DESIGN OF IITMSAT ONBOARD ANTENNAS

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **Design of IITMSat Onboard Antennas,** submitted by **Shahul Hameed Ansari Md.,** to the **Indian Institute of Technology Madras,** for the award of the degree of **Master of Technology**, is a bonafide record of the research work done by him under supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Keywords: IITMSat, Satellite uplink/downlink communication, Ansoft HFSS, Quarter Wave Antenna, Inverted F Antenna (IFA), Return Loss and Antenna Gain

IITMSAT, a Nano satellite being developed by the students of IIT Madras, is slightly smaller than one feet cube without antenna appendages. The 145 MHz uplink and 435 MHz downlink frequencies chosen for communication with the satellite have the free space wavelengths larger than the sides of the satellite cube. Design configurations of the onboard antennas for these frequencies with the finite ground (cube) and dimensional constraints have been studied in the present work.

The Ansoft HFSS based simulation studies have been carried out for the antenna radiation characteristics using Quarter Wave Pole and the Inverted F Antenna mounted in different orientations on the satellite cube.

The simulation results are validated for the known antenna configurations and a brief qualitative analysis of the Finite ground effects and radiation properties of the IFA is also presented.

Based on the radiation characteristics, the final design of the IITMSAT onboard antennas is frozen and optimized for achieving the desired matching for 50 Ohms. The radiation patterns and the return loss for each configuration have been provided.

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Symbols and Abbreviations

λ : Free space wavelength

λ_t : Free space wavelength for 435 MHz transmitter frequency

λ_r : Free space wavelength for 145 MHz receiver frequency

ε_{r} : Relative permeability (Relative Dielectric constant)

AOCS: Attitude Orientation and Control System

FEM: Finite Element Method

GND: Ground

HFSS: High Frequency Structure Simulation Software

IITMSat: IIT Madras Satellite

IFA: Inverted F Antenna

ILA: Inverted L antenna

Rx: Receiver

Tx: Transmitter

UHF: Ultra High Frequency (435 MHz)

VHF: Very High Frequency (145 MHz)

CHAPTER-1

INTRODUCTION

IITMSat, a student initiated satellite project has chosen 435 MHz (UHF) for downlink and 145 MHz (VHF) for uplink communication with the Ground station. The design of the Onboard Antennas for the establishing communication link with the ground station is presented in this document.

Several simulation studies for different mounting configurations have been carried out using Ansoft HFSS tool.

The satellite dimensions used in the simulations are: 286 x 286 x 268 mm3. The satellite consists of Polyvinyl Toluene on its top face, which is the High Energy Particle detector payload of IITMSat. In the simulation model, this material is also modeled (εr= 2.1) on the top portion of the satellite with the dimensions 225 x 225 x 80 mm^3.

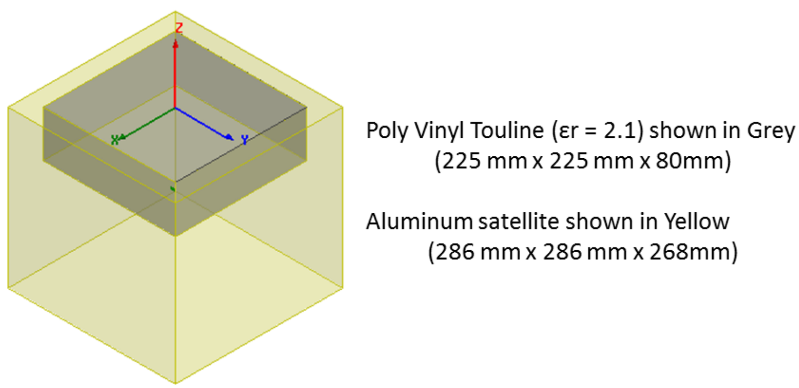


Fig-1.1: The IITMSat model without Antenna Appendages

First, the IITMSat Mission requirements (design specifications) for onboard antennas are summarized and also the constraints from the mission are provided.

Then, using the above satellite model, several antenna configurations have been studied for their radiation patterns and return loss characteristics.

Initially, the monopole characteristics of the 435 MHz transmitter antenna were studied. It was observed that, because of the finite ground size (satellite cube), the peak of the radiation was 40° below the payload face (XY Plane in Fig-1.1) of the satellite. The effects of tilting the poles and modeling of the solar panels was also studied to observe any change in the peak direction.

Later, the 145 MHz receiver antenna characteristics were studied using the single and double Inverted F Antennas (IFAs). The observations have been summarized at the end of each chapter.

Finally a suitable design configuration for meeting the project requirements of the IITMSat mission is provided using the IFAs for the Transmitter and Receiver onboard. A summary of each designs merits and demerits is also provided.

CHAPTER-2

DESIGN REQUIREMENTS AND LIMITATIONS

2.1 Design Requirements/Specifications:

1. Establish the Uplink and Downlink communication with the Ground Station
    a. 2 Transmitters (Beacon and Main Data downlink)
    b. 1 Receiver (Telecommand uplink)

    The Beacon and Main transmitters are operated one at a time with the other being off. Thus, both these transmitters are connected to a common downlink antenna system using coupler. Hence only one downlink antenna design is sufficient for the mission.
2. Center Frequencies of operation (min 20 KHz bandwidth)
    a. 435 MHz (Downlink)
    b. 145 MHz (Uplink)
3. Physical dimensions
    a. Satellite < 300x300x300 mm^3 ; Antenna Appendages < 200mm so that the total satellite size with antennas will be less than 0.5 meter on each side.
4. Radiation coverage : Omni directional in the region of visibility
5. Antenna Gain : sufficient enough to meet link margins
6. Polarization
    a. Faraday rotation effects in the ionosphere causes rotation of the field
    b. Circular Polarization for uplink/downlink is immune to rotation angle
7. Return loss >10dB which corresponds to VSWR < 2

Thus the overall objective is to achieve a circularly polarized omnidirectional compact sized antenna that operates at the desired frequencies. However, there are several constraints from the project that have to be met with and are given in the next section.

2.2 Project Constraints:

1. Space occupied by Antennas not to exceed 200mm in axial directions. IITMSat being a Nano satellite, the total space occupied by the fully integrated satellite with antenna appendages is to be less than 50 cm in any axial direction. As the cubic dimensions of the satellite are about 30cm, design the antenna that will be smaller than 20cm in any axial direction

    This will have the following engineering limitations

Antenna Size will be λ/4 at least, for efficient radiation and the free space wavelengths for uplink and downlink frequencies are as given below.

i. 435 MHz (Downlink) → λ_t = 690 mm → $\lambda_t/4$ = 172.5 mm

ii. 145 MHz (Uplink) → λ_r = 2069 mm → $\lambda_r/4$ = 517.25 mm

The quarter wavelength values suggest that for UHF, monopole can be considered but for VHF, some compact antenna has to be designed that will be smaller than 20cm axially.

Exploring the different antennas available, Inverted F antennas (IFA) for both UHF and VHF have been proposed as the space occupied by these antennas will be less in the axial directions.

2. Edge/Corner mounting on the top payload face is only allowed
   a. Center mounting obstructs payload visibility and hence not allowed.
   b. Antennas can be mounted only on the Side faces (between solar cells) and on the top face edges.
   c. In the bottom face, there will be a launch adaptor ring connected to mate the satellite with the launch vehicle.

Simulations have shown asymmetrical radiation pattern with a single UHF antenna at the top face edge. Hence four antennas are used for the design to get a Omni pattern in horizontal plane.

3. S/C Spins across the payload axis (Z-Axis)

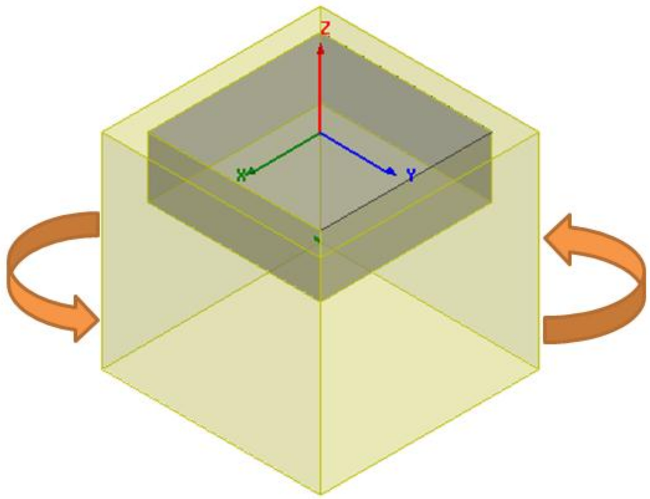


Fig-2.1: Satellite with the Payload on top face and Spin axis along Z

This is due to the limitation of AOCS because there are no reaction wheels and only one magnetometer is used for attitude control. The spin is maximum 0.5 degrees/second.

This will necessitate the requirement of omnidirectional pattern in XY plane, which will be symmetric about spin axis and hence the link is not affected.

4. Wire Antennas are Linearly Polarized

The Quarter wave pole and IFA are linearly polarized wire antennas. Considering the Faraday rotation effects, one has to use a circularly polarized antenna on the ground station and it will have a 3dB impact on the link margin.

However, Quadrature phasing with linear onboard antennas gives Circular Polarization. But simulation studies have revealed that, Peak radiation happens along the payload axis Z which is not desirable as per the orientation of satellite in the orbit. Hence Design is limited to Linear Polarization only and the 3dB impact on Link Margin is considered for the link budget

5. Two or more antennas produce a null due to destructive interference

Simulations have shown that having more than one antenna produces null in some directions where the individual radiation patterns from each antenna interfere destructively.

Having a null in the downlink is acceptable if it is outside the coverage requirements of the mission. Also, if the satellite attitude is mis-oriented, it can be corrected using the AOCS. For this, it is essential that the receiver radiation pattern shall not have a null.

Hence the design is limited to use a single VHF antenna for uplink ensuring that the link has enough margins with the worst case (least) gain value of the antenna radiation gain.

2.3 Advantage of Bi-directional peak in the orbit

In the orbit, path loss varies with the elevation angle and having a bidirectional peak radiation gives advantage for the power available at the ground station as explained below.

