EXPERIMENT: Design and simulation of a Microstrip Patch Antenna (MPA)

Related course: KIE3004 (Applied Electromagnetics) or KEET4208 (Antenna & Propagation)

EQUIPMENT:
Software (CST)

INSTRUCTIONS:

1. Record all your results and observations in a log book.
2. Follow the demonstrator's instructions throughout the experiment.

OBJECTIVES:

1. Understand the theoretical concept of Microstrip patch antenna (MPA).
2. Understand the design aspects of MPA.
3. Understand the design steps of MPA.
4. Simulate MPA using CST studio software.
5. Understand the characteristics of MPA using CST studio software.

Description:

Microstrip Patch antennas (MPA) are low profile, low cost, low weight, robust, printed circuit manufacturable antennas and are compatible with MMIC design. These high-performance antennas have tremendous prospect in aircraft, space craft, satellite, missile, present and future wireless technology (such as LTE, WiMax, 3G, 4G, 5G, 6G) applications. They can be designed by sophisticated software simulation technologies for different frequency, polarization, radiation characteristics so that they can be integrated into wide bandwidth high speed complicated communication network in a flexible and comfortable manner. Major disadvantages are low efficiency, low power and low Q factor. The concept of MPA was initiated during 1953 and received much attention from 1970.

As shown in Fig below, the antenna structure consists of dielectric substrate on ground plane, microstrip metallic patch and feeding line. Electric energy received by feed line is converted in electromagnetic energy and is radiated through thin metallic patch. Thickness, width and length of patch are denoted as t, w, L and substrate height as 'h' (small fraction of wavelength, $0.003\lambda << h << 0.05\lambda$) with dielectric constant between $2.2 < \varepsilon r < 12$. Thick substrates with lower dielectric constant are required for better efficiency, larger bandwidth. Thin substrates with higher dielectric constant are suggested for undesired coupling minimization. This antenna is a broad side radiator (maximum radiation perpendicular to patch). End fire radiation can be also be possible. For rectangular patch, L is to be in the range $\lambda/3 < L < \lambda/2$.

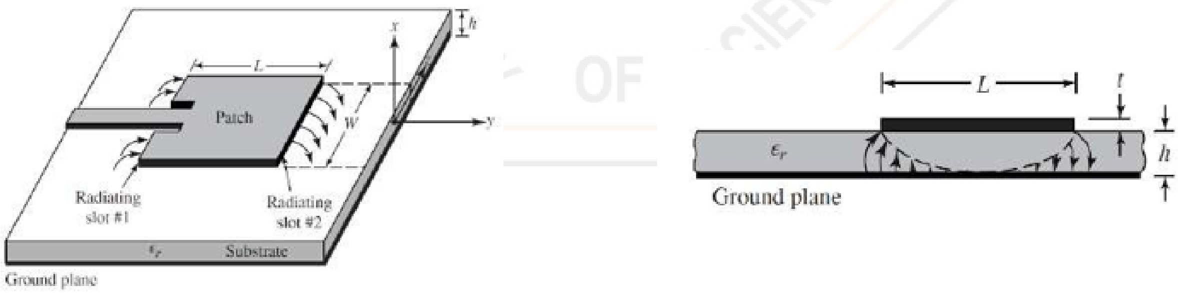

Fig.1. Microwave Patch antenna (a)Top View (b) Side view.

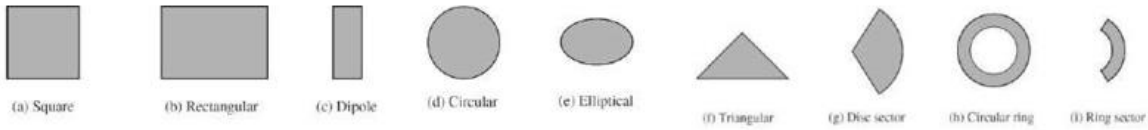

Fig.2. Different type of patch design.

Feeding Technique:

There are many feeding techniques developed so far (Fig. 3a). Such as microstrip line feed, probe feed, aperture coupled feed, proximity feed etc. Corresponding equivalent circuits are shown in Fig. 3b.

