
Right click on polyline1 → cover lines → *Properties*



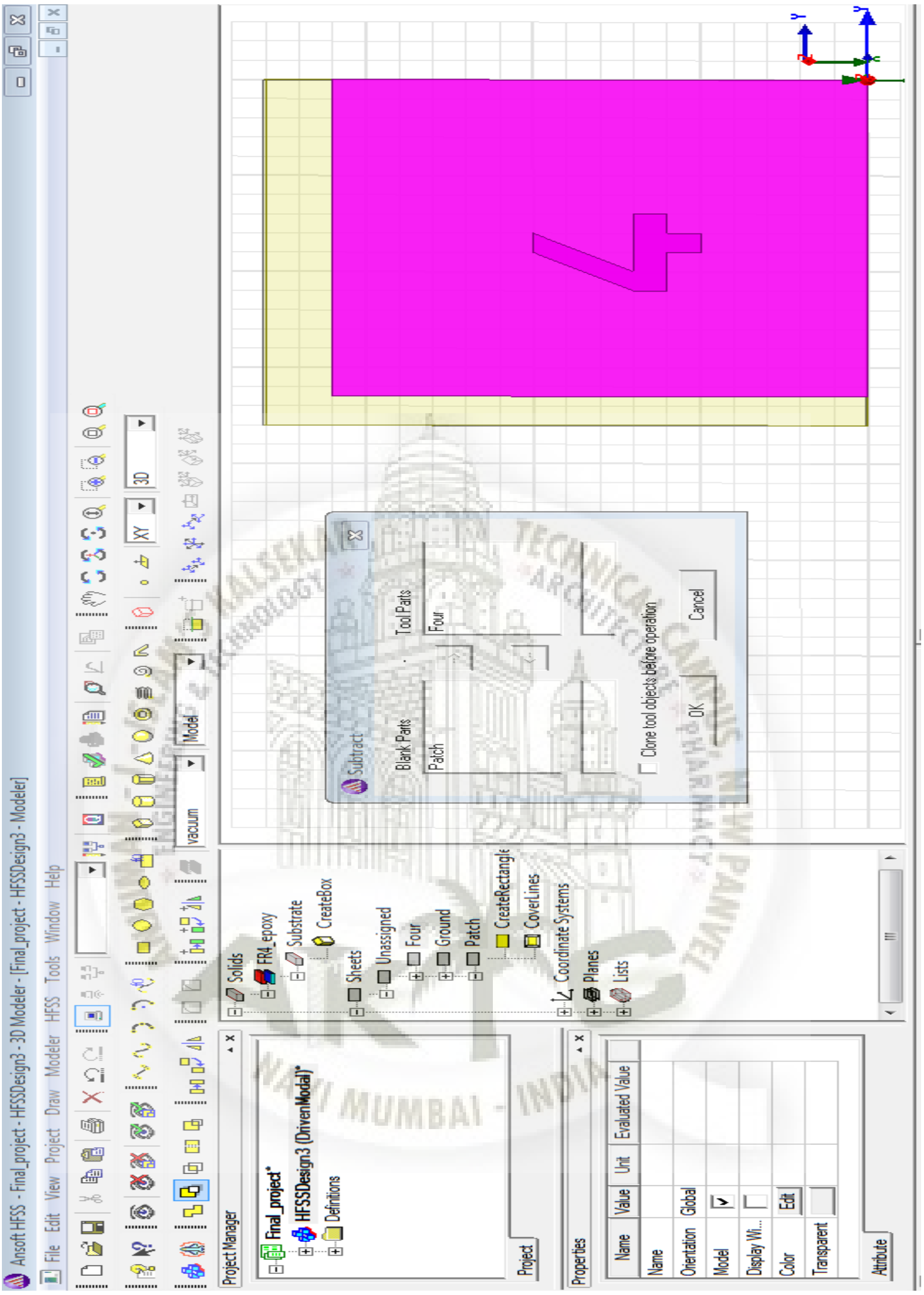
Select polylines1 → Ctrl+ Select rectangle3 → Select rectangle4 → *unite* → *Ok*..



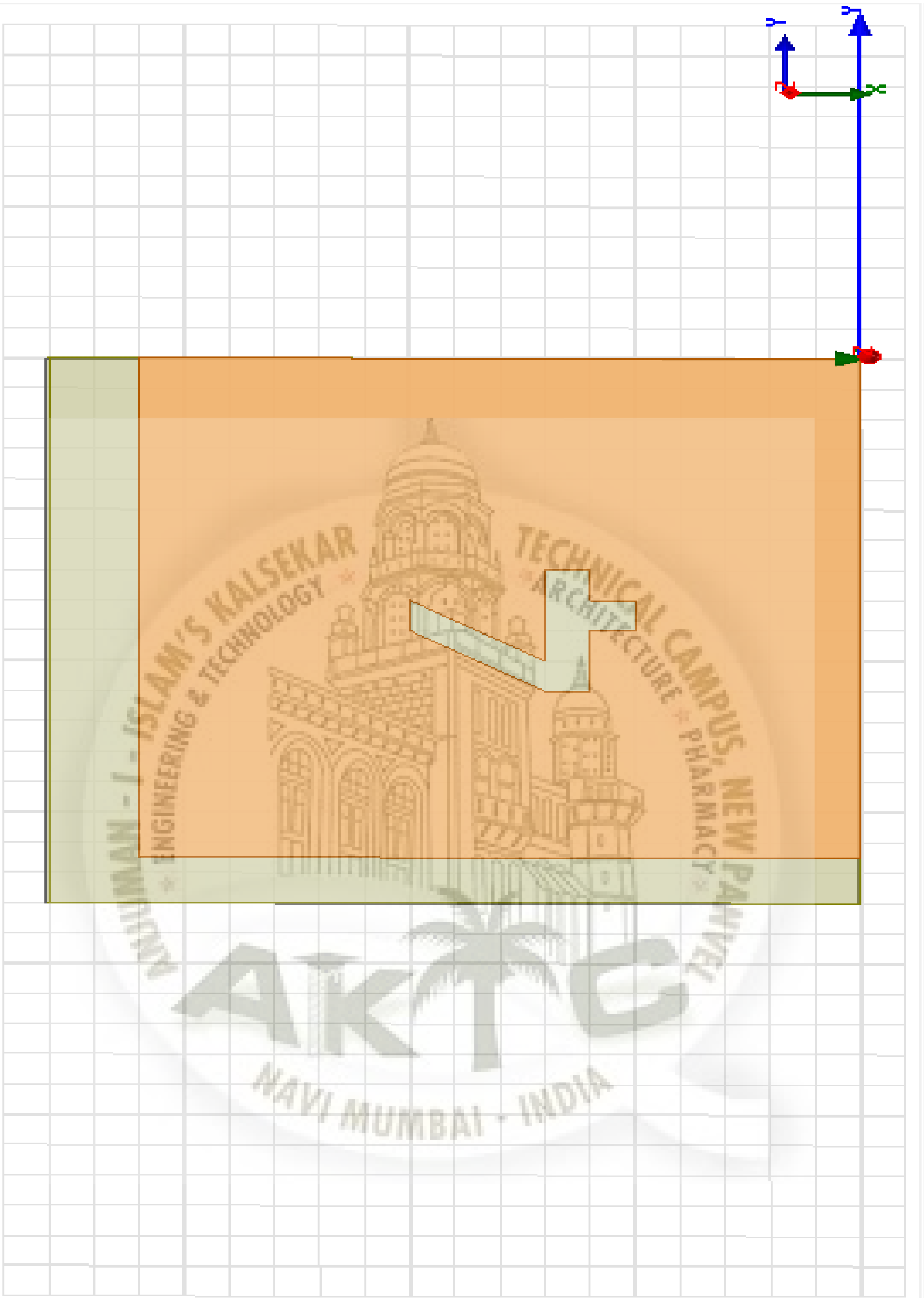
Select move command and place it on the patch as show below and name it four (p2.png)



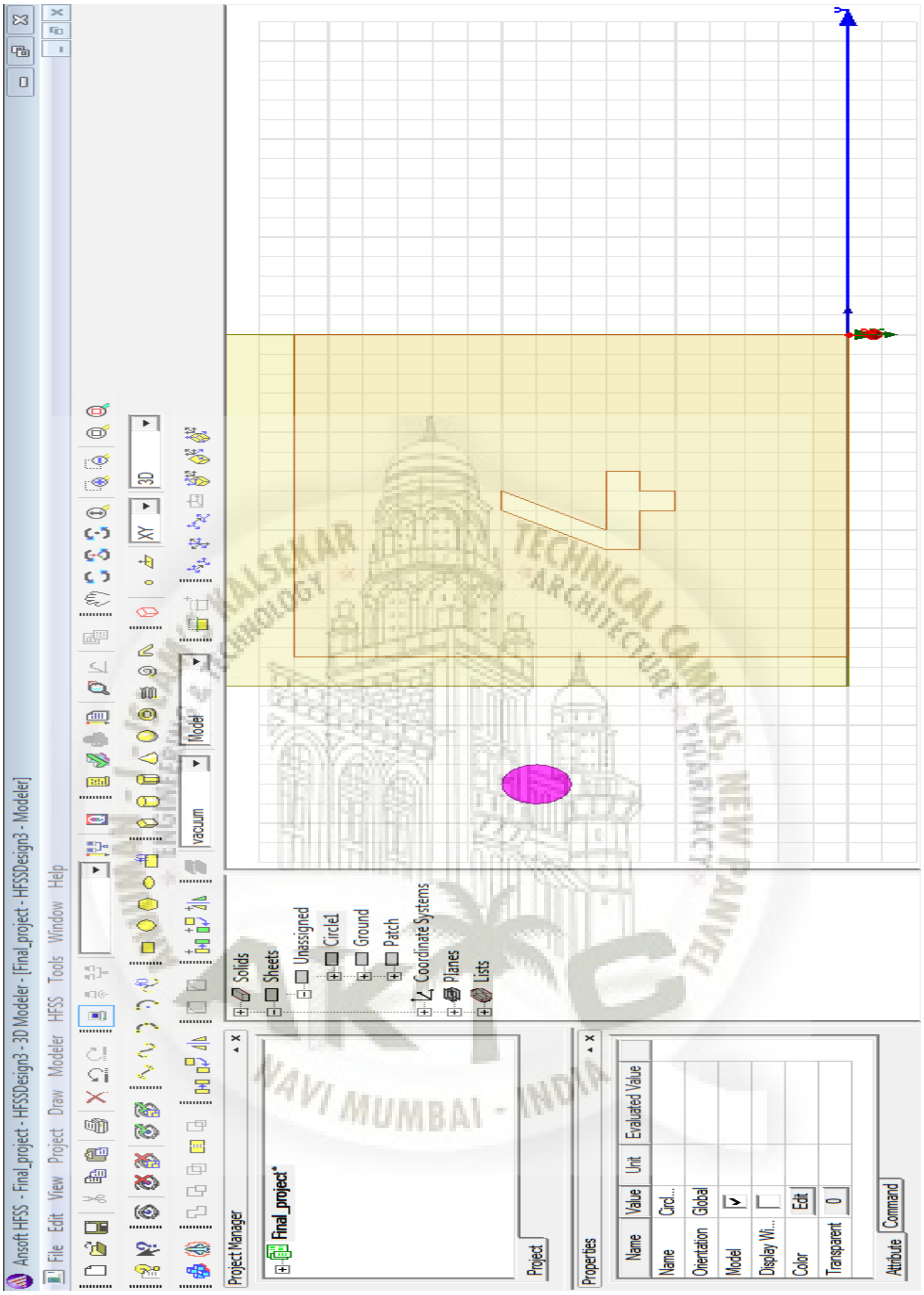
Ctrl+ Select PATCH → Select FOUR → $SUBTRACT \rightarrow Ok$.