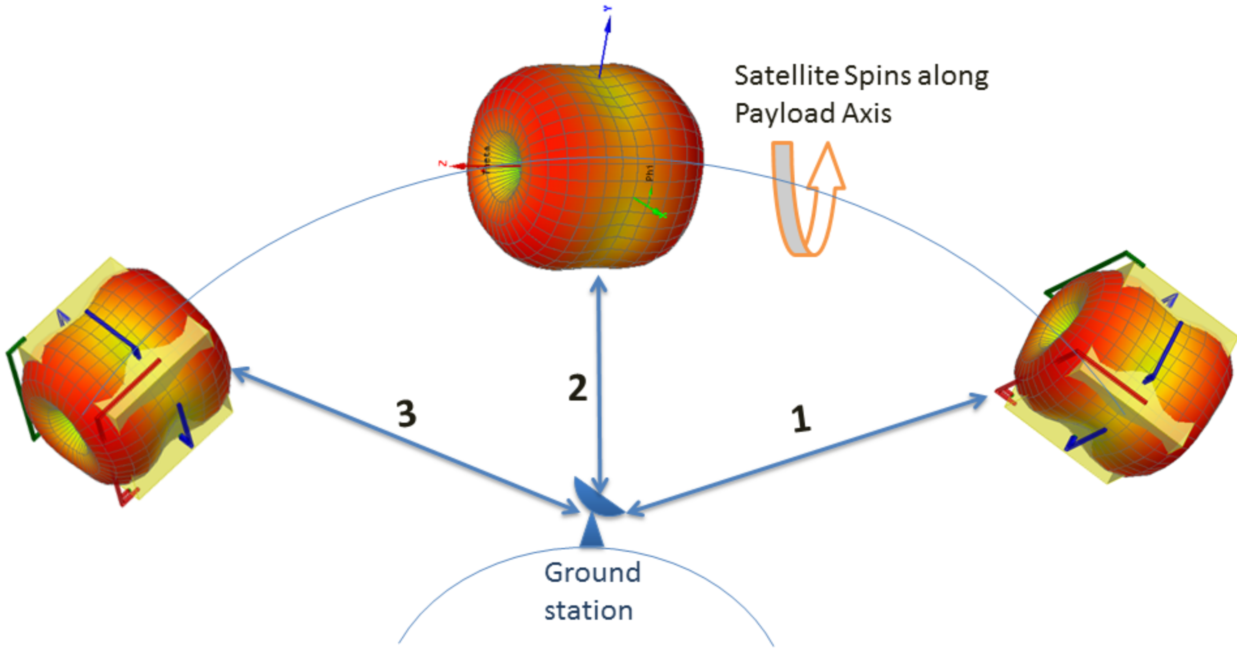


Fig-2.2: Satellite orbit and orientation showing varying elevation angles

Table-2.1: Elevation angle Vs. Path Loss in the Orbit

Elevation Angle Theta Degrees	Path Loss dB at 435MHz 900Km Orbit
5	155
10	153
30	149
60	145
90	144

From the above table, it is clear that path loss varies from 155dB to 144dB, a maximum variation of about 11dB. Hence, at 90° elevation angle, even though the antenna gain(of the proposed design for IITMSat, see chapter-5) is 6 dB below its peak value in the bidirectional peak radiation pattern, the power levels will be (11-6=5) 5dB higher than that at the elevation of 5° at the ground station. This will improve the link performance. Hence a bi-directional peak radiation pattern is desirable for the link.

CHAPTER-3

QUARTERWAVE POLE CONFIGURATIONS FOR 435 MHz

3.1 Validation of the Simulator for an Monopole on Infinite Ground Plane

The Quarter wave (172mm) monopole at 435MHz on the infinite ground plane was simulated in HFSS with finite wire diameter of 3mm. As per the theory [1], the monopole resonates at quarter wavelength if the wire diameter is infinitesimally small (< λ/1000, tending to zero in limiting case). However, for finite diameter of the wire, [1] the resonant length will be slightly shorter than λ/4. The radiation reactance also varies with the diameter of the pole. These results were verified in HFSS simulation and are tabulated as below.

Table-3.1: Comparison of Literature data with the simulator data for Monopole antenna

Case/Parameter	Pole Height (mm)	Pole radius (mm)	Directivity	Peak Gain (dB)	Antenna Impedance (Ohms)
Ideal (Zero Radius)	172.4 ($\lambda_t/4$)	0	3.52 (2*1.76)	5.46	36.5 + j21.25
Theoretical finite radius	164 (95.11% of $\lambda_t/4$)	1.5	3.52	5.46	32 + j??
HFSS finite radius	164	1.5	3.45	5.39	36.4 + j6.38

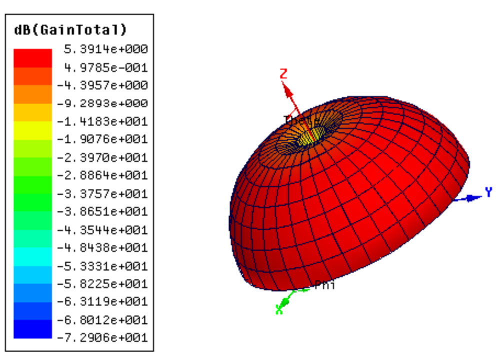


Fig-3.1: Radiation pattern of a Monopole on infinite ground plane

It can be observed that the HFSS simulation results are within 10% of the theoretical values.

3.2 Study of UHF Quarter wave pole configurations for IITMSat

This section gives the overall observations on the UHF quarter wave antenna characteristics on the IITMsat. For more detailed observations, refer to the Annexure A-1.

The Quarter wave pole on the finite cube of IITMSat was simulated with a single pole at the center of the top face. **It was observed that the peak of the radiation was 40° below the horizontal. This is due to the diffraction of the fields at the satellite cube edges.**

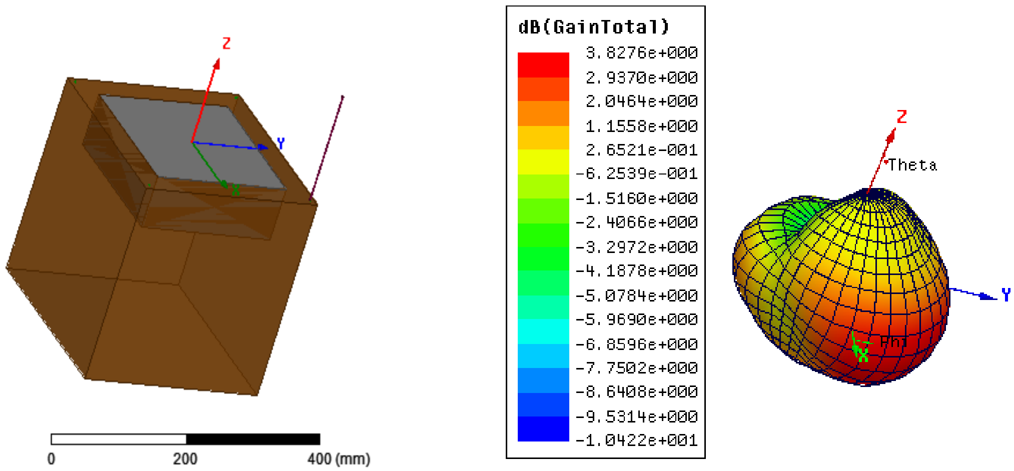


Fig-3.2: Single Quarter wave Pole at the corner with its radiation pattern

However, mounting the pole at the center of the top face is not possible because of the IITMSat payload. Hence the pole was placed in the corner of the satellite and its radiation characteristics are as shown in the figure-3.2. The radiation pattern is distorted/asymmetrical and not omnidirectional. Simulations with the two and three poles at the corners also showed the non-omnidirectional distorted radiation patterns.

It can be noted that the face dimension 286 mm is about (λ_t/2.4) for 435 MHz. This value being closer to half wavelength severely affects the radiation pattern at 435 MHz

Thus either single or two or three poles at the top face edges/corners are not suitable for IITMSat mission. Henceforth, four poles were considered for simulation.

Using four poles at the face edges, feeding them in equal amplitude and phase, it was observed that the radiation pattern was same as that of the single pole at the top face centre. The radiation peak was also 40° below the horizontal, due to edge diffrcation.

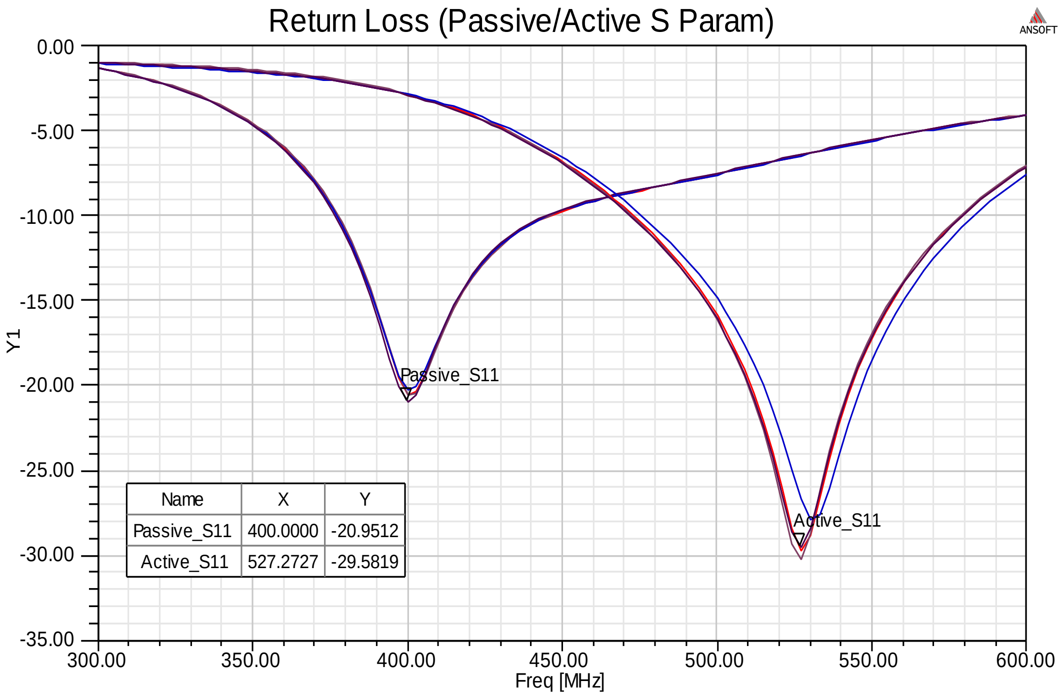


Fig-3.3: Return Loss Plot for Four Quarter wave Poles at the Edge centers

The return loss plot shows that the active S parameters resonate at 527 MHz whereas the passive S resonates at 400 MHz In order to make the active S resonate at 435 MHz, it was computed and verified in simulation that the length of each pole should be 205 mm, larger than its quarter wavelength. However, this will also give the peak of the radiation 40° below horizontal.