Microstrip line feed is easy to fabricate, simple to match by controlling inset position and simple to model. But there is bandwidth constraint for higher thickness substrate, but for probe feed, inner conductor is connected with patch and outer conductor to ground plane. Its characteristic more or less similar to that of probe feed but it is difficult to model Aperture coupled feed take care of the cross-polarization problem of previous one by using non contacting aperture. But it is difficult to fabricate. Have narrow bandwidth. On the bottom side of lower substrate, there is a microstrip feed line whose energy is coupled to a patch through a slot on the ground plane separating the two substrates. It allows independent optimization of the feed mechanism. Typically matching is done by controlling the width of the feed line and length of slot. Finally, proximity coupled feeding provides the best bandwidth, it is easy to model but difficult to fabricate. The length of feeding stub and width to line ration of patch is used to control the match.

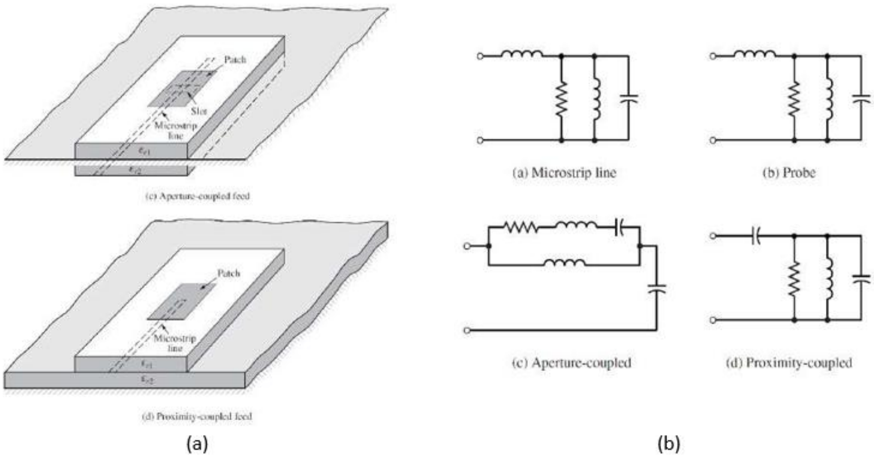

Fig.3. (a)Microstrip antenna feeding technique (b)Their circuit equivalent.

Fringing Effects:

It is be mentioned that dimensions of the patch are finite along length and width. So the field at the edge of patch undergoes fringing (Fig. 4)

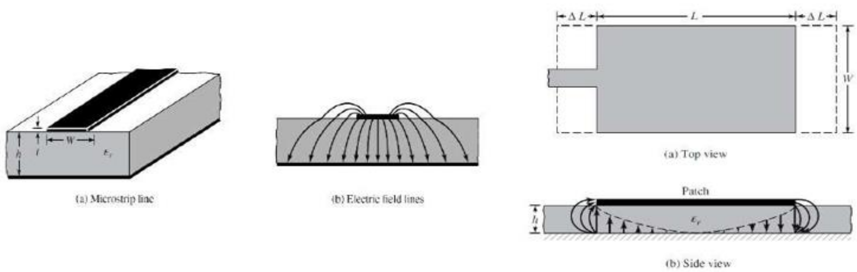

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Fig.4. Fringing effect on MPA.

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate. The initial values (at low frequencies) of the effective dielectric constant are referred to as the static values, and they are given by:

For $W/h \geq 1$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-0.5} \quad (1)$$

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the principal E-plane (xy-plane), this is demonstrated in Fig. 13.4 where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant εeff and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is

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

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now (L = λ⁄2 for dominant TM010 mode with no fringing).

$$L_{eff} = L + 2\Delta L \quad (2)$$

For the dominant TM010 mode, the resonant frequency of the microstrip antenna is a function of its length. Usually, it is given by

$$(f_r)_{010} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \quad (3)$$

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}}$$

MPA Design Steps:

Based on the simplified formulation described, a design procedure is outlined for practical designs of rectangular microstrip antennas. The procedure assumes specified information regarding the dielectric constant of the substrate (εr), the resonant frequency (fr), and the height of the substrate (h). Then determine W, L.