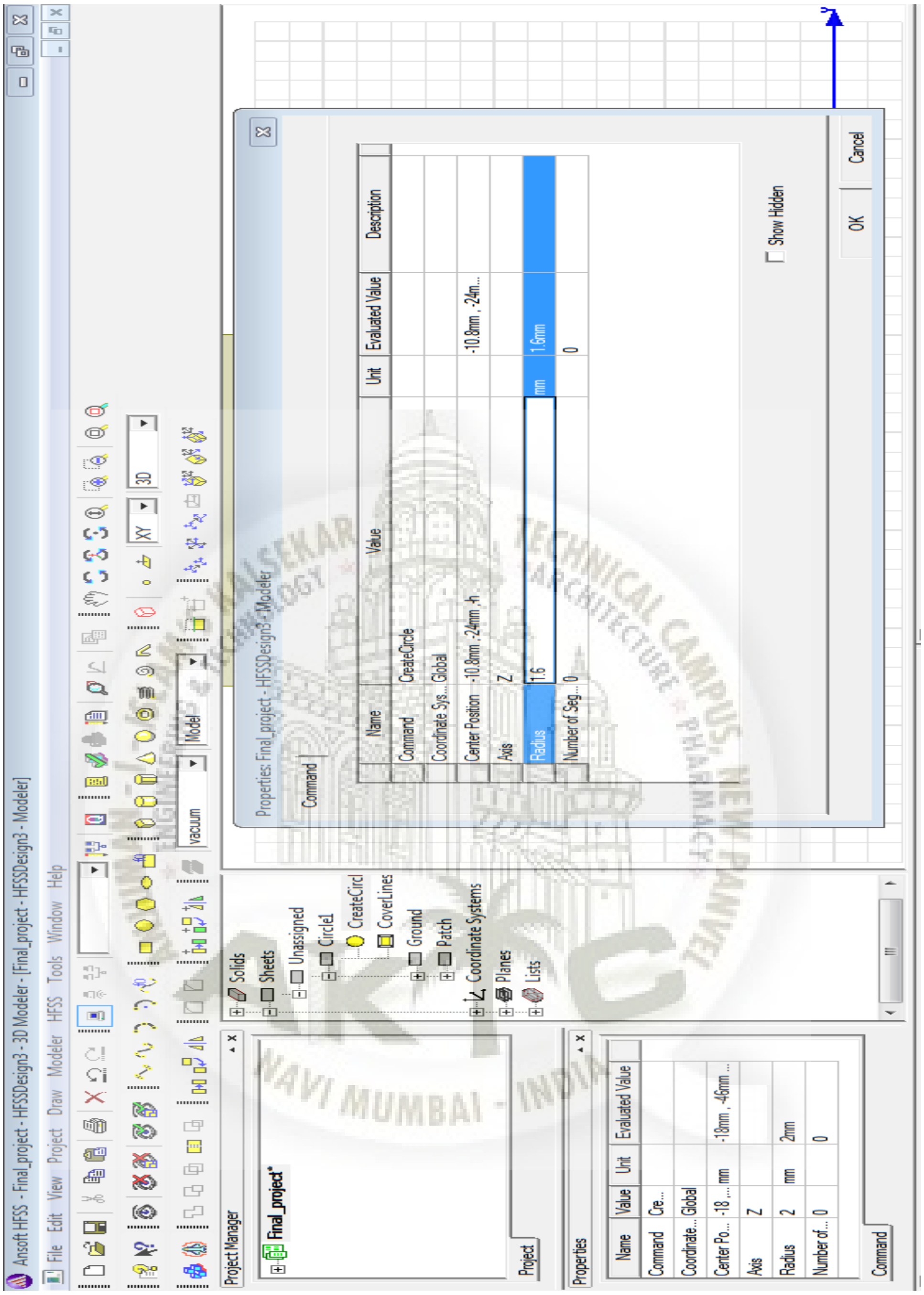
The antenna will look as shown below



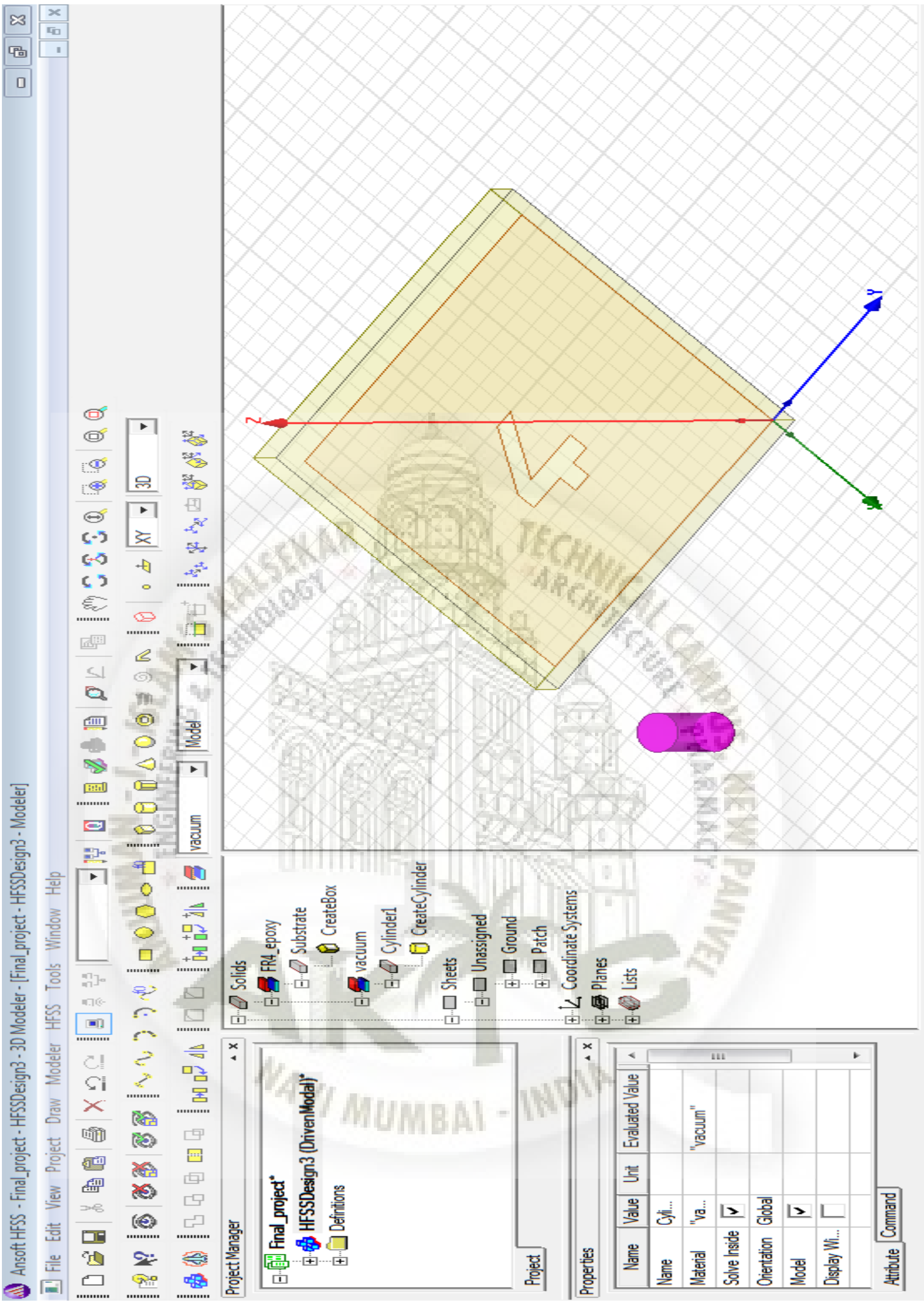
Draw a circle



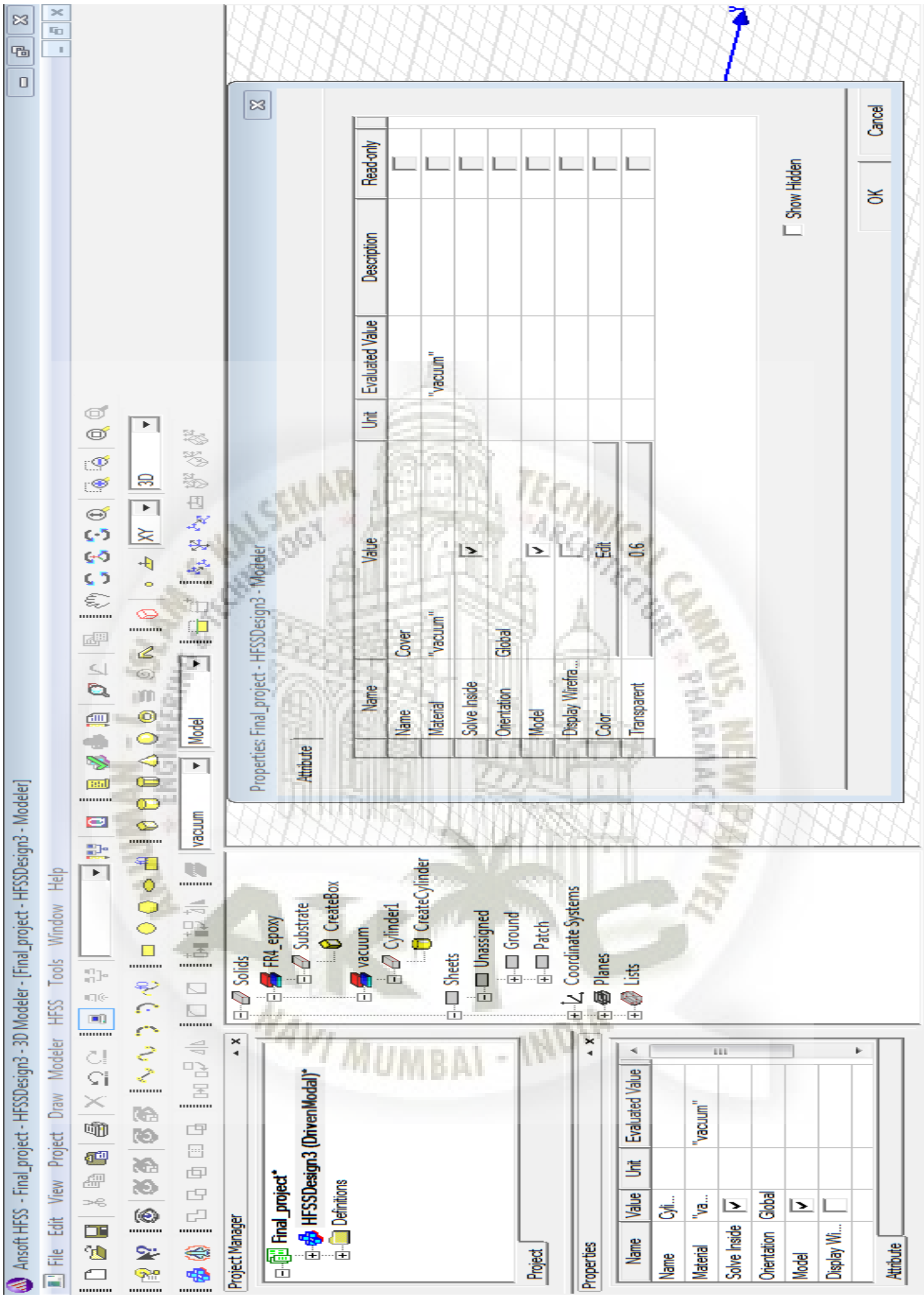
Select create circle → Change radius to1.6mm → *Ok*.



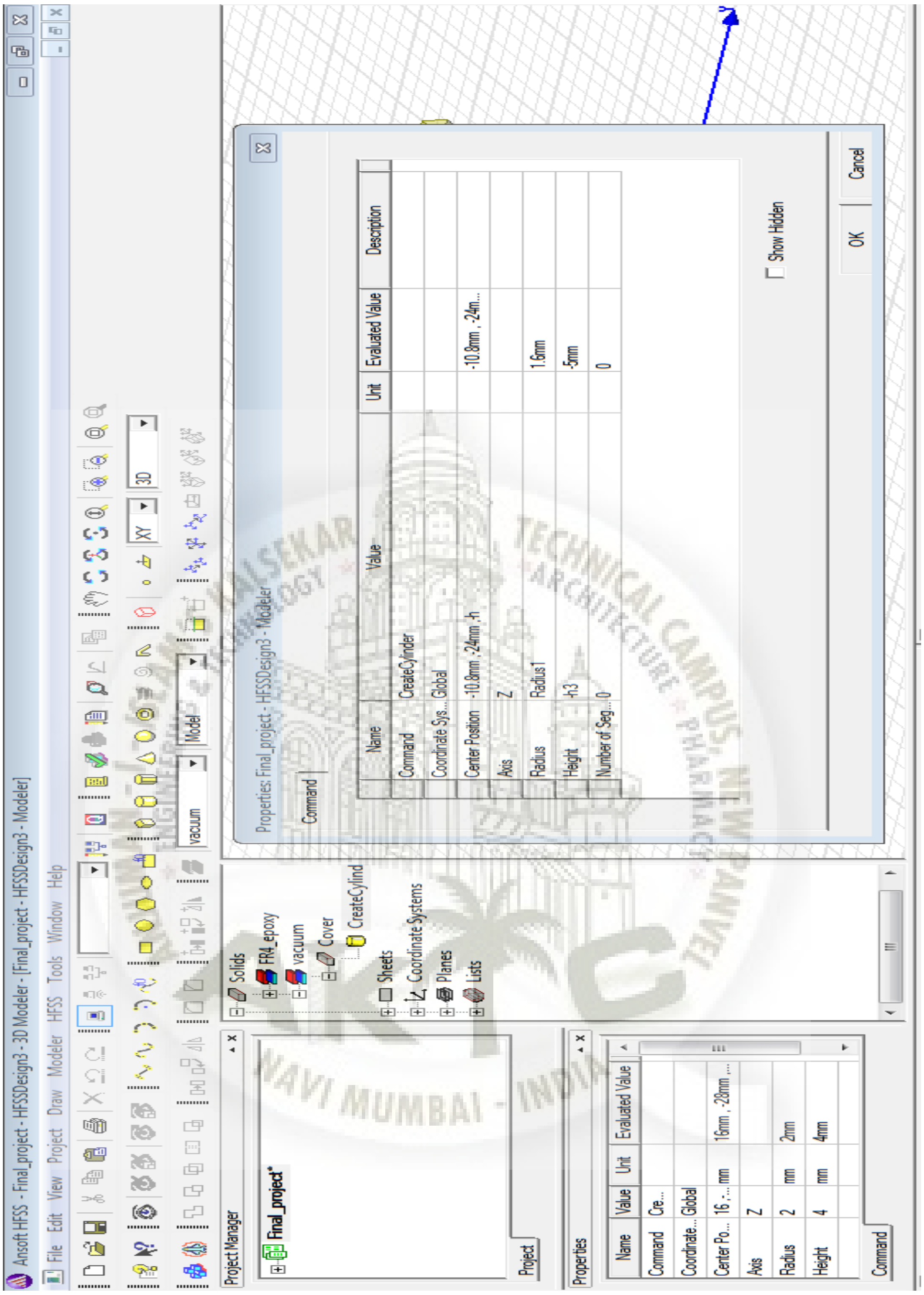
Select Draw Cylinder → Change radius to1.6mm → *Ok*.



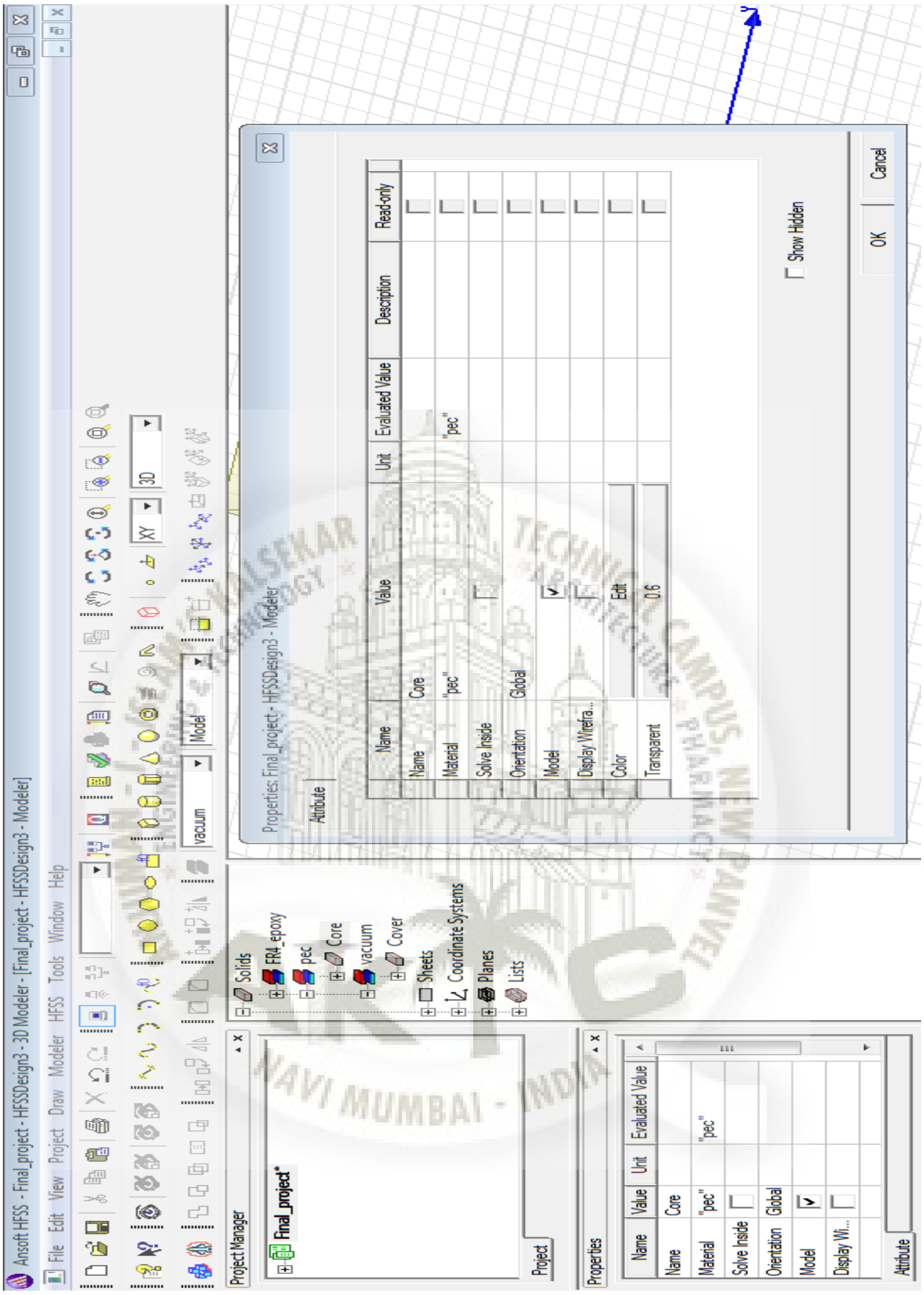
Select Cylinder1 → Change name to cover → Select material → Change to vaccum → *Ok*.