Simulations were done by tilting the poles inward and also outward, but the peak did not change its direction from being 40° below.

Insulating the ground plane of the monopoles using a 2mm Teflon sheet between the poles ground plane and the satellite top face also did not change the direction of the peak.

Simulating the solar panel FR4 PCBs in the model also didn't change the direction of the peak being 40° below.

When an extra larger ground sheet was placed on the top of the satellite, the peak changed its directions for different lengths of the sheet as given below.

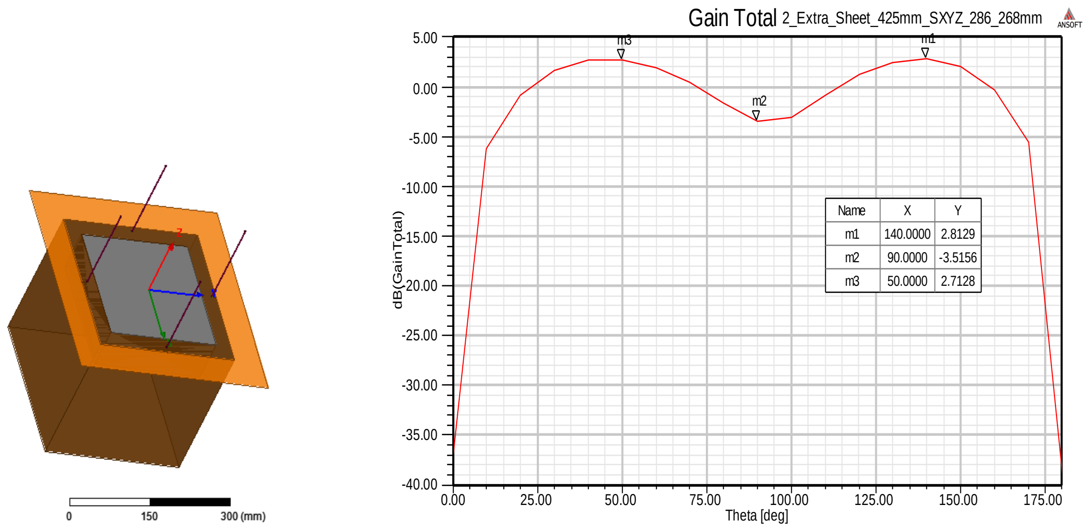


Fig-3.4: (Orange Colored) 425mm Extra Ground Sheet placed on the top with radiation pattern

The observations with the length of the ground sheet are

Sheet Length < 400mm (Extra 57mm each side) – Peak (40°) below the horizontal

Sheet Length = 425mm (Extra 70mm each side) – Bidirectional symmetrical Peak

Sheet Length > 460mm ($^{2}/_{3}\,\lambda$) - Peak shifts Upwards.

These results are consistent with [2], where the effects of ground plane dimensions on the peak direction of the monopole radiation on a finite ground plane are analysed.

The mutual coupling between the poles is also reduced (active S comes closer to passive S), which means the pole length can be shortened from 205 mm with a larger ground plane.

This option was however rejected and the quarter wave poles based design for IITMSat has been dropped due to the following reasons.

Having an Extra Ground Sheet on the top face

- Obstructs the solar power generation as the sun light is shadowed
- Increase in mass due to the extra sheet
- Pattern distorted with the presence of VHF receiver antenna

3.3 Summary of Observations on UHF 435 MHz Quarter wave pole configurations

1. Four poles in the Edge Centres are necessary to get a symmetrical and omnidirectional radiation pattern as a single pole in the centre of the satellite top face is not allowed.
2. Radiation peak occurs 40° below the horizontal face for a single pole at the centre and also for the four poles at the edge centres
    - Diffraction from the satellite cube edges is causing the peak of the radiation to be below the top face by about 40°
3. Active S-parameters resonate at 527 MHz instead of 435MHz in Edge Centred Mounting
    - Pole length should be increased to 205mm from 164mm for 435MHz resonance
4. Tilting Poles/Insulating GND/Solar Panel modelling was not effective to shift the tilt
5. Extra 425mm GND Sheet on Top face gives bidirectional peak
    - This is not a practical solution for the Nano satellite as the sheet increase weight and also obstructs the solar power generation
6. All the four monopoles are excited in equi phase and have a null along the pole's axis Z
7. Quadrature Phasing the Poles gives Circular Polarized Radiation with peak along the end fire(+Z), normal to payload face
    - Not Desirable for our Application
8. The radiation pattern in the presence of Receiver Antenna is distorted and not Omni directional

CHAPTER-4

IFA Configurations for 145MHz and 435 MHz

As the active S parameters (considering the mutual coupling) for the four quarter wave poles showed that the height of the each pole should be 205mm so that the resonance occurs at 435 MHz and as the extended ground sheet cannot be used on the satellite, an Inverted F antenna based design was considered for the antennas at 435 MHz.

For 145 MHz, quarter wavelength being close to half meter, the pole was bent to form an inverted F with additional U bend.

In the following section, the structure of the Inverted F Antenna (IFA) designed for VHF and UHF are given in detail.

4.1 The structure of Inverted F antenna (IFA)

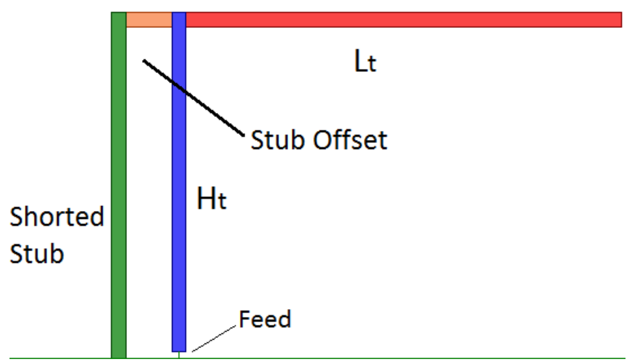


Fig-4.1: The structure of 435 MHz IFA

The structure of the IFA at 435 MHz is as shown in the figure 4.1. It is basically a bent monopole [3] at appropriate height (~ λ/16 to λ/20) 'Ht' and the additional length 'Lt' is horizontal to the ground plane. The total length (Ht+Lt) is close to quarter wave length.

The structure of the 145 MHz IFA is as shown in the figure 4.2. The sum of (Hr+Lr+Ur) is approximately equal to quarter wavelength. As the lateral dimension of the satellite is 286mm and we restrict the height of the receiver antenna to be less than 200mm, the IFA structure is modified with an additional U bend, to compactly accommodate 500mm across the cube.

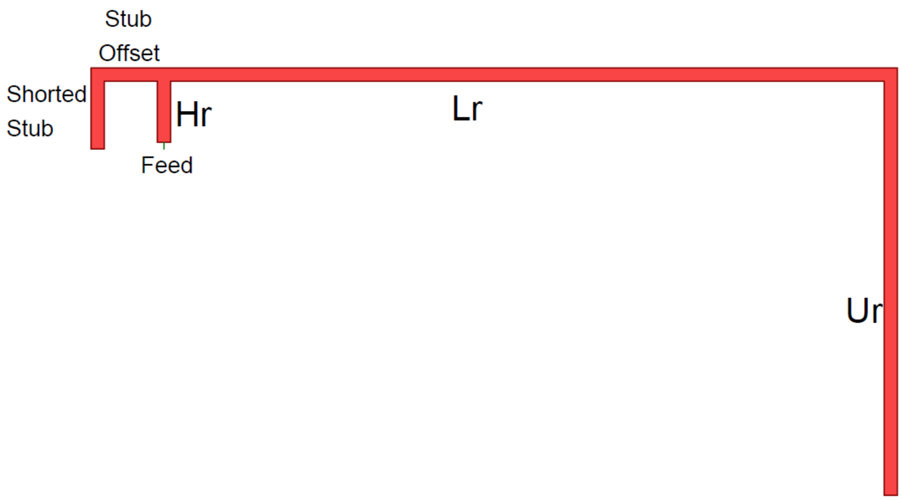


Fig-4.2: The structure of 435 MHz IFA

4.2 Matching using a short circuited stub

As the pole is bent, it offers a high reactance due to the capacitance between the pole and the ground plane. To compensate this high value of C and match the antenna for good return loss, a short circuited stub is used with the tunable offset distance for matching at resonance. The loop current in the stub gives inductive reactance that cancels out the capacitive reactance of the horizontal section of the IFA.

For obtaining a good matching, the IFA height should be approximately ~ λ/16 to λ/20. This is because, the radiation resistance and reactance are functions of height of the IFA and a value close to 50 ohms can be obtained when height is about λ/16 to λ/20. [3]

4.3 IFA Simulation results for 435 MHz UHF Antenna

The detailed simulation results for the IFA at 435 MHz are provided in the annexure A-2. The salient observations of the results are given in this section.

A single IFA placed either on the top face edge or on the solar panel faces of the satellite did not give omnidirectional radiation pattern. Hence four IFAs at 435 MHz were used on the satellite.

When the IFAs were placed on the top face of the satellite, the peak of the radiation was 40° below the horizontal. Also, as the height 'Ht' of the IFA was increased, the mutual coupling

(Active S) between them was dominant requiring larger length of the poles for resonating at 435 MHz.

In order to change the peak of the radiation from being below and also to minimize mutual coupling effects, the IFAs were mounted on the four sides of solar panel faces. This configuration gave the bi-directional peak which is desirable and also the mutual coupling effects were minimized, as each IFA was on a different face.