Specify:

$$\varepsilon_r, f_r(in\ Hz) and\ h$$

Determine:

$$W, L$$

Design Procedure:

For an efficient radiator, a practical width that leads to good radiation efficiencies is

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

where v_0 is the free-space velocity of light.

Determine the effective dielectric constant of the microstrip antenna using equation (1)

Once W is found, determine the extension of the length ΔL using equation (2).

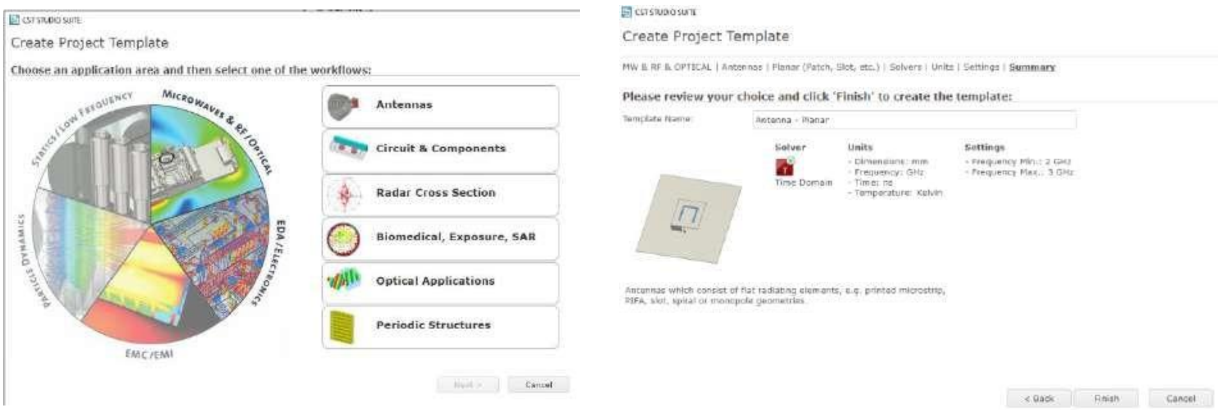
The actual length of the patch can now be determined by solving equation (3) for L, or

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\varepsilon_0\mu_0}} - 2\Delta L$$

Modeling the MPA:

Let the dielectric constant for FR4 material $\varepsilon_r = 4.3$, Height of the copper layer, Ch=.035mm and Height of the FR4, h=1.6mm. Using the parameter mentioned above calculate the L and W of the 2.4GHz patch antenna. Also using a microwave line calculator, the width of a 50ohm microstrip line is, Fw=3.12mm.

1. Open CST Studio suite
2. Click 'New Template'. A window called 'Create Project Template' will appear (Fig. 5).



(a) (b)

Fig. 5. (a)New template wizard (b)Summery of the wizard.

3. In the 'Choose an application area and then select one of the workflows' section click 'Microwave &RF/Optical' then click 'Antennas'. Click 'Next'.
4. In the 'Please select a workflow' section click 'Planar (Patch, Slot, etc.)'. Click 'Next'.
5. In 'The recommended solvers for the selected workflow are:" section select 'Time Domain'. Click 'Next'.
6. In 'Please select the units:' section keep the default setting. Click 'Next'.
7. In 'Please select the Settings' section enter '2GHz' as 'Frequency Min.:' and '3GHz' as 'Frequency Max.:;. As we want to create an antenna at 2.3GHz that is why we have chosen this parameter. We can change this later on. Click 'Next'.
8. Finally, a window will appear that will show the summary of the setting (Fig. 13.6b). Click 'Finish'.
9. The main Window of the CST will appear.