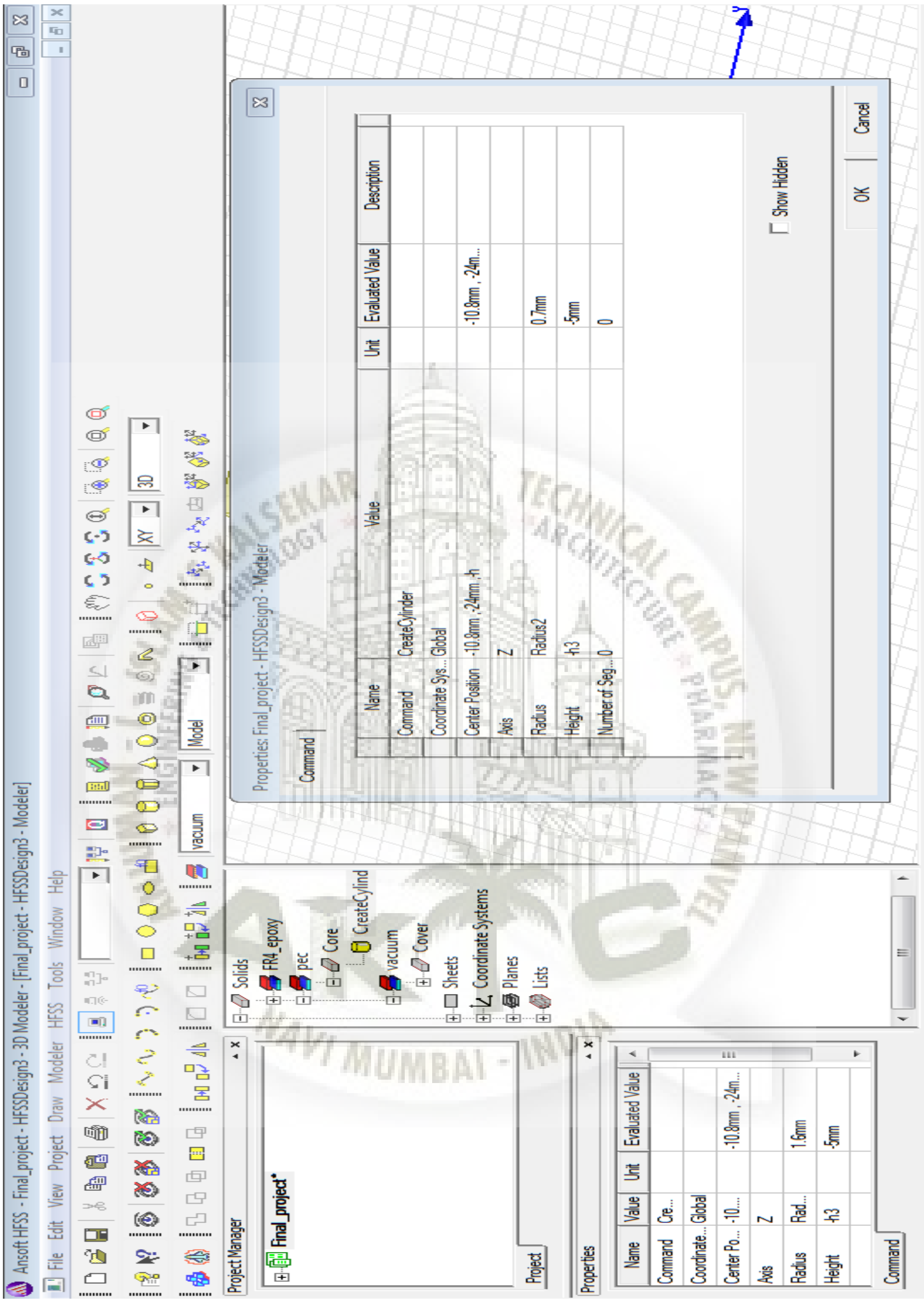
Select create Cylinder1 → Change radius to radius1 → 1.6mm → Ok.



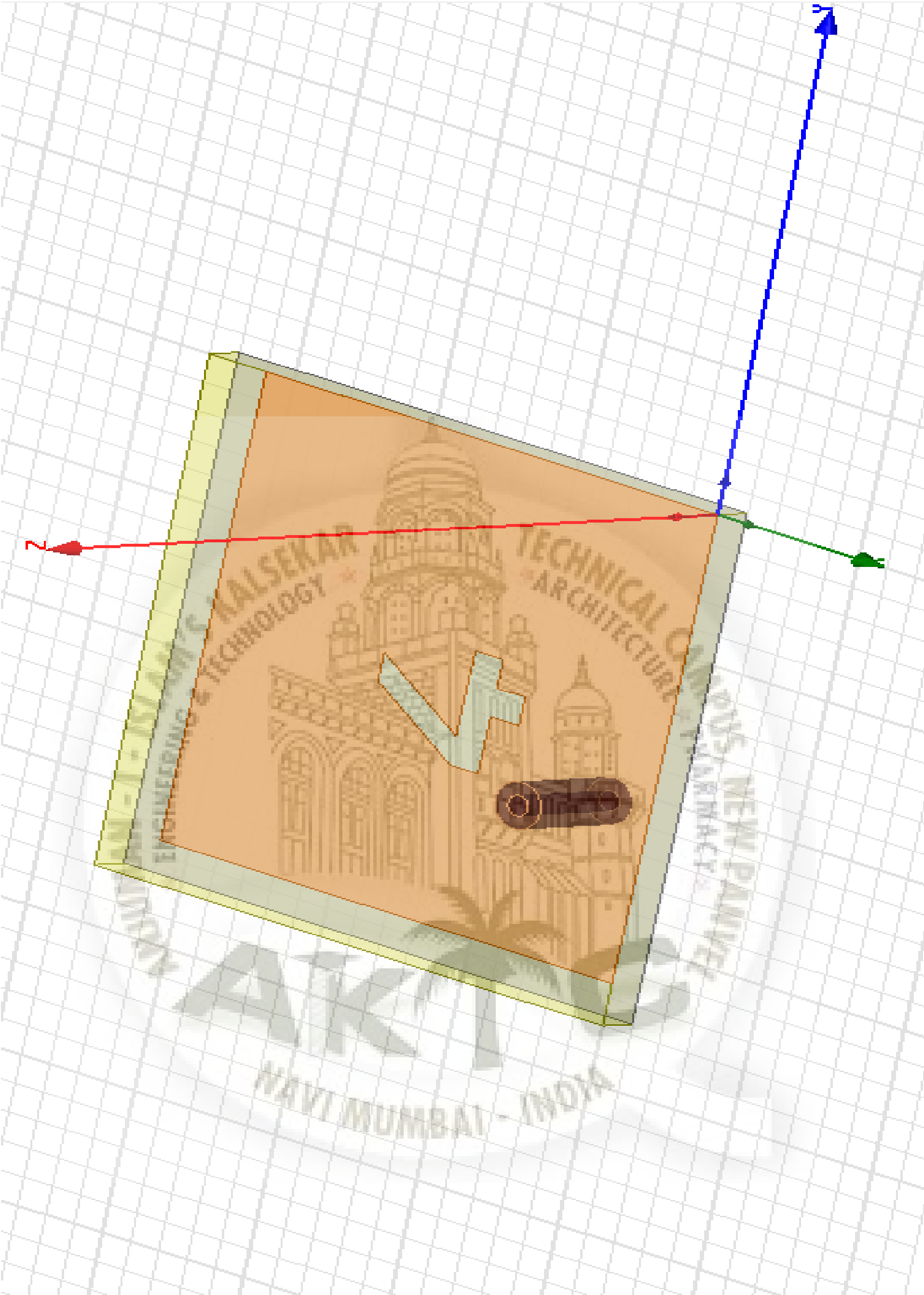
Select draw cylinder → Change name to core → Change material to pec → *Ok*.



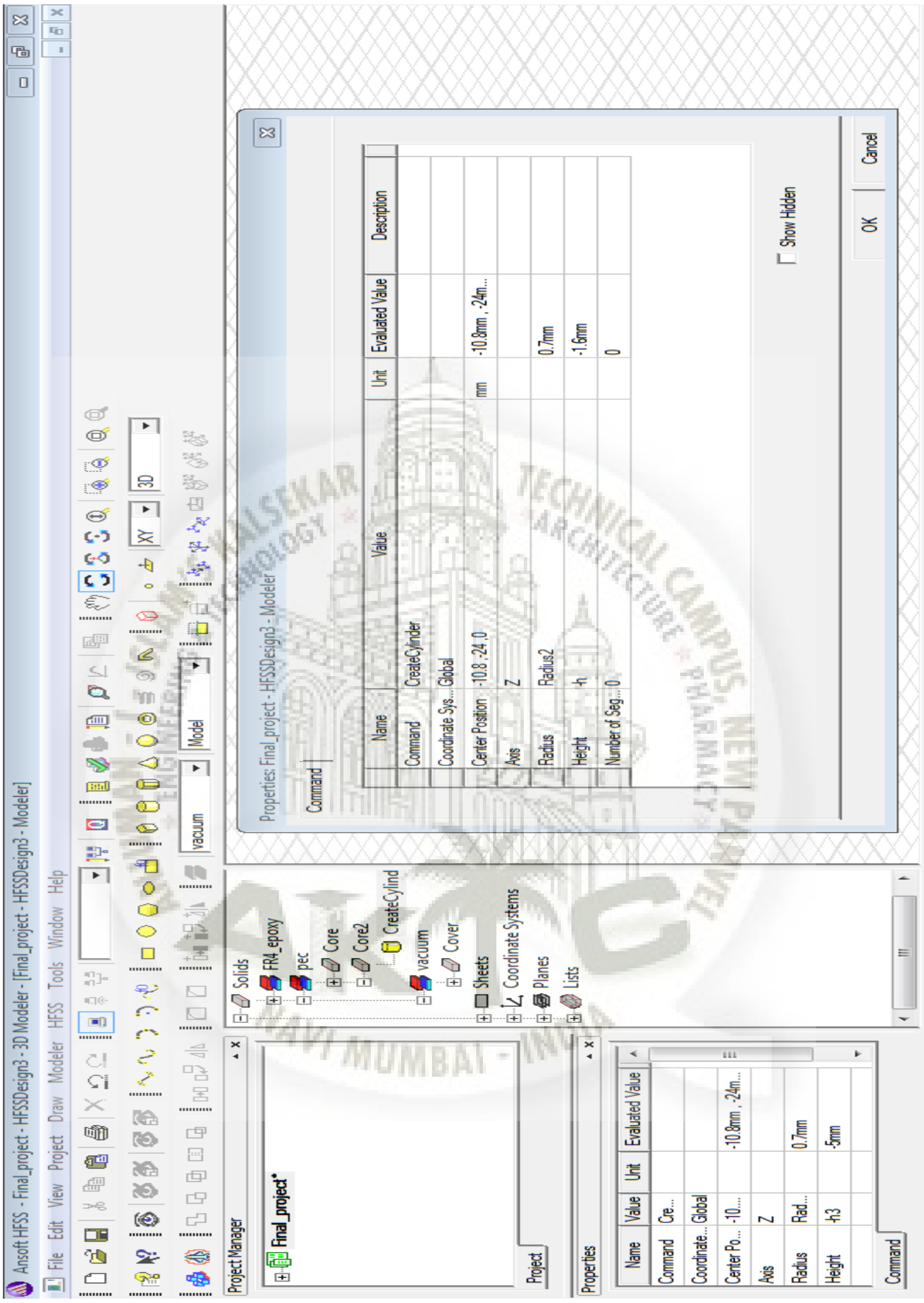
Select create Cylinder2 → Change radius to Radius2 → 0.7mm → Change height to 5 mm → Ok.