Henceforth, it was decided to mount the UHF IFAs in the center of the solar panel faces of the satellite

4.4 IFA Simulation results for 145 MHz VHF Antenna

The detailed simulation results of the 145 MHz receiver antenna are given in the Annexure A-3. The salient observations are given in this section.

The satellite edge dimension 286mm is very small (about $\lambda_r/7$) in comparison to its free space wavelength. Hence the results of the radiation patterns and return loss characteristics for the VHF antenna were observed to be different from that of the UHF antenna.

As using more than one antenna resulted in the null (due to destructive interference of two antennas radiation), the design was restricted to use only one receiver antenna.

Different orientations of the VHF antenna across the face edge, along the face diagonal were studied and the details are given in the annexure A-3.

Following are the observations summary on the IFA at 145 MHz

1. Single IFA with U bend at 145 MHz on IITMSat with Height < $\lambda_r/20$ i.e. < 100mm

    a. For the small (< $\lambda_r/20$) heights of the IFA, the radiation pattern is predominantly across the horizontal (Lr) section of the antenna i.e. it behaves like an end fire antenna.
    b. Antenna structure losses were found to be > 0.3dB
    c. However, for Hr < $\lambda_r/20$, the stub offset tuned from 1mm to 50mm gave return loss only between 2dB to 6dB. This will not meet the specification requirements for the VHF antenna of IITMSat.
    d. Parasitic coupling [3], by placing an additional inactive IFA structure closer (<$\lambda_r/10$) to the active and appropriately tuning the length and position gave the return loss better than 10dB.
    e. The return loss sweep across the 100 to 600 MHz showed a second resonance of the antenna around 435 MHz which has wide bandwidth and good return loss than at the first resonance. This will necessitate the stringent isolation

requirements of the receiver filter design to reject 435 MHz high power from being received by the receiver.

f. The small height <30mm) of the receiver antenna did not distort the omnidirectional pattern of the 435 MHz IFA radiation. However return loss achieved was not better than 2dB. This will require matching 145 MHz IFA externally using the reactive components or improve return loss by parasitic coupling. These results are given in the Final design configuration chapter-5.

2. Single IFA with U bend at 145 MHz on IITMSat with Height > $\lambda_r/20$ i.e. > 100mm

   a. For the larger (> $\lambda_r/20$) heights of the IFA, the radiation pattern is predominantly uniform across the horizontal plane i.e. it behaves like a broad fire antenna.
   b. Antenna structure losses were found to be < 0.1dB
   c. For Hr > $\lambda_r/20$, the stub offset tuned from 1mm to 50mm gave return loss better than 10 dB and up to 28dB for smaller values (<10mm) of the offset.
   d. Parasitic coupling [3], by placing an additional inactive IFA structure closer (<$\lambda_r/10$) to the active IFA and appropriately tuning the length and position gave the return loss better than 10dB.
   e. The return loss sweep across the 100 to 600 MHz showed a second resonance of the antenna around 435 MHz which has wide bandwidth but poor return loss than at the first resonance. This will relax the stringent isolation requirements of the receiver filter design to reject 435 MHz high power from being received by the receiver.
   f. The larger height (>75mm) of the receiver antenna distorts the omnidirectional pattern of the 435 MHz IFA radiation. A near symmetric pattern for the 435 MHZ IFAs can be obtained by placing an inactive 145 MHz structure (parasitic coupling to Rx antenna) on the opposite face edge of the satellite. The detailed design is provided in the Final design configuration chapter-5.

CHAPTER-5

Final Design Configurations

After the detailed study on the radiation patterns of the UHF IFA and VHF IFA, following configurations have been finalized for fabrication and testing. Four design options are provided which shall be tested and the best one after doing trade off analysis w.r.t. link budget, mass and structural rigidity will be finalized for the flight model.

5.1 Design-1a: 105mm Receiver Antenna without Parasitic Coupling

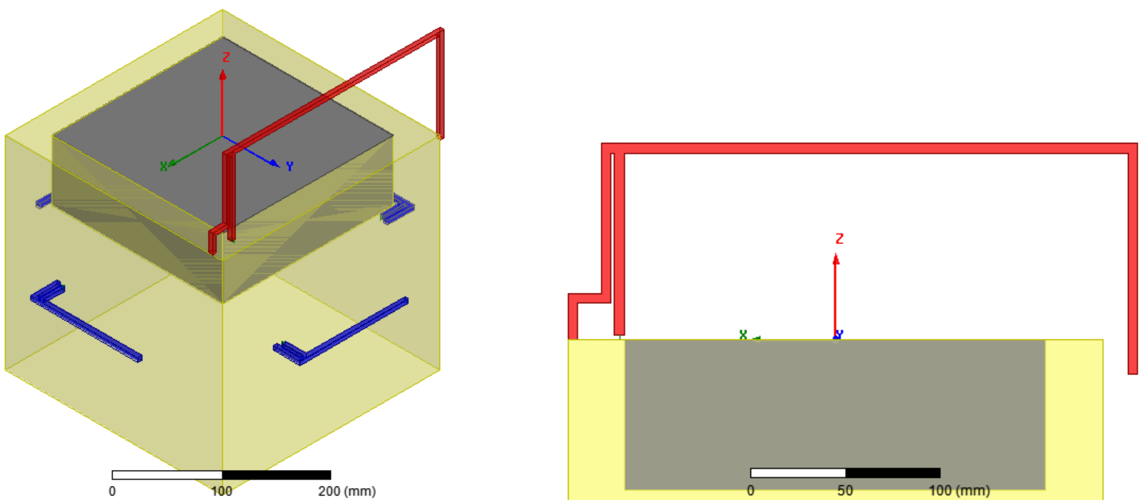


Fig-5.1: Design 1a configuration and the front view of the 105mm VHF IFA

5.1.a: 145 MHz Receiver Antenna Design-1a

In this configuration, the height of the receiver is chosen to be 105mm which gives a good return loss of 24dB at 145 MHz for a stub offset of 2mm. The stub is bent at the bottom to provide 20mm space for easily mounting the connector. The radiation patterns and return loss plots are given below.