10. On the bottom part of the Main interface of CST, create and enter the following variable in the "Parameter List" section as shown in Table-1:

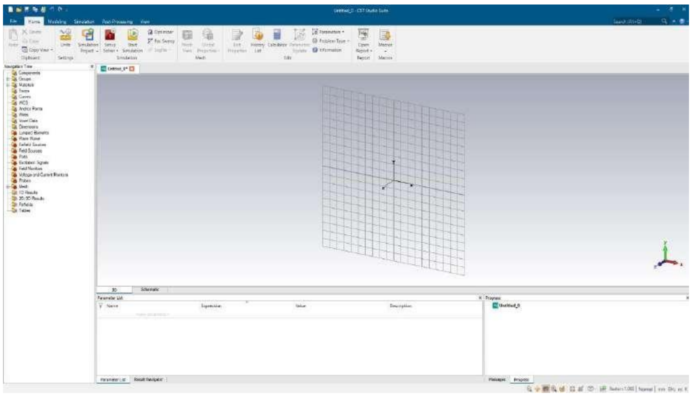
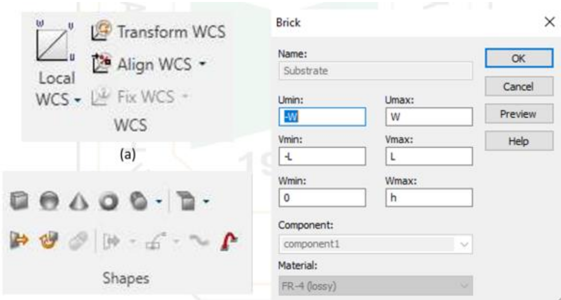


Table 1: Parameter for Patch antenna

Name	Expression	Description
W	38	Width of the patch
L	29.5	Length of the patch
h	1.6	Hight of the substrate
Ch	0.035	Hight of the copper layer
Fw	3.12	50ohm Feedline width

11. On the Top ribbon click "Modeling" tab.

12. Click 'Local WCS' From the WCS group. We can see the axis change from Global x,y,z to local U,V,W axis.
13. Click 'Brick' from Shapes group. Click on the main window and press Esc in keyboard. A window will appear. Enter parameter as shown Table 2 for substrate. Select FR-4 (lossy) as the material. Click 'Ok'. This will be the main substrate (FR4) board.

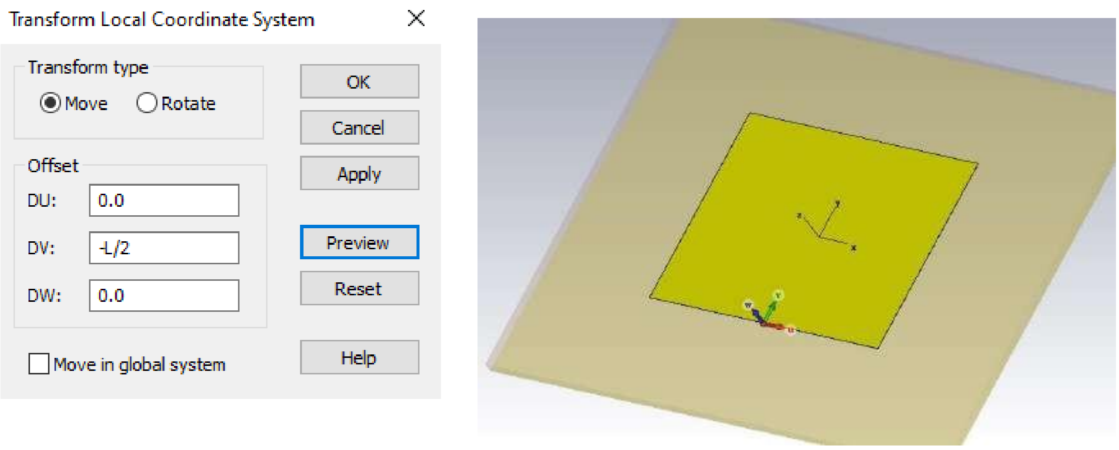


14. Repeat the previous step and create the Ground copper layer at the back of the substrate. Substrate will be highlighted. From WCS group click Align WCS>Align WCS with the selected face. This will align the Local WCS reference frame with the top face.

Table 1: Parameter for all dimensions.