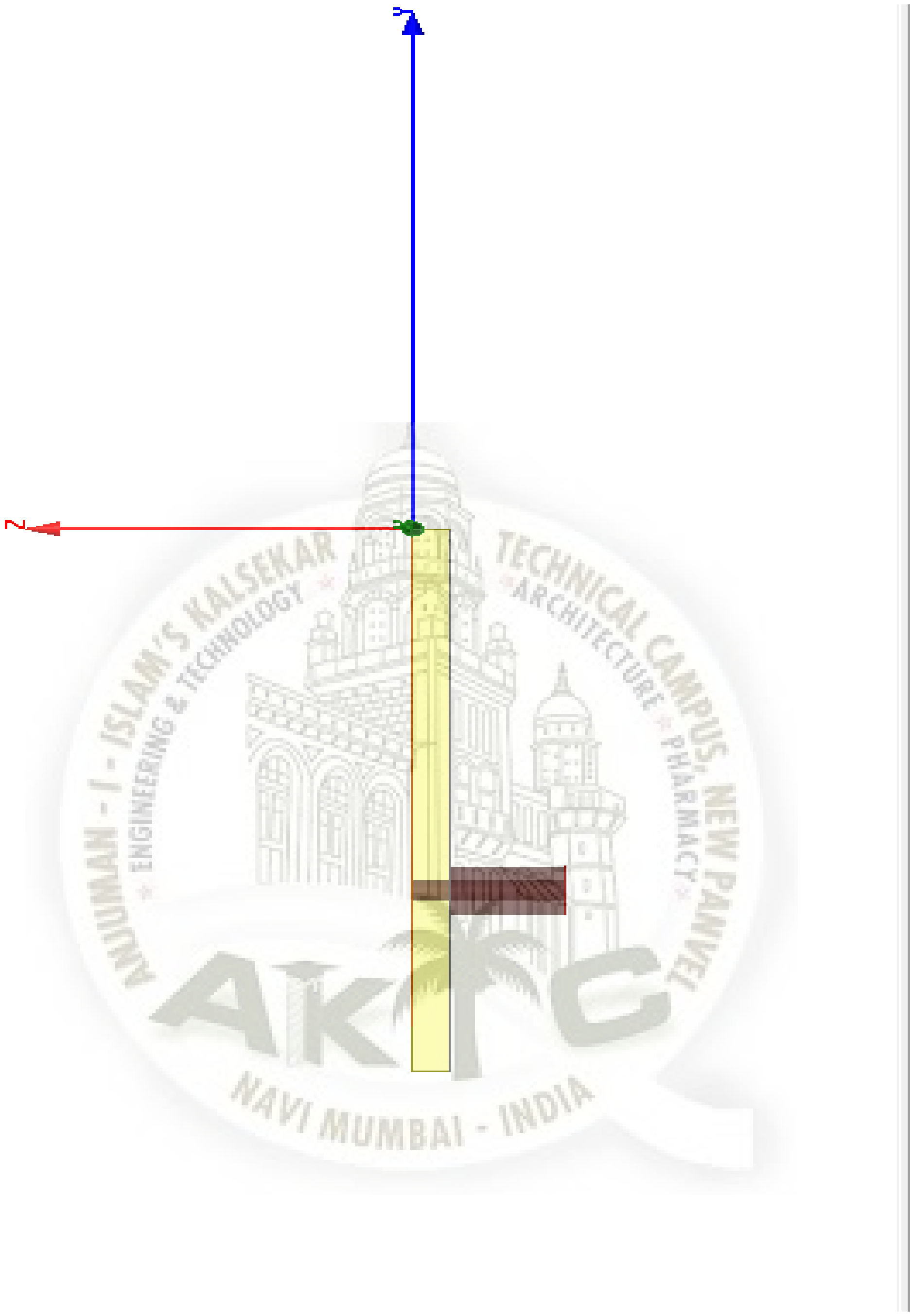
The antenna will look as shown in below



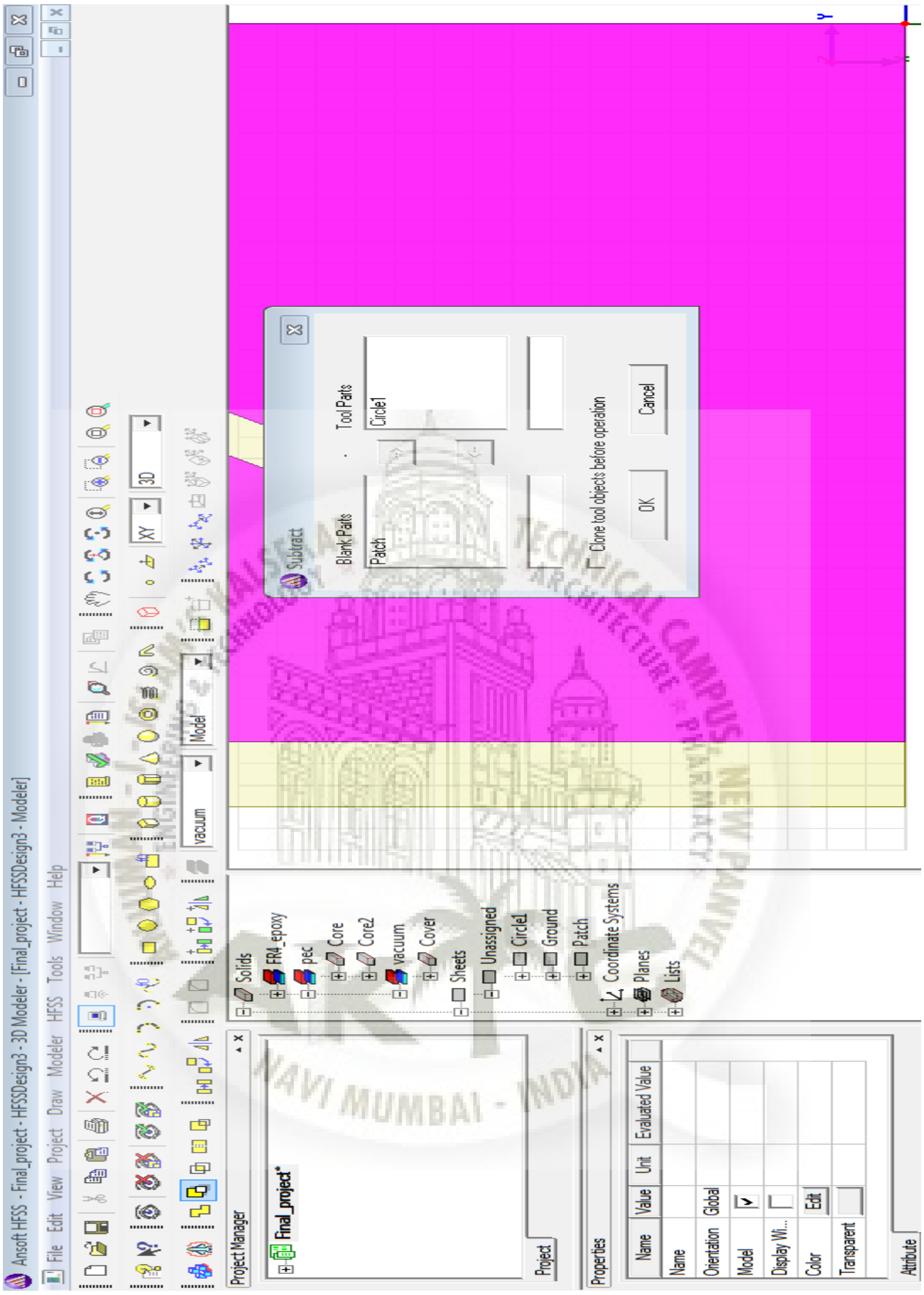
Select Draw Cylinder → change name toCore2 → change material to pecs → Change radius to radius2 0.7mm → Change height to h -1.6mm → *Ok*



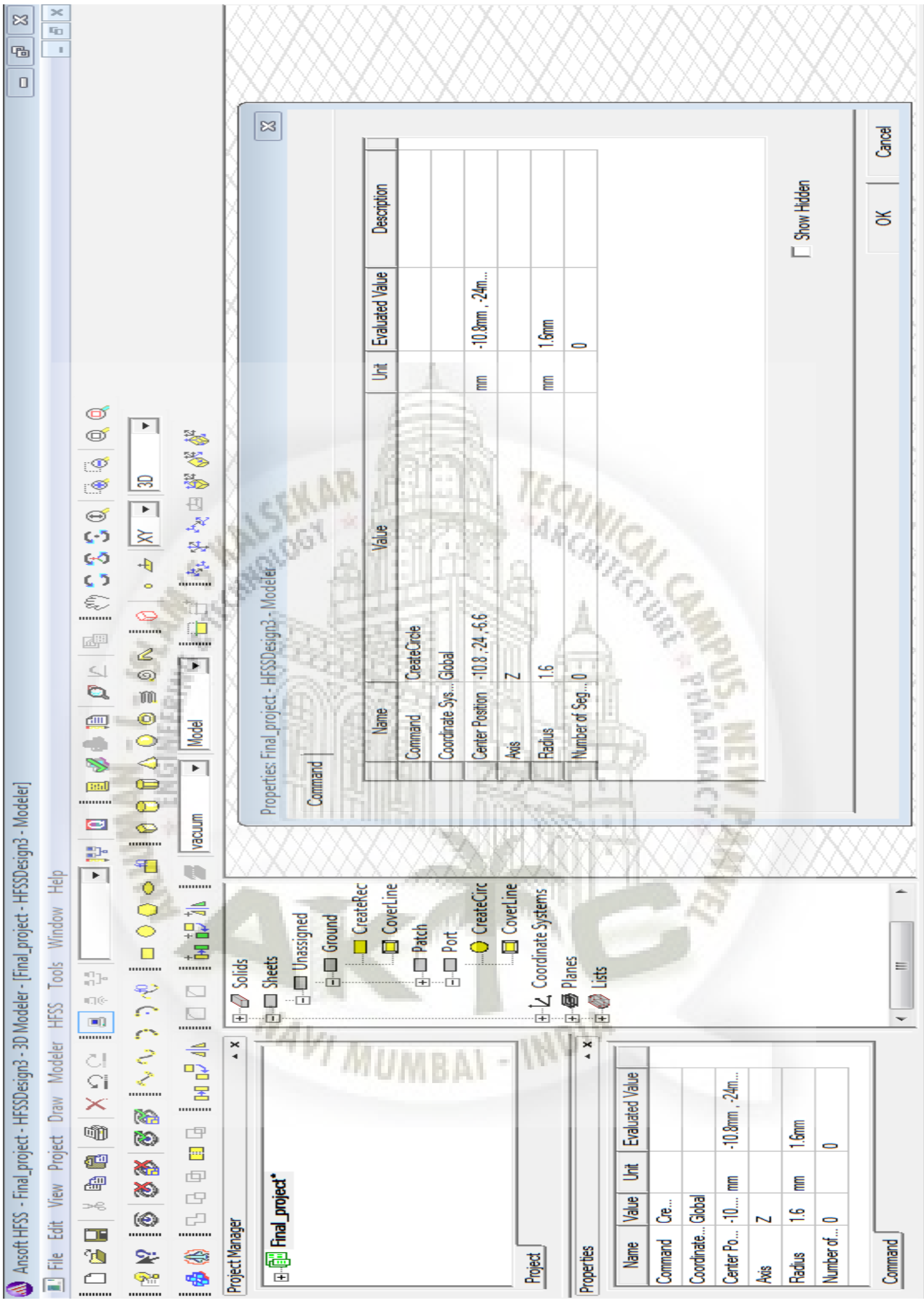
The side view of antenna with co-axial feed as shown in below



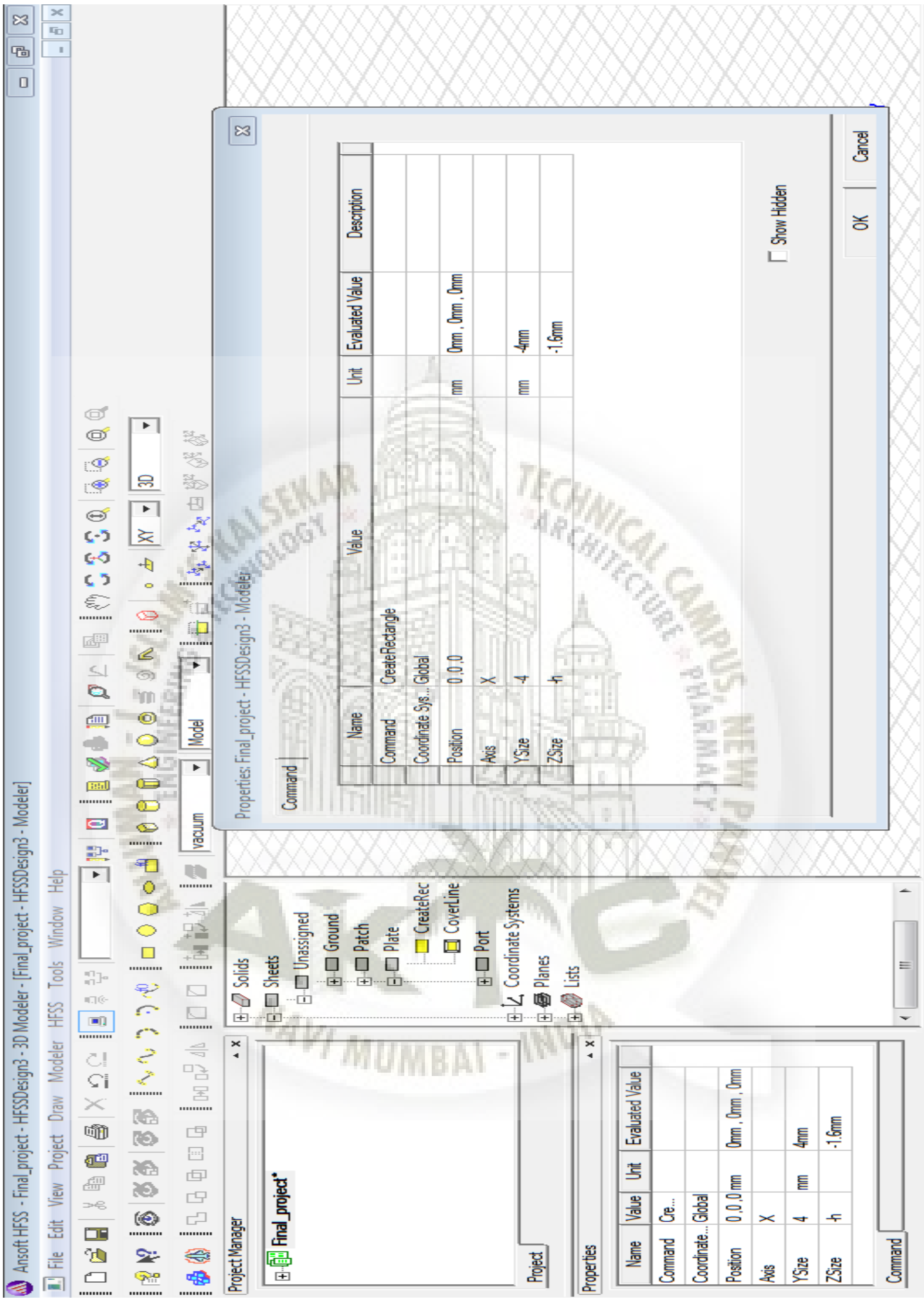
ctrl+Select patch → ctrl+Select circle1 → *Subtract* → *Ok*



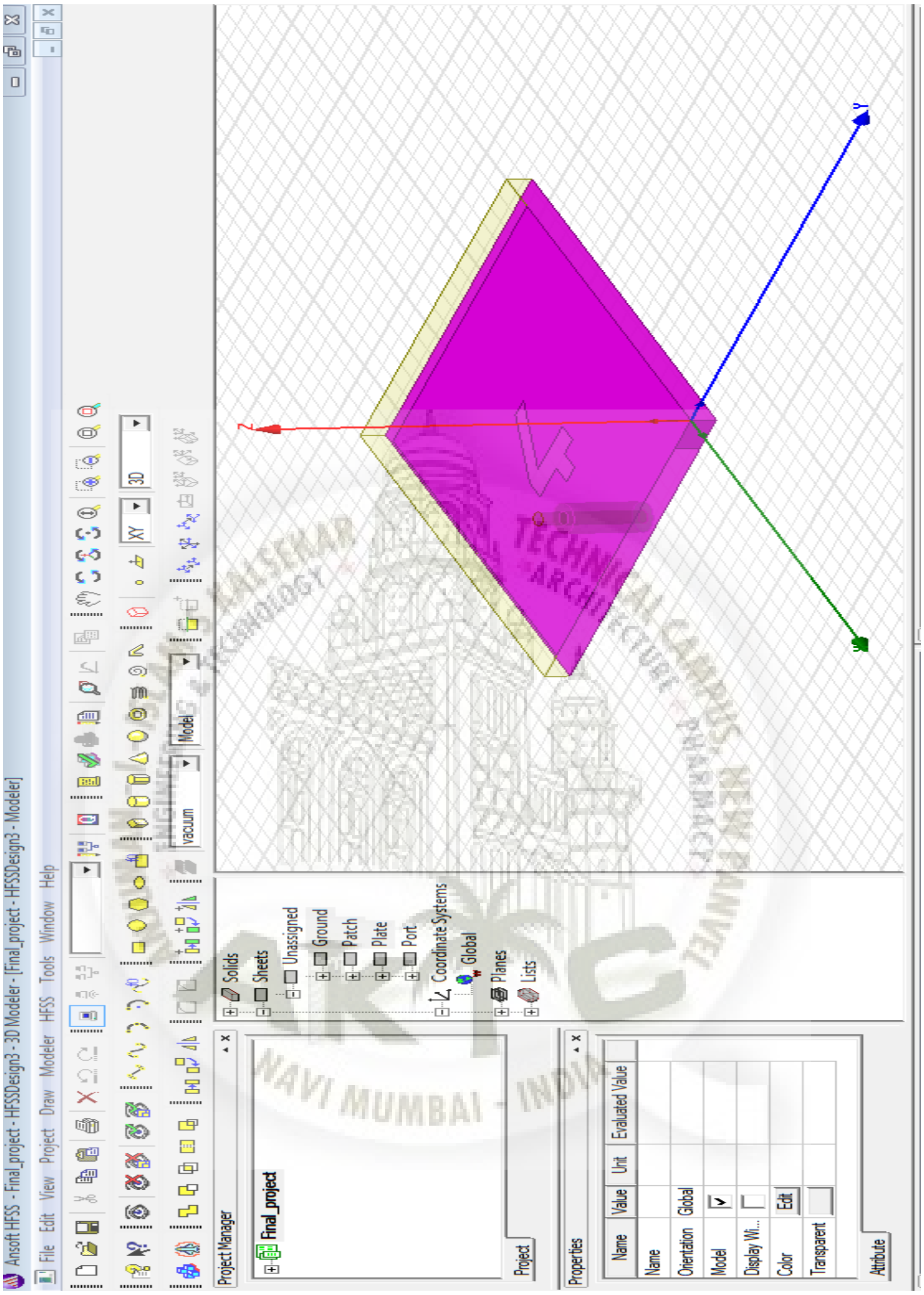
Select Draw CIRCLE → change name toport → Change radius to radius21.6 mm → Ok