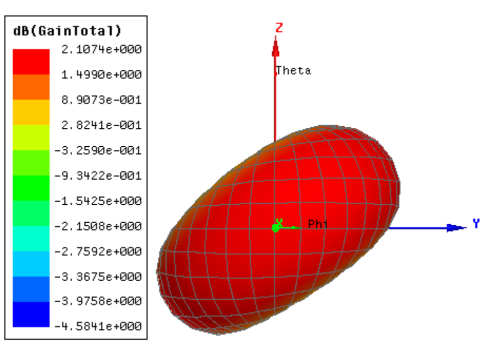


Fig-5.2: 3D Polar Radiation plot for 145MHz IFA

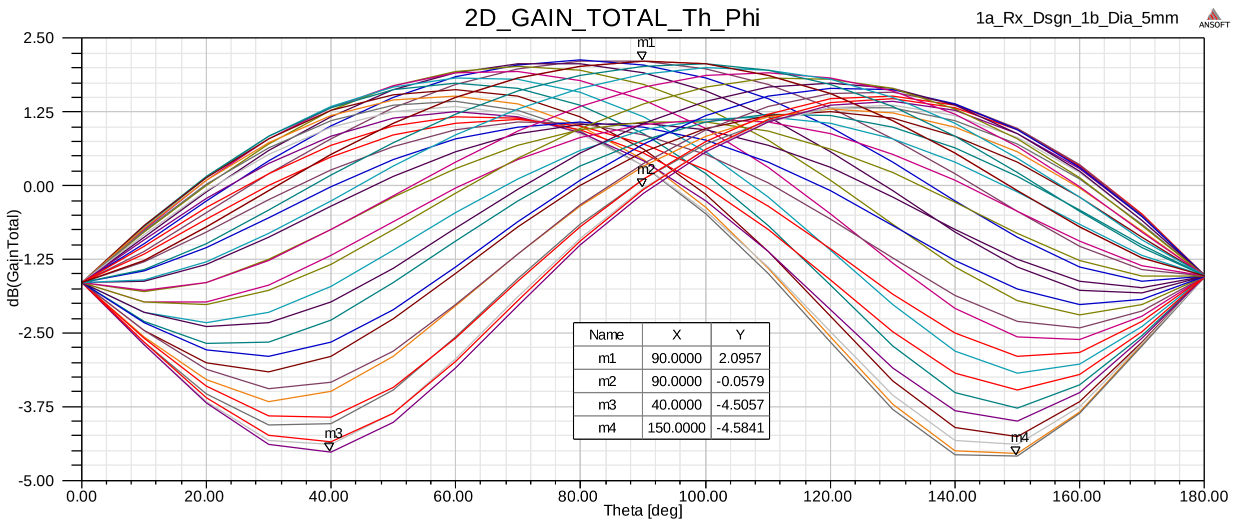


Fig-5.3: 2D Rectangular Radiation plot for 145MHz IFA Design-1a

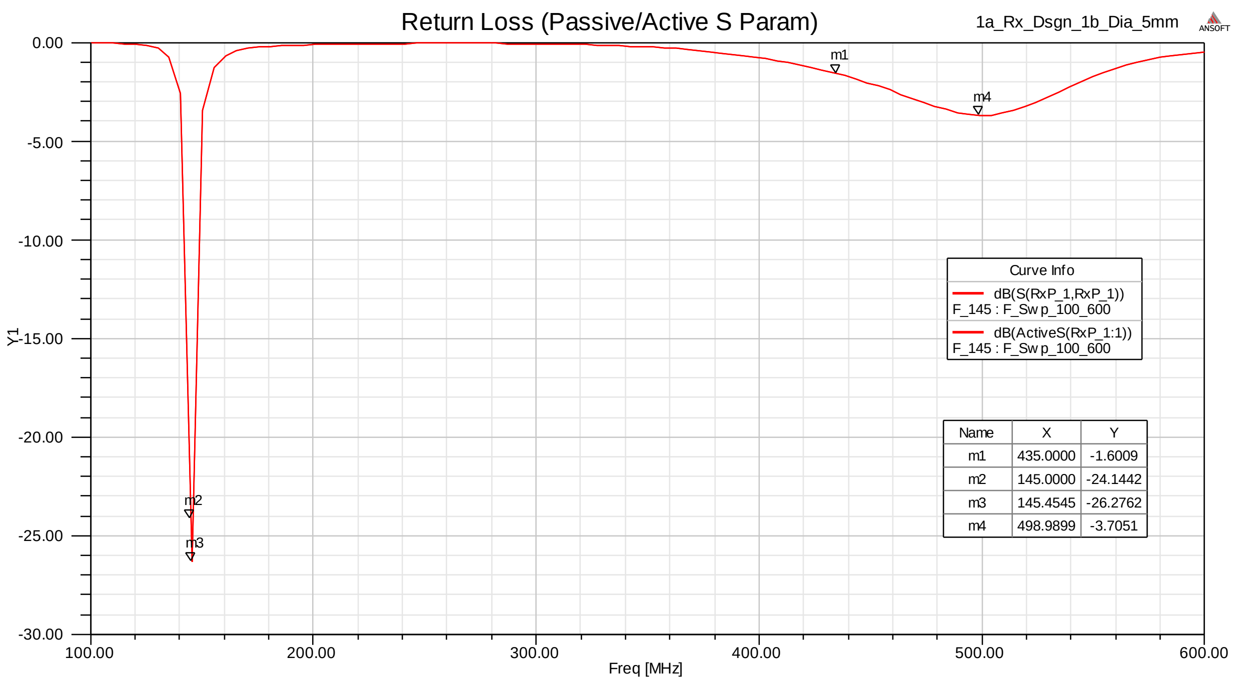


Fig-5.4: 2D Rectangular Return Loss plot for 145MHz IFA Design-1a

5.1.b: 435 MHz Transmitter Antenna Design-1a

In this configuration, four UHF IFAs are mounted at the centers of the solar panel faces with the height ‘Ht’ being 35mm. The stub offset is set to 3mm. We get a symmetrical radiation pattern if the Receiver Antenna structure was not present. However, the tall receiver antenna is distorting the radiation pattern of the 435 MHz transmission. The plots are given below.

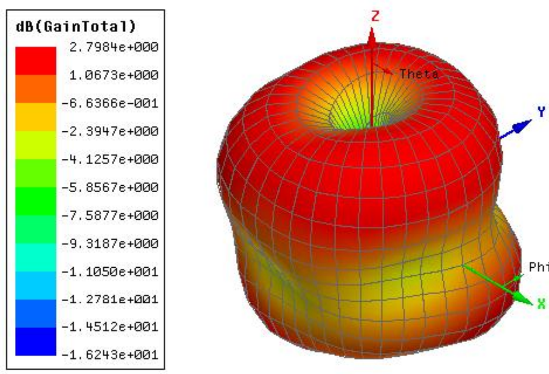


Fig-5.5: 3D Polar Radiation plot for 435 MHz IFAs Design-1a

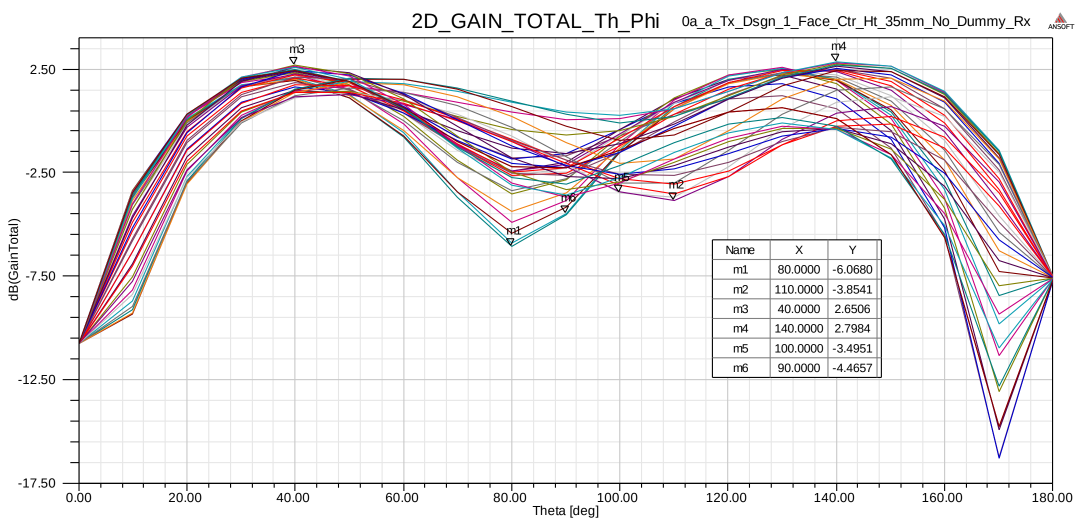


Fig-5.6: 2D Rectangular Radiation plot for 435 MHz IFAs Design-1a

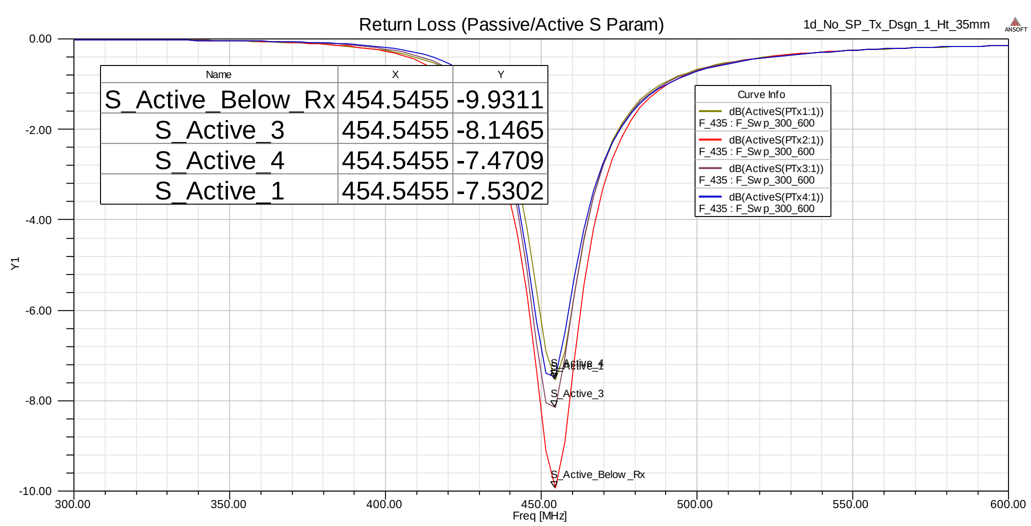
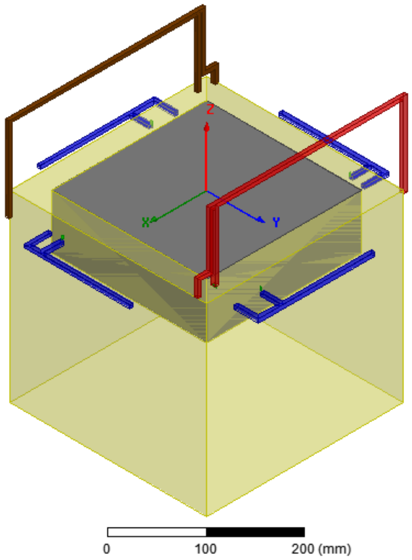


Fig-5.7: 2D Rectangular Return Loss plot for 435MHz IFA Design-1a

5.2 Design-1b: 105mm Receiver Antenna with Parasitic Coupling

In the design-1a, it was observed that the 435 MHz radiation pattern was distorted due to the presence of tall receiver antenna. Simulation studies revealed that this distortion can be minimized by placing an inactive receiver antenna structure on the face opposite to the active receiver antenna on the satellite. The details are as given below.



- Red color structure is Active Rx Antenna
- Brown structure is the inactive receiver antenna
- Four no's of blue structures are 435 MHZ IFAs
- Transmitter IFAs are mounted 20mm below the edge of the top face of the satellite

Fig-5.8: Design 1b with the inactive receiver antenna

5.2.a: 435 MHz Transmitter results for design-1b

The presence of inactive receiver antenna has improved the otherwise distorted radiation pattern of the transmitters IFAs as shown below.

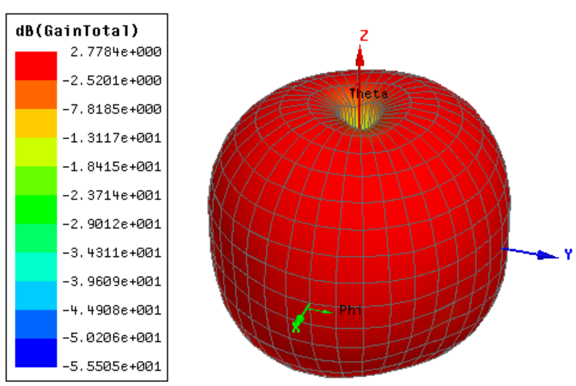


Fig-5.9: 3D Polar Radiation plot for 435 MHz IFAs Design-1b

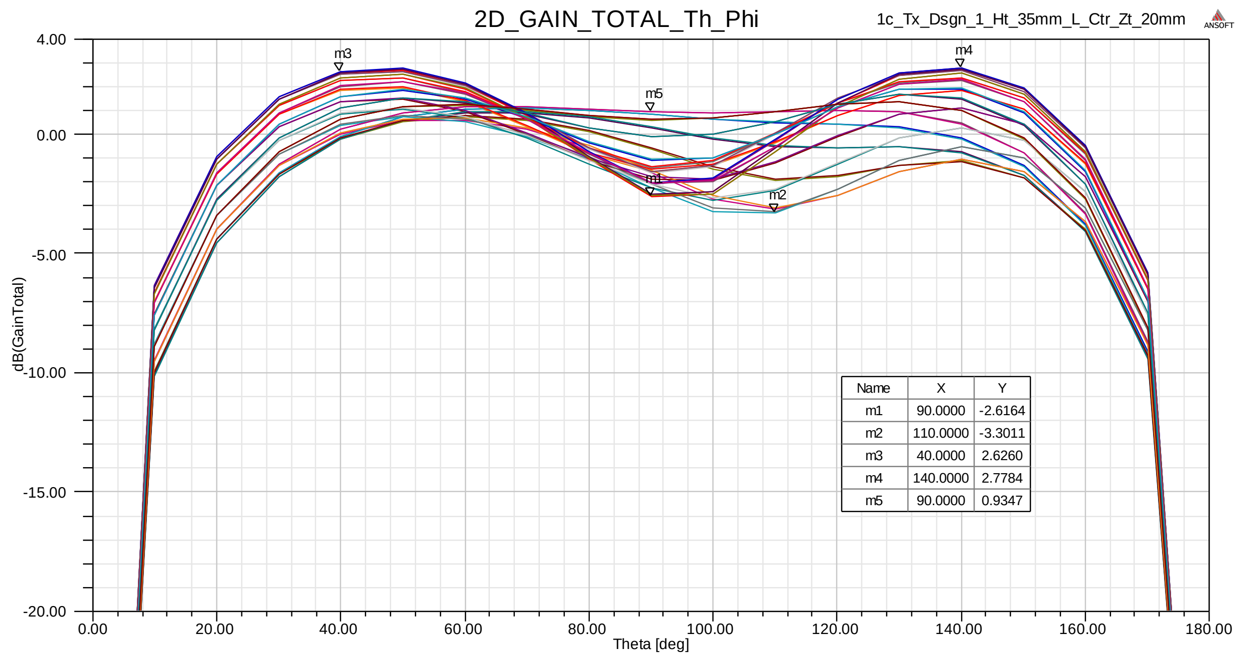


Fig-5.10: 2D Rectangular Radiation plot for 435 MHz IFAs Design-1b

5.2.b: Summary of observations in Design-1a and 1b:

1. 105mm tall receiver antenna at 145 MHz with 2mm stub offset gives the good return loss and satisfactory radiation pattern that meets the link margin requirements.
2. However, the tall antenna distorts the omnidirectional radiation pattern of the transmitter antenna.
3. Placing an inactive receiver antenna on the opposite side of the satellites face makes the transmission radiation pattern nearly symmetrical, when the antennas are shifted to 20mm below the top face instead of being at the center.

However, these designs-1a and 1b were not suitable for the IITMSat project due to the following reasons.

1. Tall active receiver antenna and the inactive receiver antenna on the satellite edges were found to obstruct the sun sensor visibility on the satellite. Hence it was recommended to reduce the height of the antenna.
2. Need for inactive receiver structure increase the mass onboard satellite.
3. Structural analysis for natural Eigen modes revealed that 3mm CS of the poles has resonance frequency below 90 Hz which is not acceptable by the launch vehicle. To shift the natural frequencies above 100 Hz, the min CS should be 5mm.

4. Also, the tall antenna requires the additional spacers made of dielectric for structural support to sustain the high levels of vibration during the launch.

Due to these reasons, the design configuration of IITMSat was modified by reducing the height of the receiver to 30mm instead of 105mm. The details of the modified design are provided below.

5.3 Design-2a: 30mm Receiver Antenna without Parasitic Coupling

A 30mm tall receiver antenna is mounted at the face edge of the satellite as shown in the figure below. This shorter antenna is not distorting the transmission radiation pattern much.

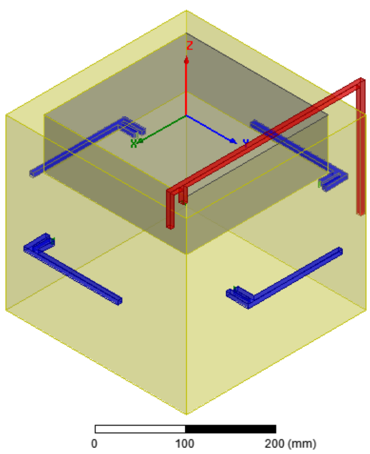


Fig-5.11: Design 2a with the 30mm receiver antenna

5.3.a Design-2a: 435 MHz transmitter antenna characteristics

Simulation results showed that the 435 MHz transmission radiation pattern is nearly omnidirectional in the horizontal plane and has a bidirectional peak suitable for the IITMSat mission. The active return loss achieved is better than 15 dB for all ports at 435 MHz

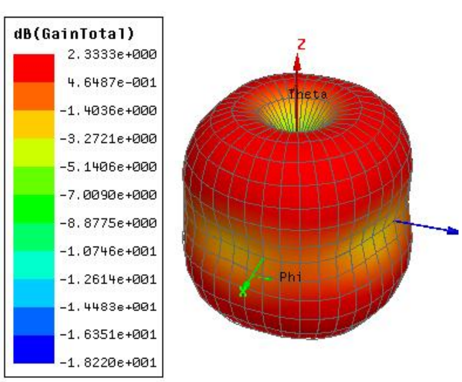


Fig-5.12: Design 2a 435 MHz radiation pattern

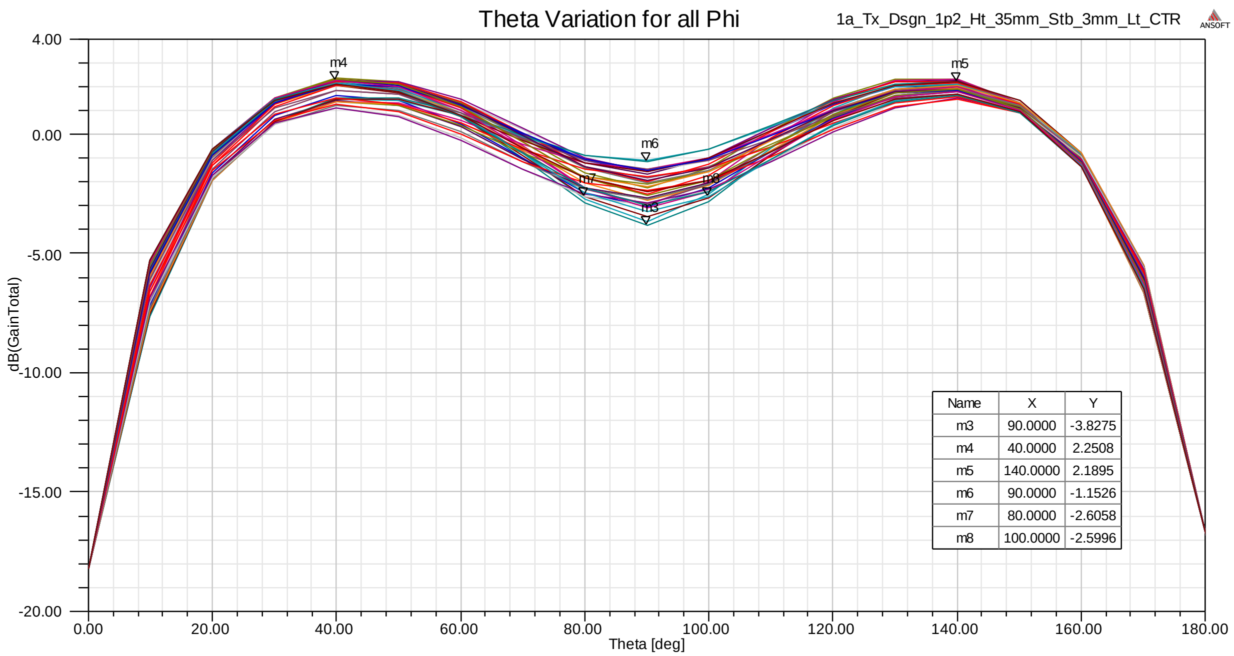


Fig-5.13: 2D Rectangular Radiation plot for 435 MHz IFAs Design-2a

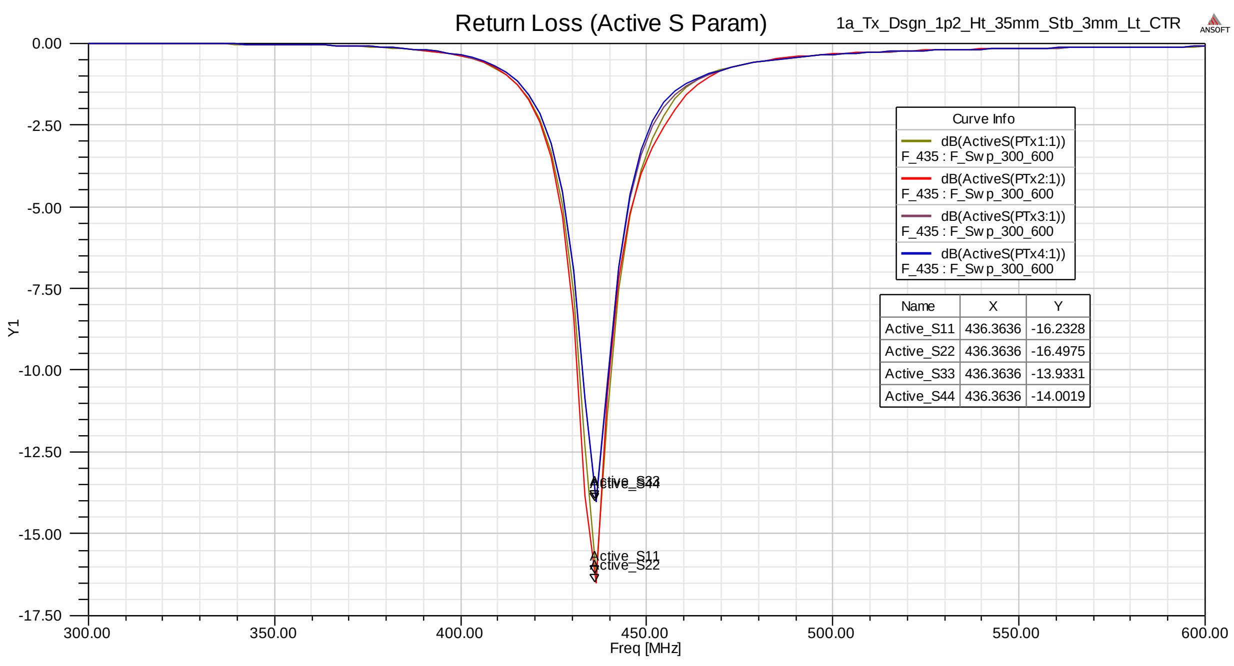


Fig-5.14: 2D Active Return Loss for 435 MHz IFAs Design-2a with stub offset 3mm

5.3.b Design-2a: 145 MHz Receiver antenna characteristics

Simulations showed that with a shorter receiver antenna the return loss achievable at 145 MHz is only about 2dB. Also the second resonance (around 435 MHz) gives a good return loss which is undesirable as it puts stringent requirements on the receiver filter design. Also, as the return loss at 145 MHz is poor, the antenna has to be matched externally using the reactive elements.