Name	Umin	Umax	Vmin	Vmax	Wmin	Wmax	Material
Substrate	-W	W	-L	L	0	h	FR4(lossy)
Ground	-W	W	-L	L	0	-Ch	Copper (annealed)
Patch	-W/2	W/2	-L/2	L/2	0	Ch	Copper (annealed)
Feedline	-Fw/2	Fw/2	0	-L/2	0	Ch	Copper (annealed)

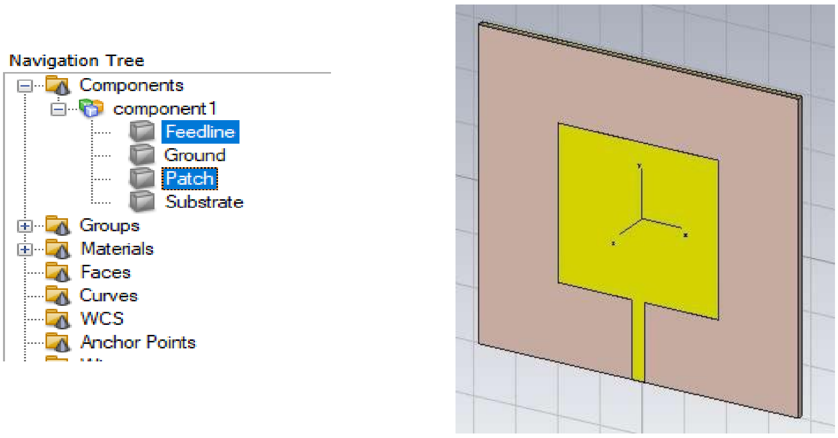
15. Now create a Brick and create the patch on the front of substrate by using WCS selection according to the Table 2.
16. Now from WCS group, click Transform WCS. Put ‘DV=-L/2’.Click Ok. This will move the WCS axis in V axis by -L/2 distance and should look like fig below.



(a) (b)

Fig. 6. (a) WCS Transform setting (b) WCS frame after transformation.

17. Now click on the Brick and create the Feedline using the values mentioned in the Table- 2.
18. Now Select Feedline and Patch both from the Navigation Tree> Components> Component1 (Fig. 7a).
19. From Modeling Ribbon click Tools>Boolean>add. This will join two separate brick Feedline and Patch and make a single compound object (Fig. 7b).

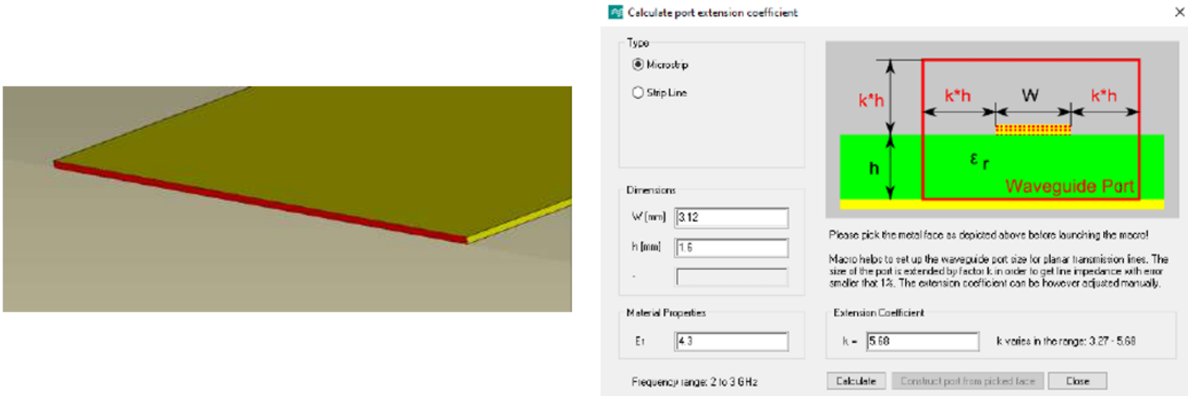


(a) (b)

Fig. 7. (a)Selecting two brick object in Navigation Tree (b)After Boolean operation.

Input Excitation:

1. Click ‘Picks>Pick Face’ from Picks group. Double click on the end of Feedline as shown in (Fig. 8a).



(a) (b)

Fig. 8. (a) Select feedline face for creation of Port (b) Port extension coefficient calculation window.