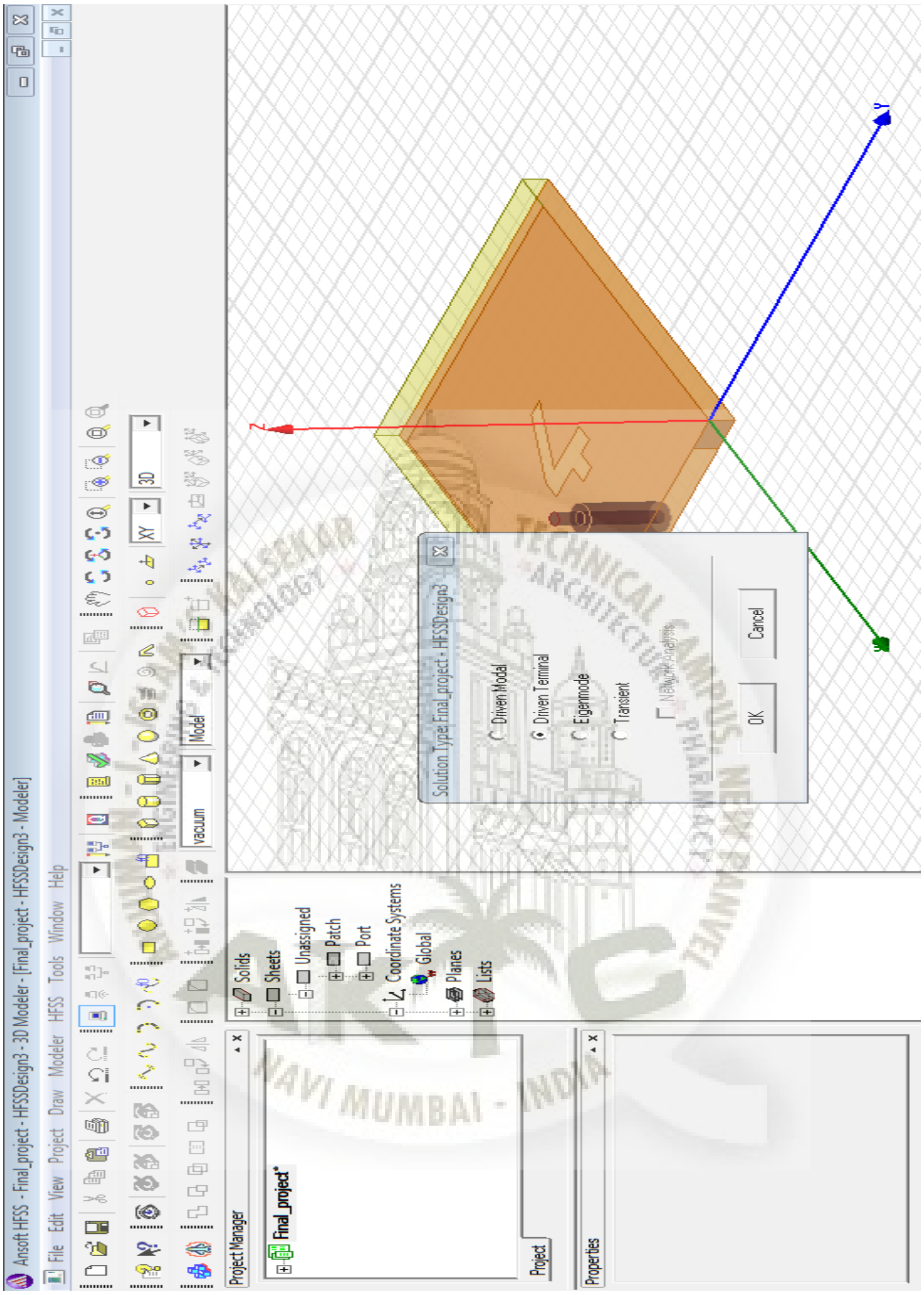
Select Draw rectangle → change name to plate → $Change axis to X-axis$ → Change Y-size to -4mm → Change Z-size to h -1.6mm → Ok

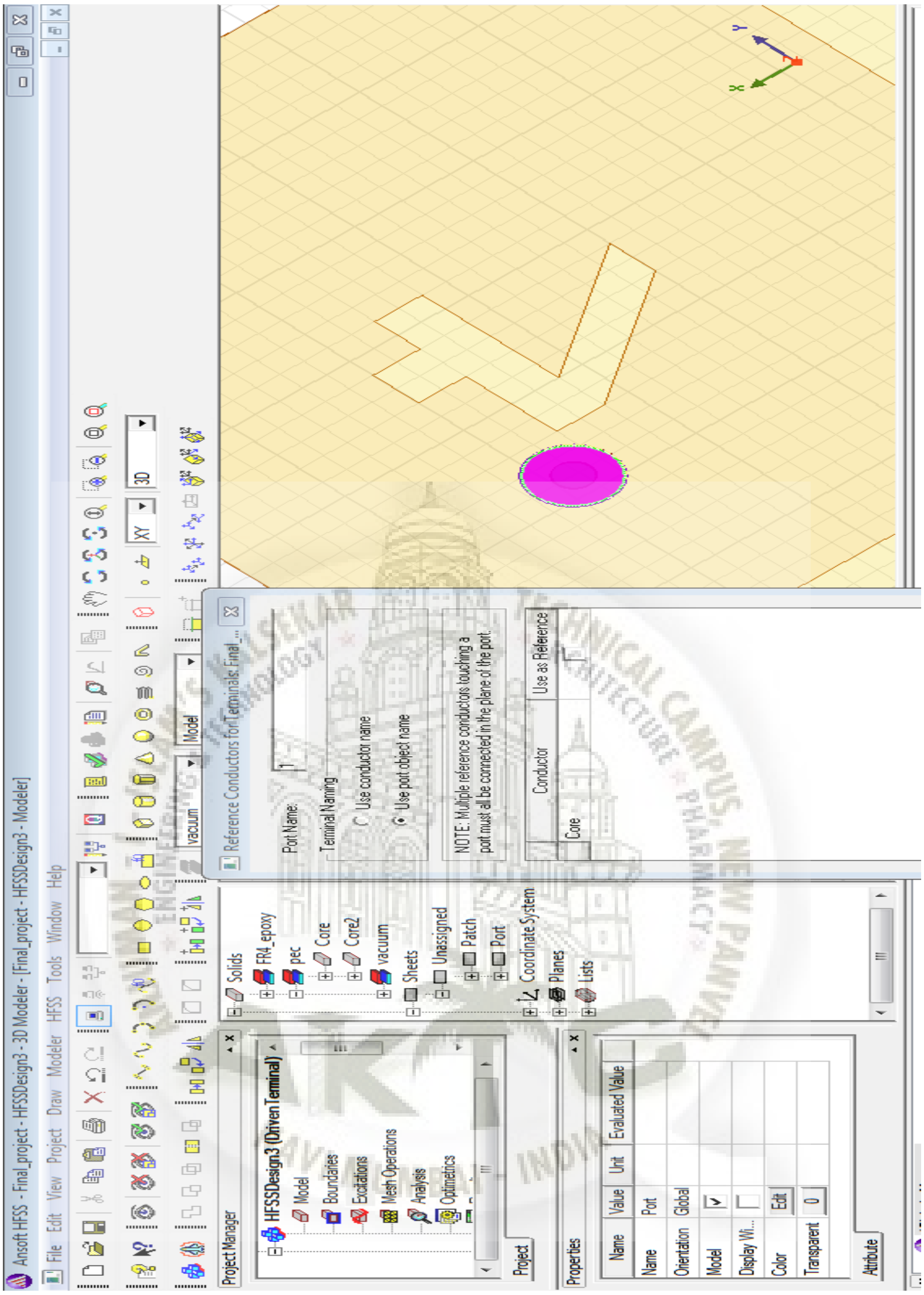


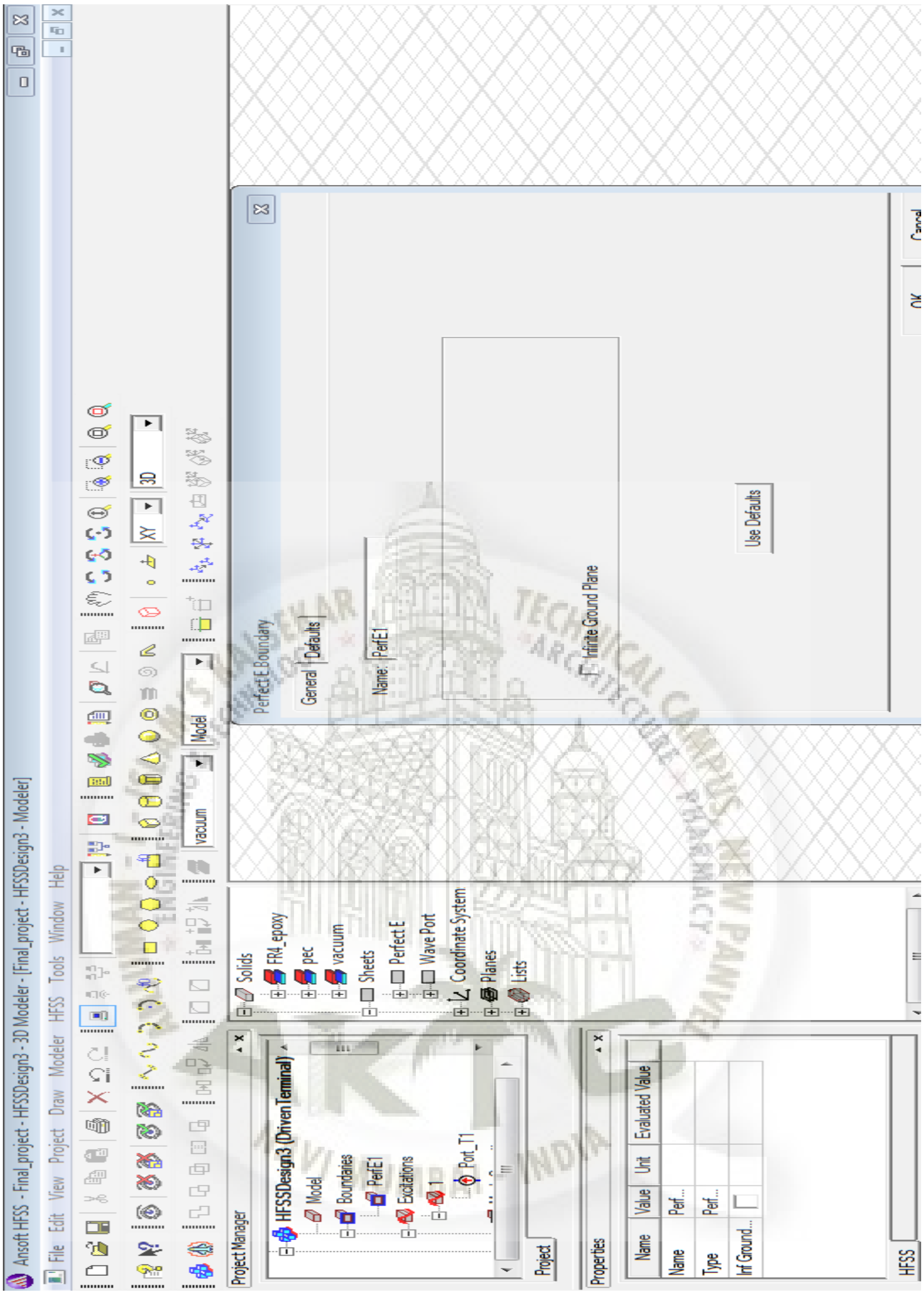
ctrl+Select patch → ctrl+Select ground → ctrl+Select plate → unite Ok