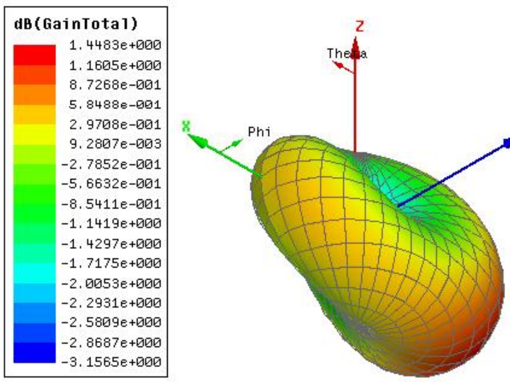


Fig-5.15: 3d Polar Plot for Rx Antenna Design-2a

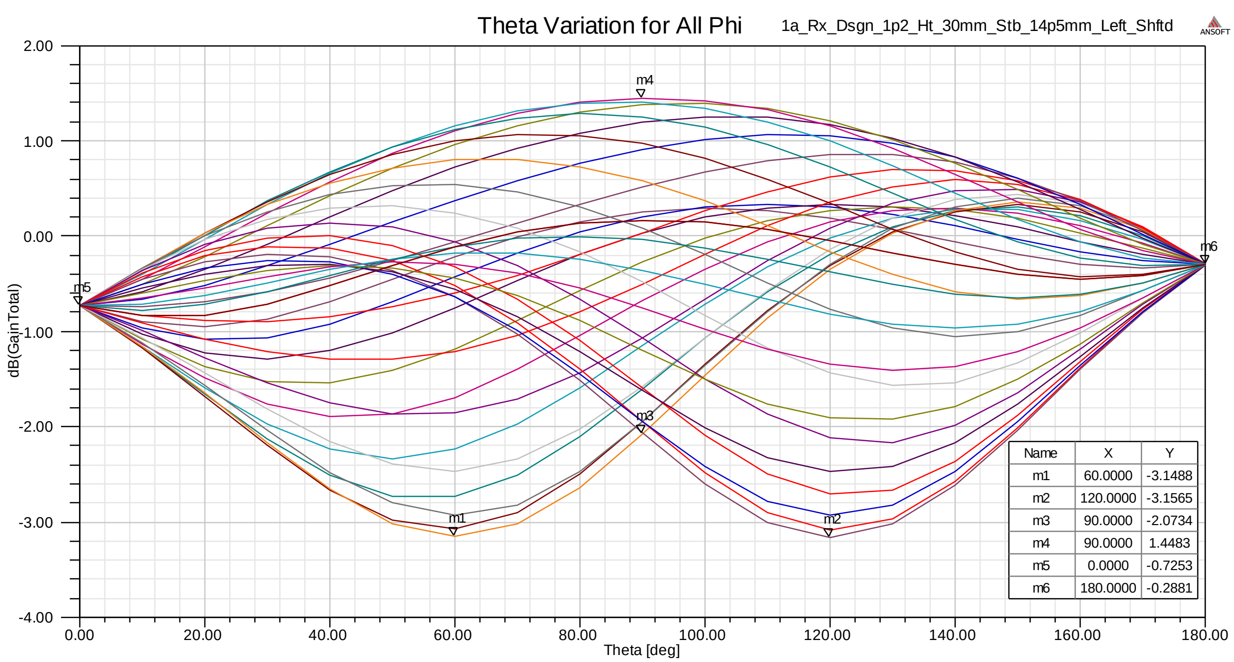
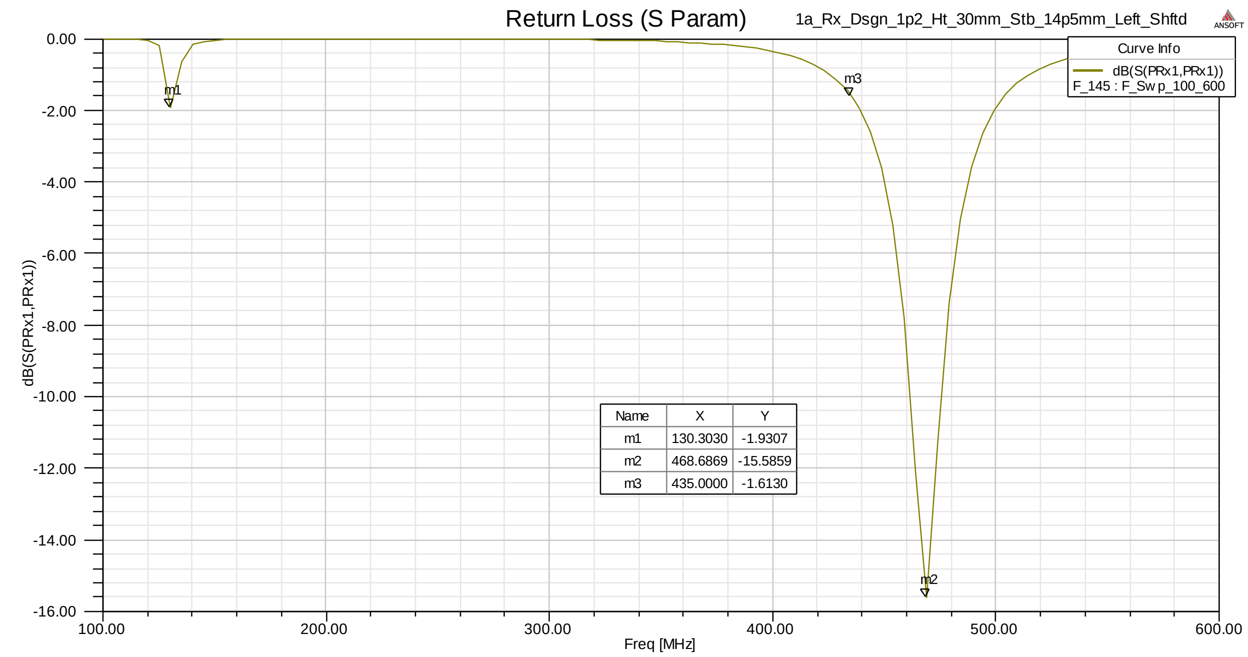


Fig-5.16: 2D Rectangular Radiation plot for 145 MHz IFA Design-2a

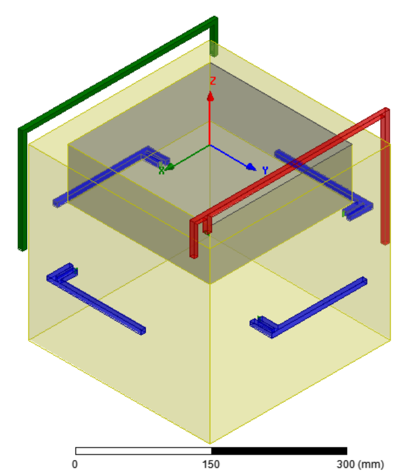


Name	X	Y
m1	130.3030	-1.9307
m2	468.6869	-15.5859
m3	435.0000	-1.6130

Fig-5.17: 2D Return Loss plot for 145 MHz IFA Design-2a with stub offset 14.5 mm

5.4 Design-2b: 30mm Receiver Antenna with Parasitic Coupling Element

The poorer (< 2dB) return loss with a shorter height of the receiver antenna can be improved using an inactive structure with parasitic coupling to the active antenna [3]. The design-2a was added with an inactive antenna structure as shown in the figure below.



- Red color structure is Active Rx Antenna
- Green structure is the inactive receiver antenna parasitically coupled to active Rx
- Four no's of blue structures are 435 MHz IFAs
- Transmitter IFAs are mounted at the centers of the solar panel faces of the satellite