2. Click Home Ribbon. Click "Macros>Solvers> Ports>Calculate port extension coefficient" (Fig. 8b). Click 'Calculate'. Extension coefficient will be calculated. Click 'Construct port from the picked face'. A port will be created based on the Dimension of the material property of the Face. CST will use the port to excite the entire structure. To see the port from 'Navigation Tree' click 'Ports>Port 1'.

Monitors and Simulation Settings:

- Click 'Simulation' ribbon.
- Click 'Field Monitor' from 'Monitor' group.
- In the monitor we can select the type of output we want to see and also at what frequency. To see the Electric field distribution at 2.3GHz, select 'E-Field' and enter '2.3' next to frequency. Click Apply. A new entry will be created in 'Navigation Tree>Field Monitor'.
- Include 'Farfield /RCS' field monitor' at 2.3 in the simulation.
- To start the simulation, Click 'Setup Solver' in the 'Solver' group.
- In the 'Time Domain Solver parameters' window Select 'Port 1' from 'source type' dropdown box. Keep all the other setting to the default position. The accuracy/ time taken to solve the problem can be modified by varying various parameter of the window.
- Click 'Start' to start the simulation.

Results Postprocessing:

- To see the S_{11} parameter of the antenna, Click Navigation Tree>1D Result>S-Parameter.
- VSWR or any other 1D result can be seen in this manner.
- To find out the lowest point of the curve Click '1D Plot' Ribbon. In the 'Markers' section Click 'Axis Marker> Move Marker to minimum'.
- To see the data at any point of the curve, click 'Curve Marker>Add Curve Markers'. Double click on the curve to see the x and y axis data on that point.
- To see the Radiation pattern of the MPA, Click Navigation Tree>Farfields>farfield (f=2.3). The 3D radiation pattern can be seen.
- To see the 1D Polar plot, click 'Properties' from the 'Farfield' ribbon.
- In the Window select '1D Polar' from the Plot type dropdown box. Enter Phi=0. Click 'Ok'. This will create the 1D polar plot at Phi=0 axis.

Tasks:

You are assigned to design, calculate, and simulate a "Microstrip Patch Antenna (MPA)" based on the frequency assigned to your lab group number. Follow the instructions and fill in the blanks according to the frequency of your group.

Frequency Calculation:
- Group **A1**: Frequency = 1 GHz
- Group **A2**: Frequency = 2 GHz
- Group **A3**: Frequency = 3 GHz
- And so on, where the group number corresponds to the frequency in GHz.

Q1: Design and simulate a "Microstrip Patch Antenna" aimed at operating at a frequency of "___ GHz" (based on your group number).

You must also consider the following parameters:
- Dielectric constant (ϵr) = ___
- Height of the substrate (h) = ___ mm
- Height of the copper layer = ___ mm
- Shape of the patch= ___ (e.g., rectangular, circular, elliptical, etc.)
- Feedline technique= Recessed microstrip-line feed

Q2: Perform the following calculations and simulations:

- Calculate the dimensions of the patch (length, width, etc.) based on the assigned frequency and given parameters.
- Simulate the antenna using CST or any appropriate simulation software. Plot the following:
    - S-parameter (S11) graph to analyze return loss.
    - Gain and directivity of the antenna.
    - Radiation pattern for E-field and H-field.
    - Surface current distribution on the patch.
- Evaluate the performance of the antenna based on your simulation results, discussing the return loss, gain, radiation pattern, and surface current behavior.

Q3: What is the effect of using the Recessed microstrip-line feed technique shown compared to the one used in the lab?

Q4: Conform the designed microstrip patch antenna to an angle based on your assigned frequency. The angle is calculated as (frequency in GHz) × 5 degrees. For example:

- Group **A1** (1 GHz) conforms to 5 degrees
- Group **A2** (2 GHz) conforms to 10 degrees
- Group **A10** (10 GHz) conforms to 50 degrees

After simulation:

1. Compare the performance (S11, gain, radiation pattern, etc.) of the conformal antenna with that of a planar (non-conformal) antenna at the same frequency.
2. Discuss any performance differences between the conformal and planar antennas.
3. If the conformal antenna fails to perform well at the specified angle, suggest the maximum

possible angle where the antenna still provides acceptable results.

END OF EXPERIMENT