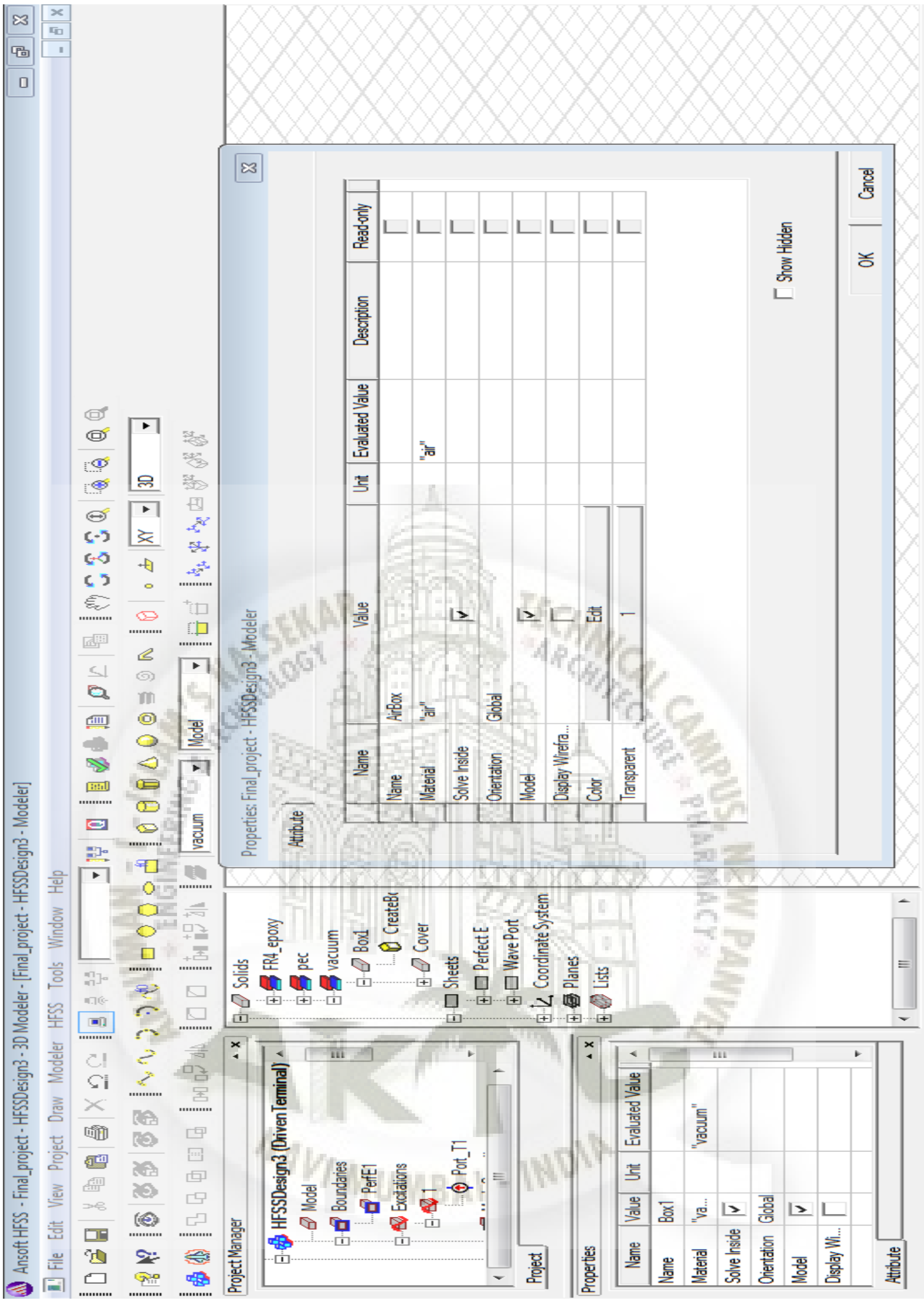


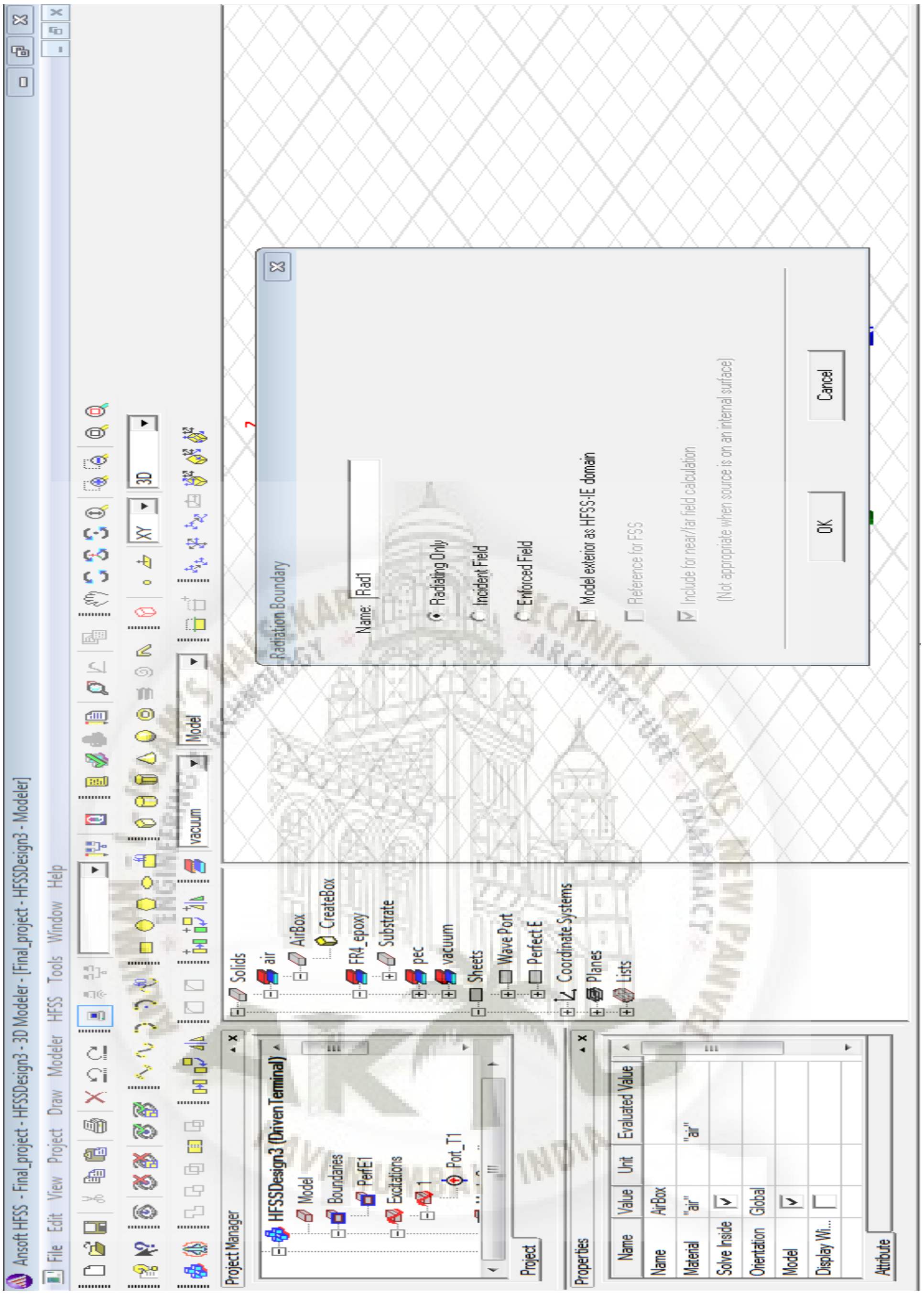
Select HFSS → Select Solution Type → Select Driven Terminal → OK



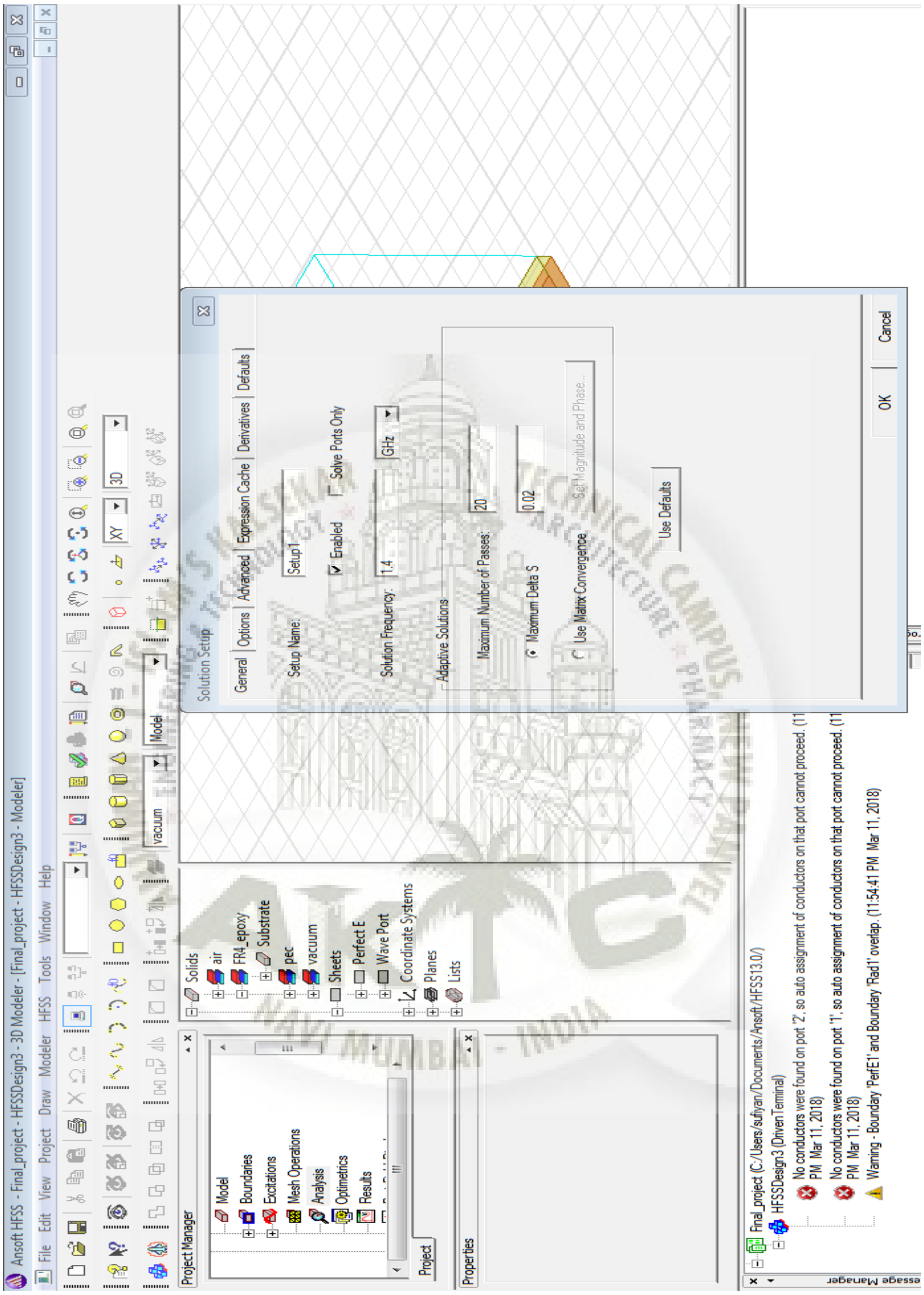

Ansoft HFSS - Final_project - HFSSDesign3 - 3D Modeler - [Final_project - HFSSDesign3 - Modeler]
File Edit View Project Draw Modeler HFSS Tools Window Help
Project Manager
HFSSDesign3 (DrivenTerminal)
Model
Boundaries
Excitations
Mesh Operations
Analysis
Optimetrics
Solids
FR4_epoxy
pec
Core
Core2
vacuum
Sheets
Unassigned
Patch
Port
Coordinate System
Planes
Lists
Reference Conductors for Terminals: Final_...
Port Name:
Terminal Naming
Use conductor name
Use port object name
NOTE: Multiple reference conductors touching a port must all be connected in the plane of the port.
Conductor
Use as Reference
Core
Properties
Name
Value
Unit
Evaluated Value
Port
Orientation
Global
Model
Display Wi...
Color
Edit
Transparent
0
Attribute
Project


Ansoft HFSS - Final_project - HFSSDesign3 - 3D Modeler - [Final_project - HFSSDesign3 - Modeler]
Perfect E Boundary
General
Defaults
Name: PerfE1
Infinite Ground Plane
Use Defaults
Project Manager
Properties

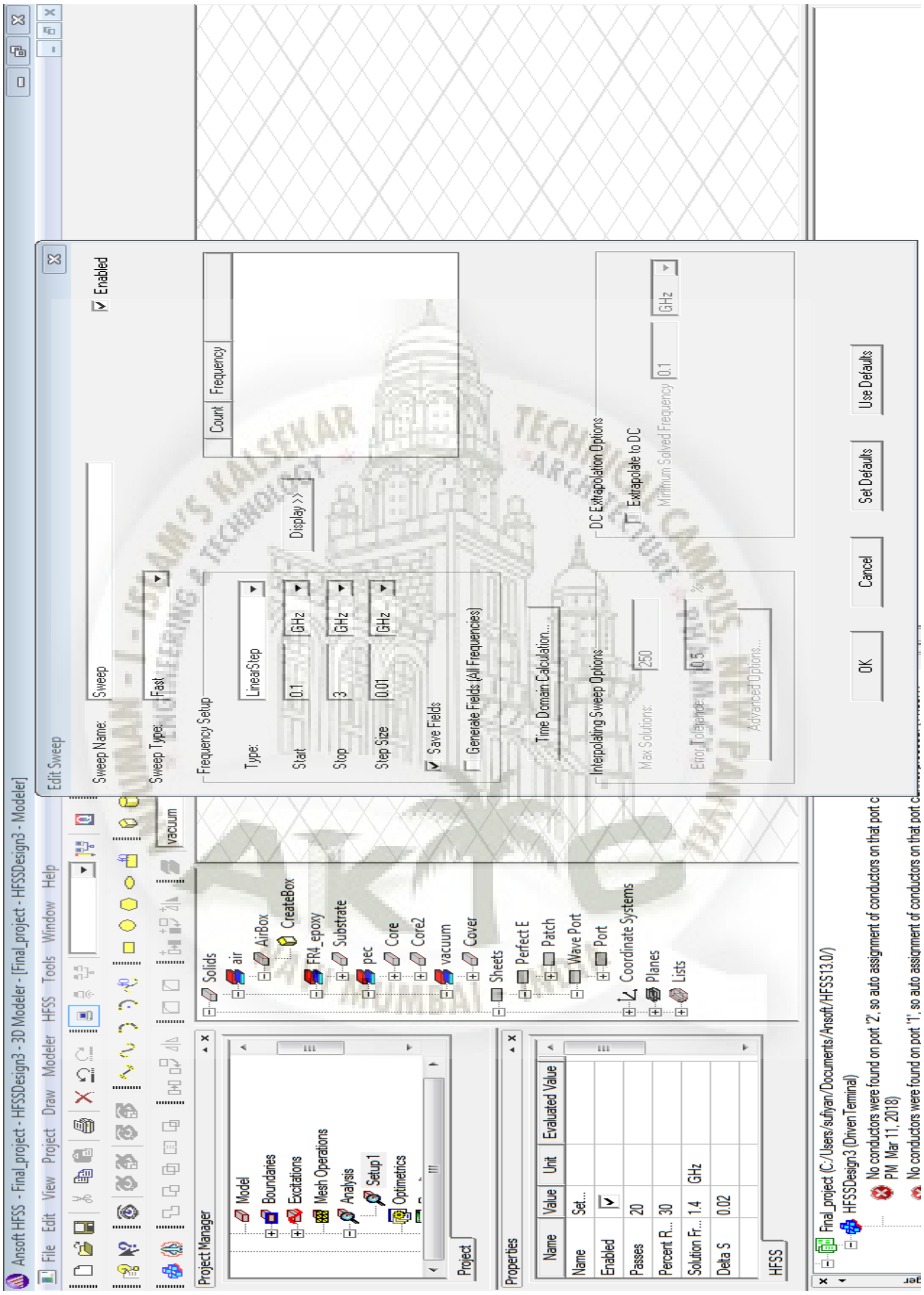

Ansoft HFSS - Final_project - HFSSDesign3 - 3D Modeler - [Final_project - HFSSDesign3 - Modeler]
Project Manager
HFSSDesign3 (DrivenTerminal)
Properties: Final_project - HFSSDesign3 - Modeler
Attribute
Show Hidden
OK
Cancel


Ansoft HFSS - Final_project - HFSSDesign3 - 3D Modeler - [Final_project - HFSSDesign3 - Modeler]
File Edit View Project Draw Modeler HFSS Tools Window Help
Radiation Boundary
Name: Rad1
Radiating Only
Incident Field
Enforced Field
Model exterior as HFSS-IE domain
Reference for FSS
Include for near/far field calculation
(Not appropriate when source is on an internal surface)
OK
Cancel
Project Manager
HFSSDesign3 (DrivenTerminal)
Model
Boundaries
PerfE1
Excitations
Port_T1
Solids
air
AirBox
CreateBox
FR4_epoxy
Substrate
pec
vacuum
Sheets
Wave Port
Perfect E
Coordinate Systems
Planes
Lists
Properties
Name
Value
Unit
Evaluated Value
AirBox
Material
"air"
Solve Inside
Orientation
Global
Model
Display Wi...
Attribute

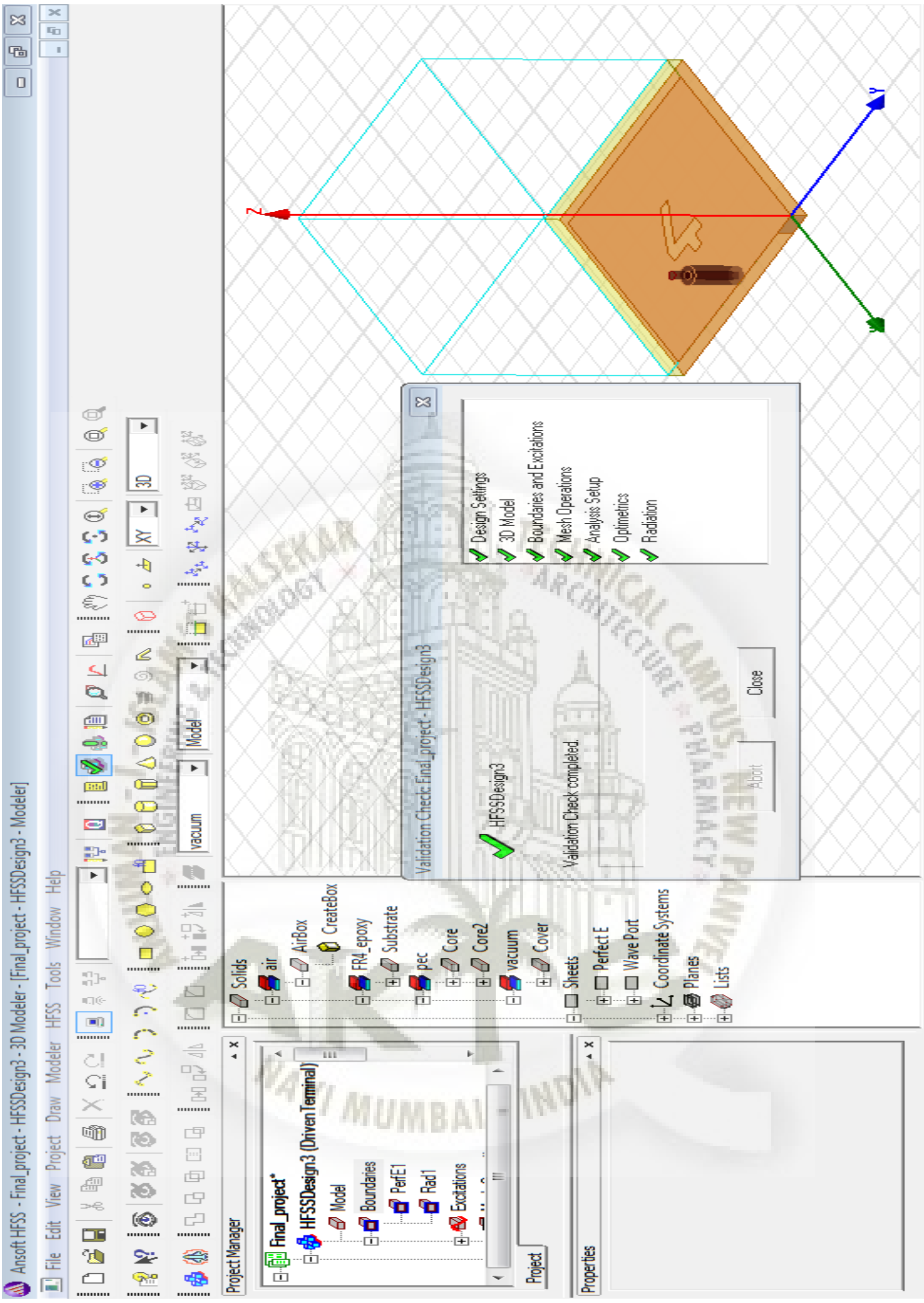
Go to project manager → right click on analysis→ solution setup → change solution frequency to 1.5 GHz → maximum no. of passes to 20 → OK



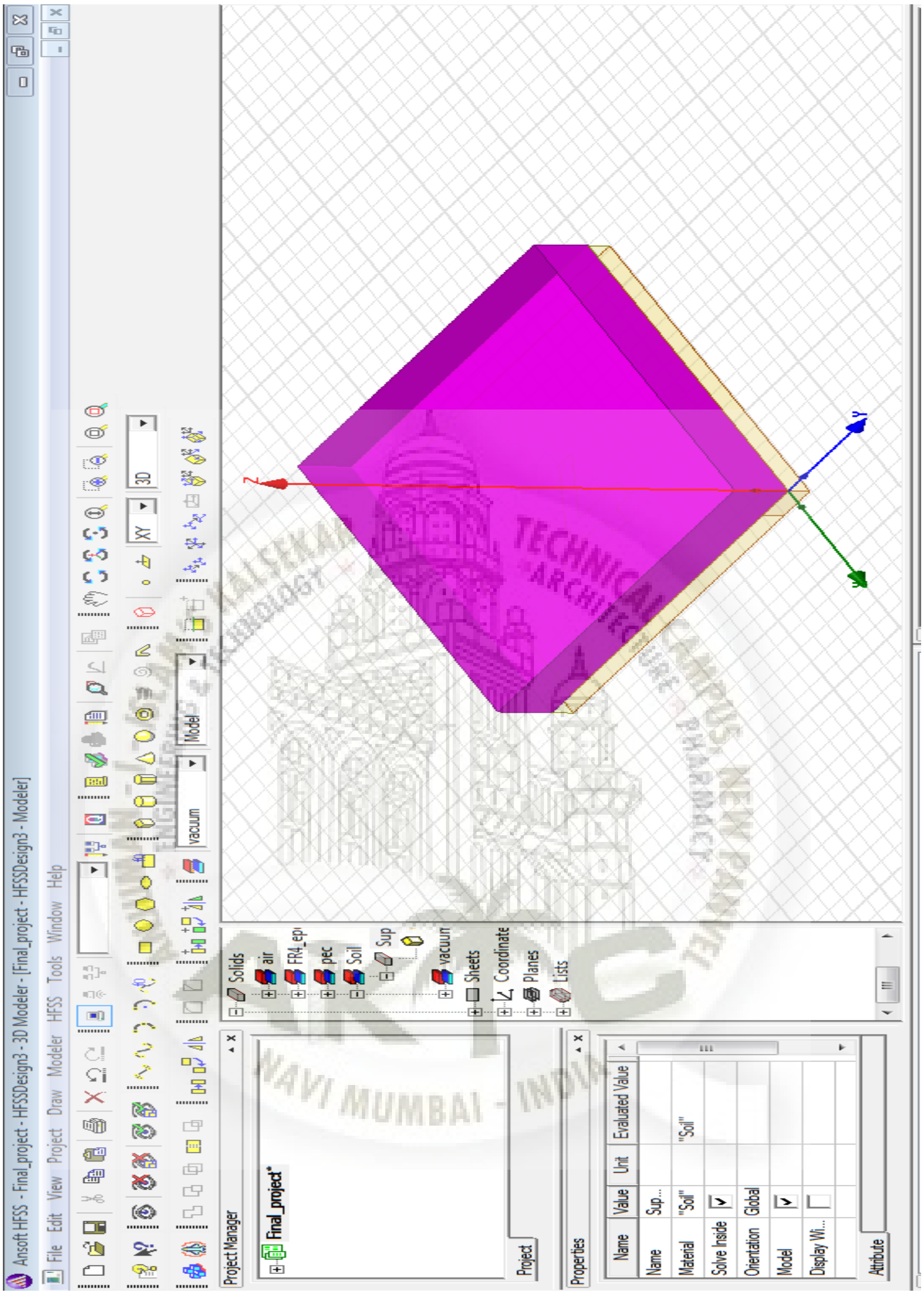
Go to project manager → right click on analysis → go to setup → edit sweep → change sweep type to fast → go to frequency step type =liner step ,start=0.1GHz, stop=3GHz,step size=0.01GHz → OK



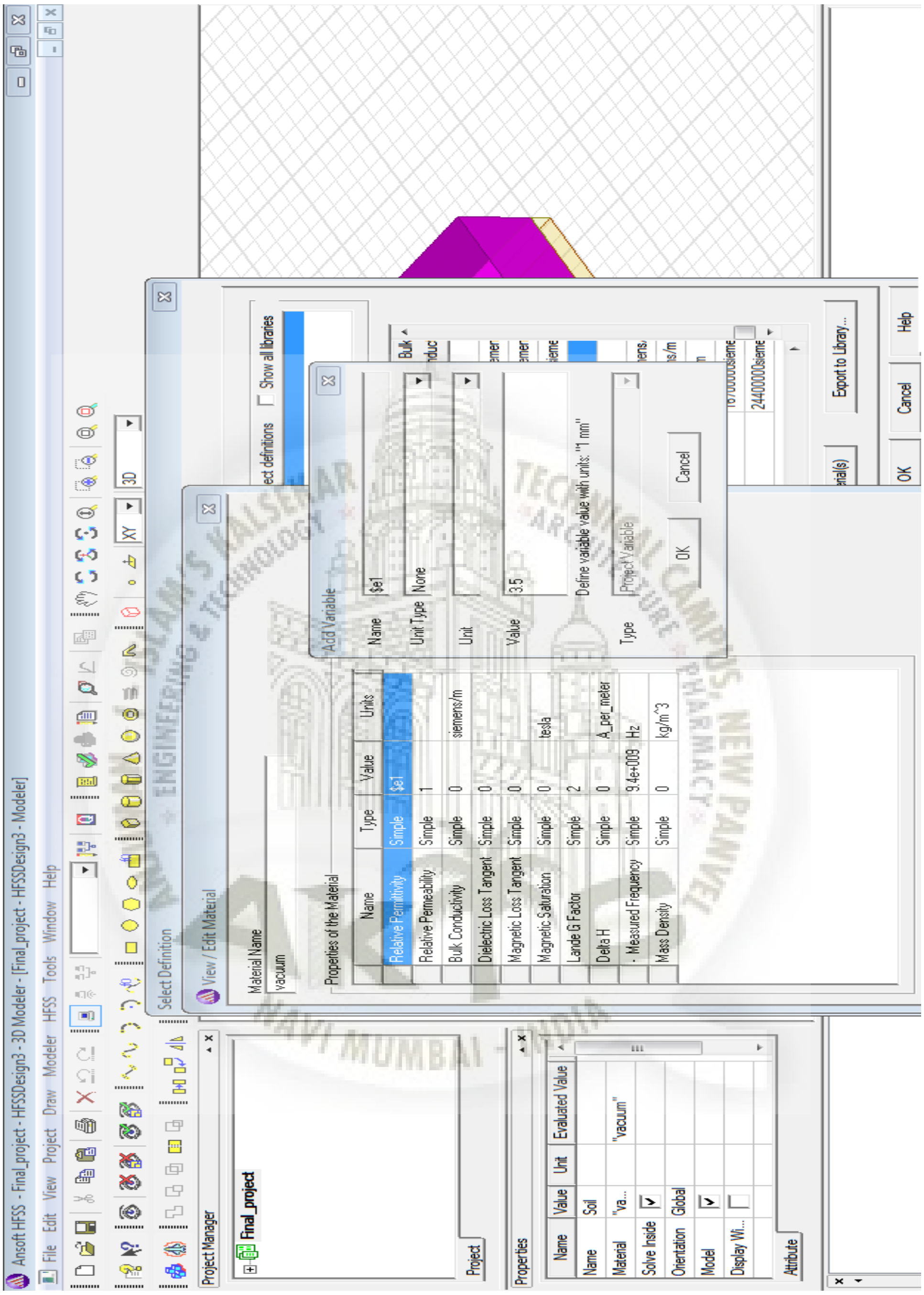
Go to validate → analyze all → OK



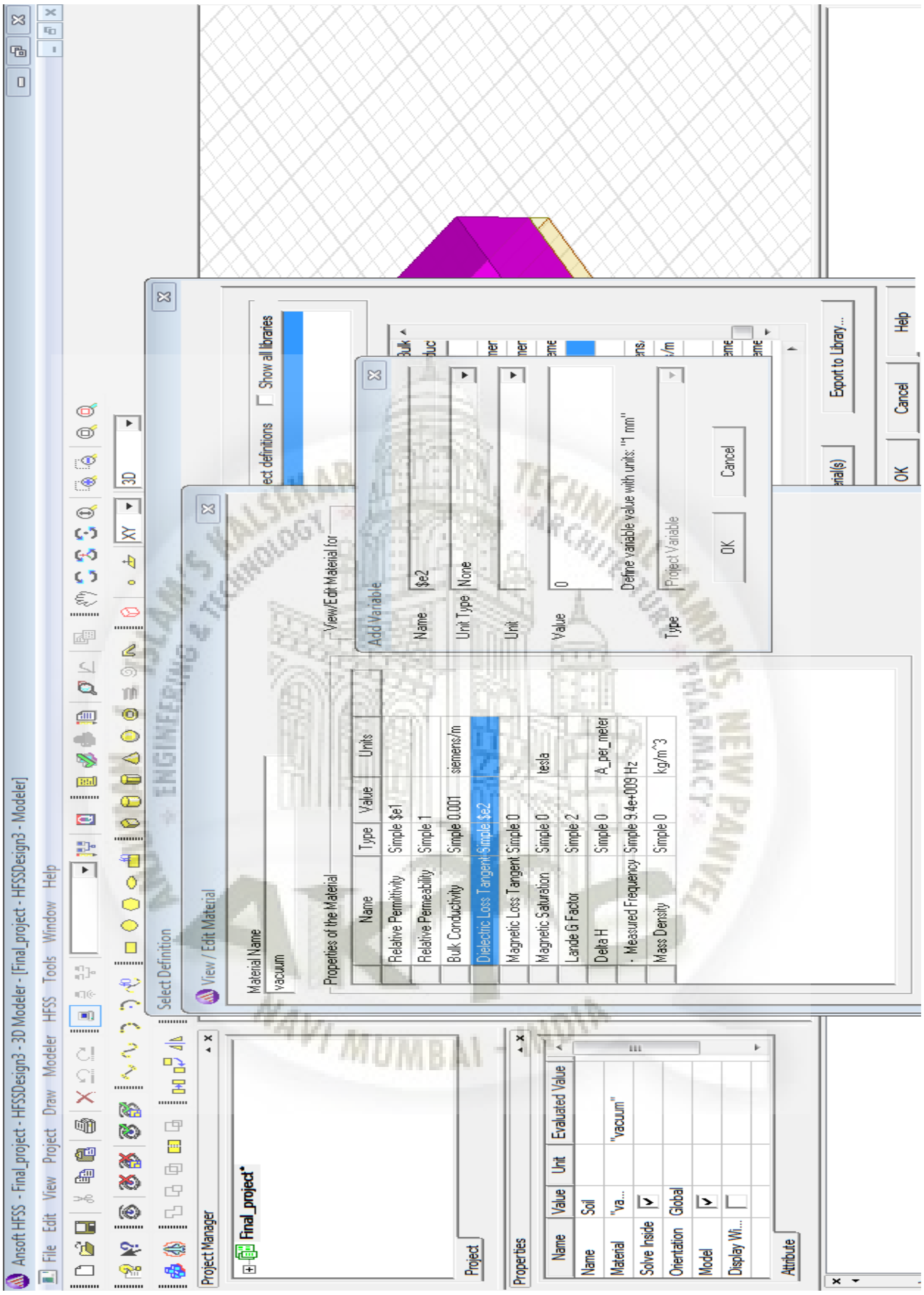
Draw rectangle → select Rectangle3 → change name to Superstrate → ok



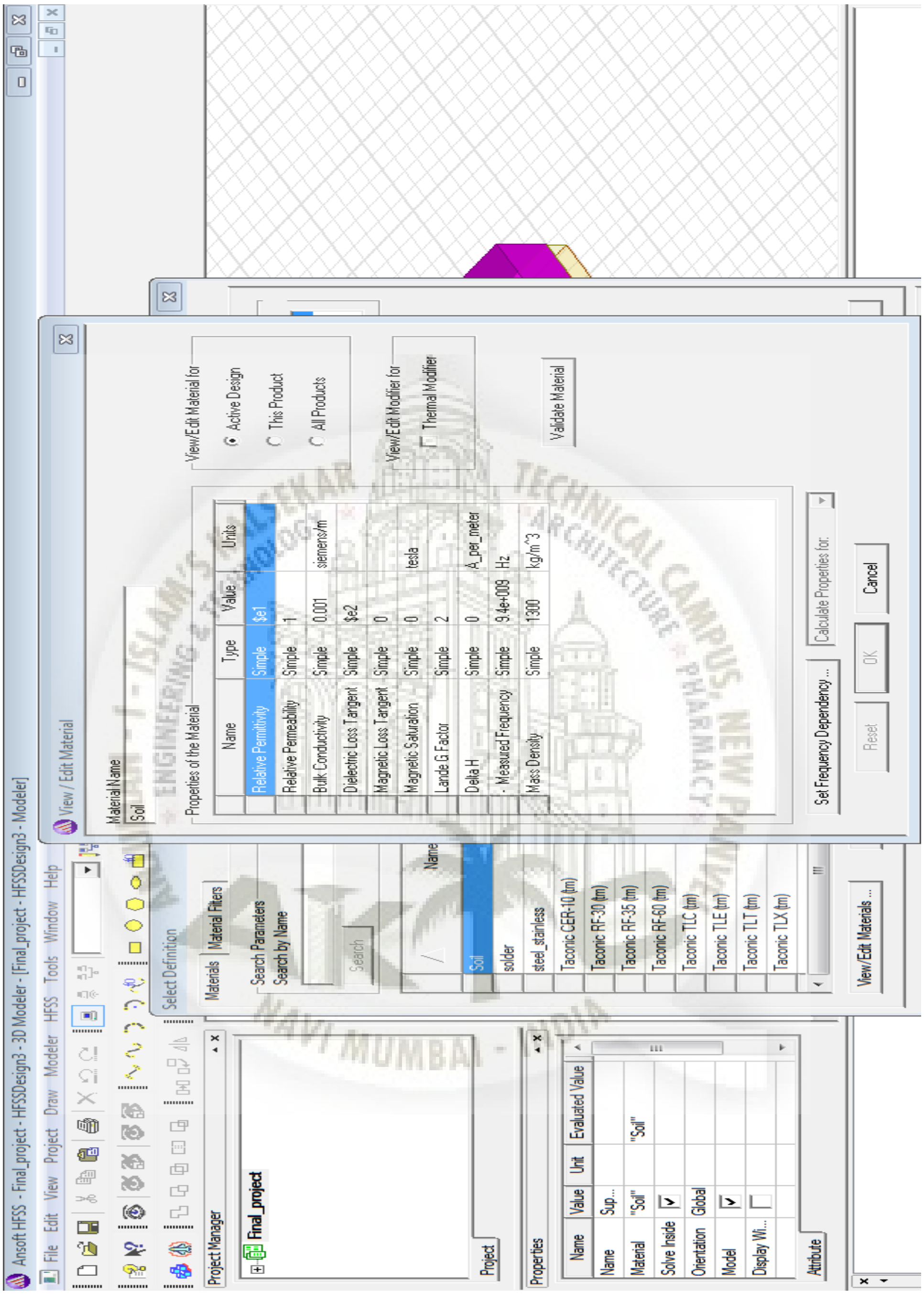
Select create rectangle → Select material then edit → Select then add material → change material name and change the properties of material → OK



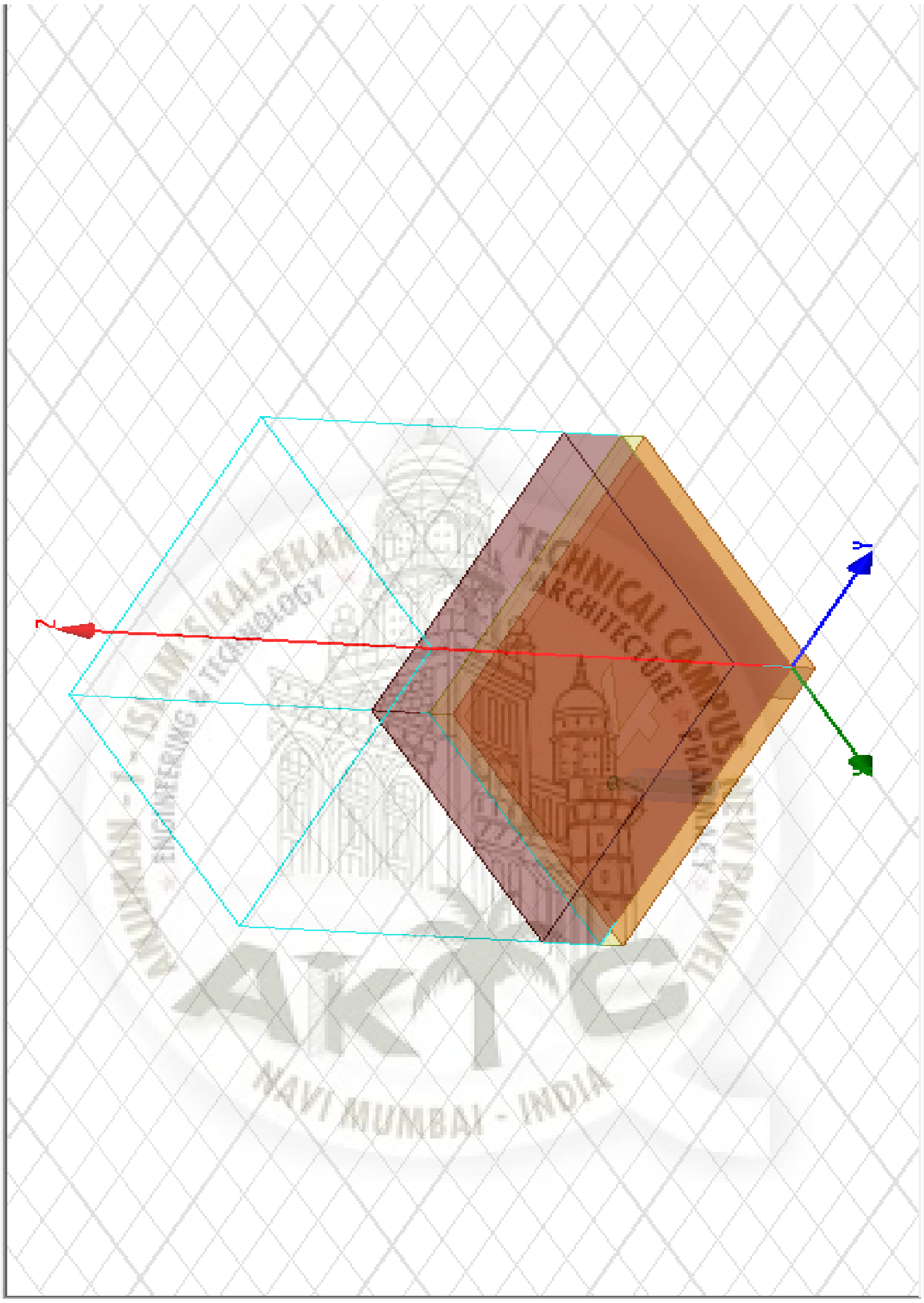
Select create rectangle $\rightarrow$ Select material - edit$\rightarrow$ $Selectaddmaterial$ $\rightarrow$ change material name and change the properties of material $\rightarrow$ OK



Select create rectangle → Select material - edit → Select add material → change material name and change the properties of material → OK



Antenna is as shown below



Chapter 5

Results

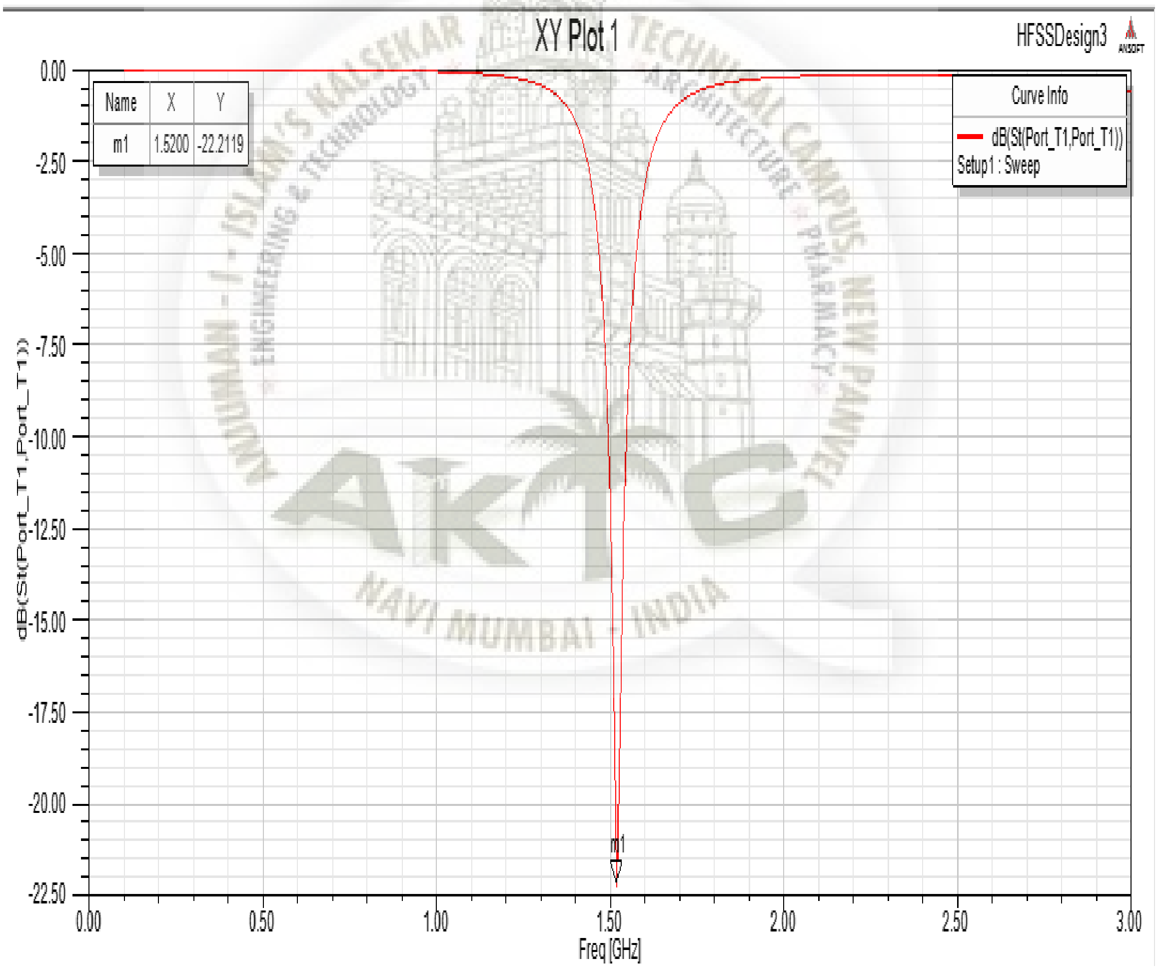


Figure 5.1: S11 plot

The resonant frequency of proposed antenna is 1.5GHz with return loss of -22dB and bandwidth of 50MHz.

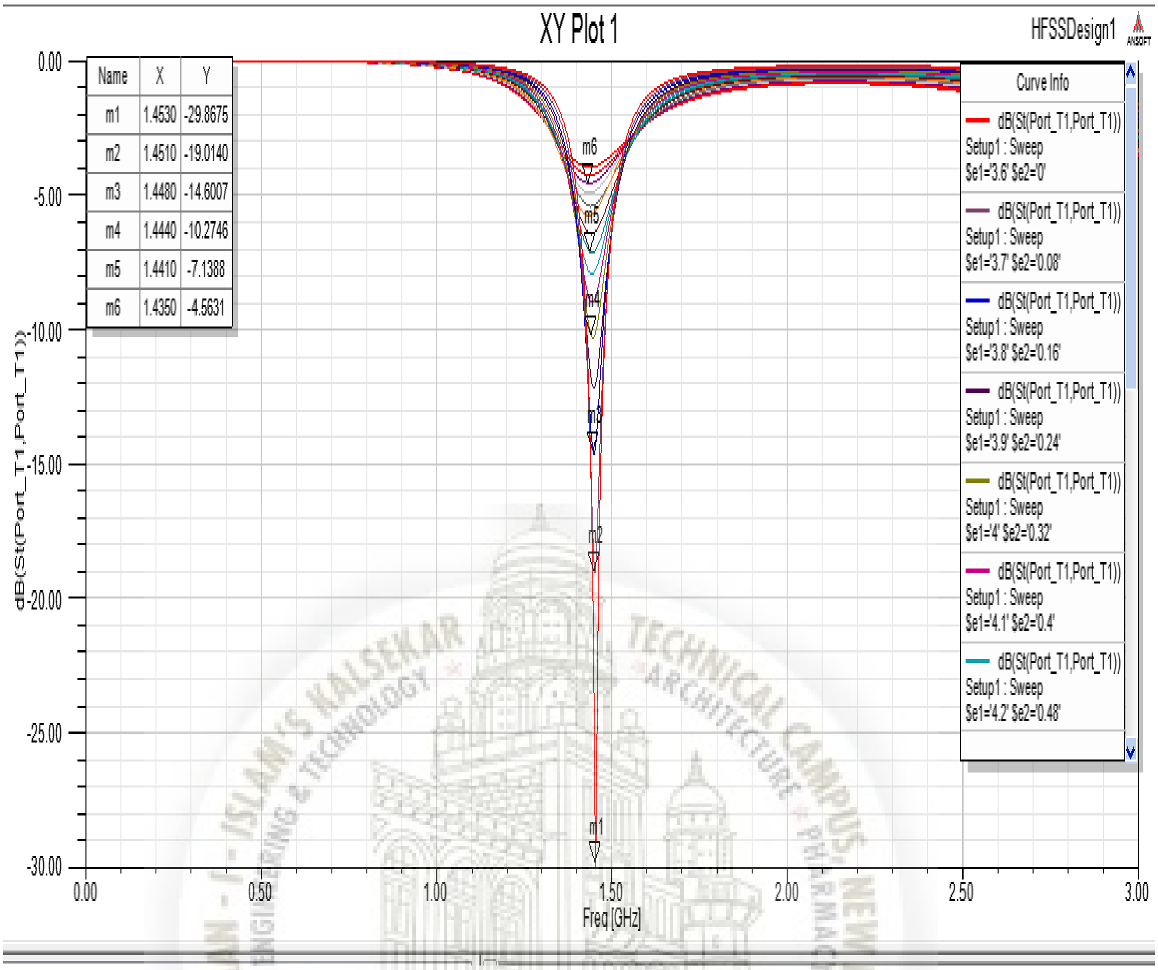


Figure 5.2: S11 plot with superstrate

The results obtained are useful in predicting the fertility of soil.The resonant frequency of antenna is inversely proportional to dielectric constant of soil. And it is observed that when the fertilizer concentration increases dielectric constant increases.As the concentration of fertilizer in the soil increases the dielectric constant increases, hence resonant frequency decreases.In the above result, $e1 and $2 represents dielectric constant(range= 3.6 to 5) and dielectric loss(range= 0 to 1.12). And when we add fertilizer in the soil, $e1 and $2 increases and this decreases resonant frequency of antenna. This results can be helpful in determining the optimum amount of fertilizer that should be added to the soil to maintain the fertility of the soil.

Chapter 6

Conclusion

6.1 Conclusion

Study of the properties of dry and fertilized soil at microwave frequencies is useful in agriculture. The results obtained are useful for predicting the fertility of soil. The resonant frequency of the antenna is inversely proportional to the dielectric constant of the soil. As the concentration of fertilizer in the soil increases the resonant frequency decreases hence the dielectric constant of soil increases. It is observed that the dielectric constant of soil increases with increase in fertilizer concentration.

It is useful for the researchers working in the field of microwave remote sensing. This study on the dielectric properties of dry and fertilized soils is thus useful not only in designing microwave sensors of soil-fertility estimation, but also needed in predicting the structure and chemical composition of soils.

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