Fig-5.18: Design 2b - 30mm receiver antenna with parasitic coupling

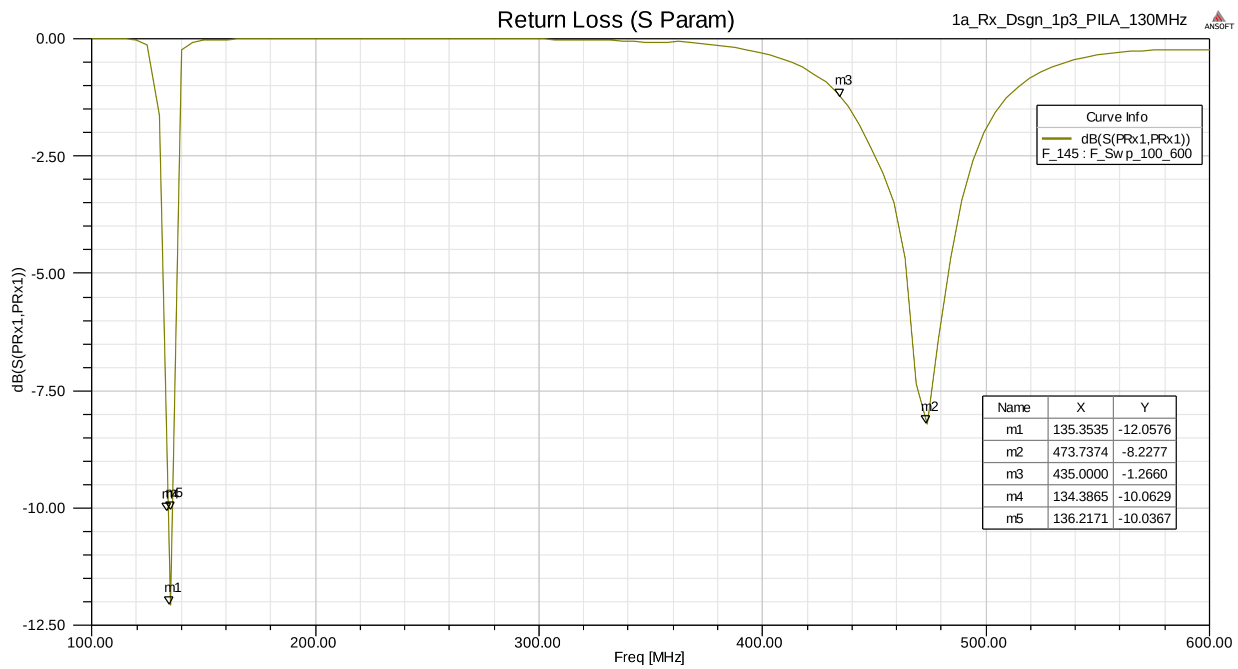


Fig-5.19: 2D Return Loss plot for 145 MHz IFA Design-2b with stub offset 14.5 mm

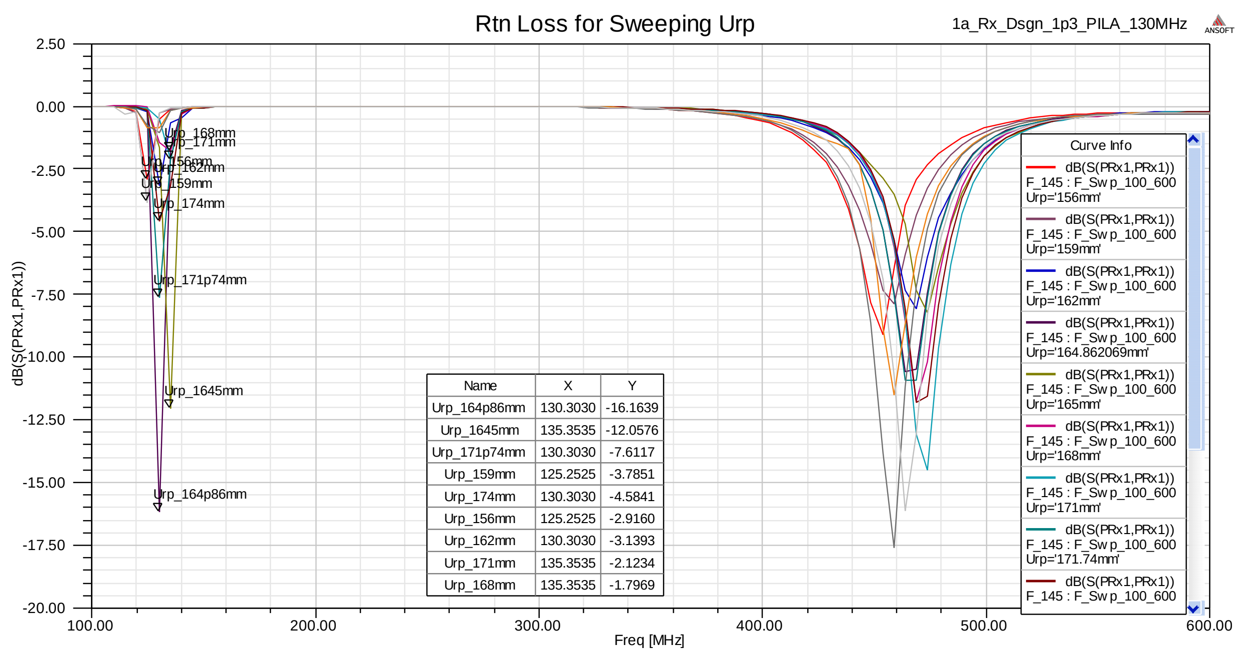


Fig-5.20: 2D Return Loss sensitivity plot for 145 MHz IFA Design-2b with U length of the parasitic element varied from 159 mm to 174 mm

The parasitic coupling can give good return loss as high as 16dB, as seen in figure 5.19. However, it is highly sensitive to the length of the parasitic element. Figure 5.20 gives the sensitivity plot of the return loss as the length of the parasitic element is varied from 159mm to 174 mm. It can be seen that both the return loss and the resonant frequency vary with the length of the parasitic element. Hence practically, one has to tune the coupling element length with care.

5.5. Summary of Design variations proposed

5.5.1. Design-1a: 105 mm Receiver Antenna without inactive element

- Receiver antenna at 145 MHz
    - Acceptable radiation pattern
    - 24dB return loss with stub offset 2mm (Antenna Impedance = 65.33+ j2.92 ohms)
- 435 MHz transmitter antenna
    - Radiation pattern is distorted due to tall Rx antenna.
    - Return loss > 10dB achieved with stub offset 3mm.

5.5.2. Design-1b: 105 mm Receiver Antenna with inactive element

- Receiver antenna at 145 MHz
    - Acceptable radiation pattern
    - >15 dB return loss with appropriate stub offset
- 435 MHz transmitter antenna
    - Radiation pattern is nearly symmetrical and acceptable
    - Return loss > 15dB achieved with stub offset 3mm.

Both designs-1a and 1b not suitable for IITMSat project as the Rx antenna is obstructing the sun sensor field of view and also increase in the mass of the satellite due to structural requirements.

5.5.3. Design-2a: 30 mm Receiver Antenna without inactive element

- Receiver antenna at 145 MHz
    - Acceptable radiation pattern

    - <2dB return loss with stub offset 14.5mm; requires external matching. (Antenna Impedance = 0.22 + j10.19 ohms)
- 435 MHz transmitter antenna
    - Radiation pattern is not affected with the presence of receiver antenna and is acceptable as it gives bi-directional peaks.
    - Return loss > 15dB achieved with stub offset 3mm.

5.5.4. Design-2b: 30 mm Receiver Antenna with inactive element coupling

- Receiver antenna at 145 MHz
    - Acceptable radiation pattern
    - >10 dB return loss with appropriate stub offset and parasitic length
- 435 MHz transmitter antenna
    - Radiation pattern is nearly symmetrical and acceptable
    - Return loss > 15dB achieved with stub offset 3mm.

CHAPTER-6

ANALYSIS OF FINITE GROUND EFFECTS ON ANTENNAS

For the quarter wave antenna placed at the center of the satellite cube on the top face, it was observed in the simulation that the peak of the radiation was 40° below the 90° elevation angle. However, for the Monopole on an infinite ground plane, the peak of the radiation occurs at 90° elevation, which is the broad side w.r.t. antenna.

In this chapter, an attempt has been made to understand the reason for the occurrence of the peak of the radiation below the horizontal. It can be explained using the geometrical theory of diffraction from the edge and surface.

6.1. Geometrical theory of Diffraction

The geometrical theory of diffraction is an extension of geometrical optics which accounts for diffraction. It introduces diffracted rays in addition to the usual rays of geometrical optics. These rays are produced by incident rays which hit edges, corners, or vertices of boundary surfaces or which graze such surfaces. A field is associated with each ray and the total field at a point is the sum of the fields on all rays through the point. The initial value of the field on a diffracted ray is determined from the incident field with the aid of an appropriate diffraction coefficient.

In [4], it was shown that the diffraction coefficient of the field from the edge of length ‘a’ for a magnetic line source is given by

$$\frac{Ed(\Psi)}{Ei(\Psi)} = \frac{1}{2}\,\frac{Csc\left(\frac{\Psi}{2}\right)}{\sqrt{2\pi\beta a}}\;e^{-j\pi/4},\quad \Psi \neq 0;$$

$$= \tfrac{1}{2} \quad \text{for } \Psi = 0; \qquad (1)$$

Where E_d is the diffracted field

E_i is the incident field

Ψ is the angle below the edge from the horizontal

‘a’ is the edge length

Observe that the equation (1) is dependent on the dimension of the edge ‘a’, and as it approaches infinity, the diffracted field (from Infinite ground plane) tends to zero for $\Psi \neq 0$.

6.2. Monopole on a finite circular ground plane

Consider a monopole on a finite PEC circular ground plane of radius 'a'. Using the principle of superposition, the radiation pattern in any plane containing the monopole consists of the monopole pattern plus the patterns of the edge-diffracted signals when added in the proper relative phase. Fig-6.1 shows the corresponding radiation patterns for each component in a plane[4].

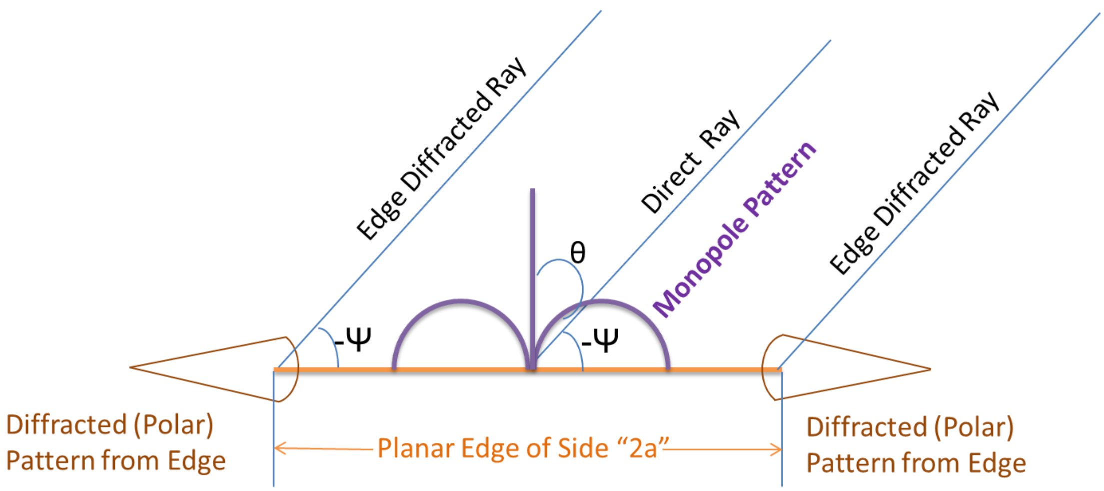


Fig-6.1: Individual radiation pattern components of the Monopole and the fields diffracted from the edges ……from [4]

The problem is reduced to the superposition of the fields of three sources separated in space, and having different radiation patterns. The monopole is next considered to act as a transmitting antenna which excites a uniform radial wave in the azimuth plane that diverges in the elevation plane. The circular edge acts as a target which reflects a uniform radial wave in the azimuth plane that also diverges in the elevation plane as it converges on the monopole.

In [2], the radiation patterns were analyzed for the different values of 'a' as shown in the figure 6.2 below. It is evident that for a finite circular ground size, the angle of peak radiation is at 50° for 1λ radius of the ground size, 75° for 10λ and it slowly converges to 90° as the ground size approaches infinity. Same results are applicable [2] to the square ground plane of equal area as the circular disc.

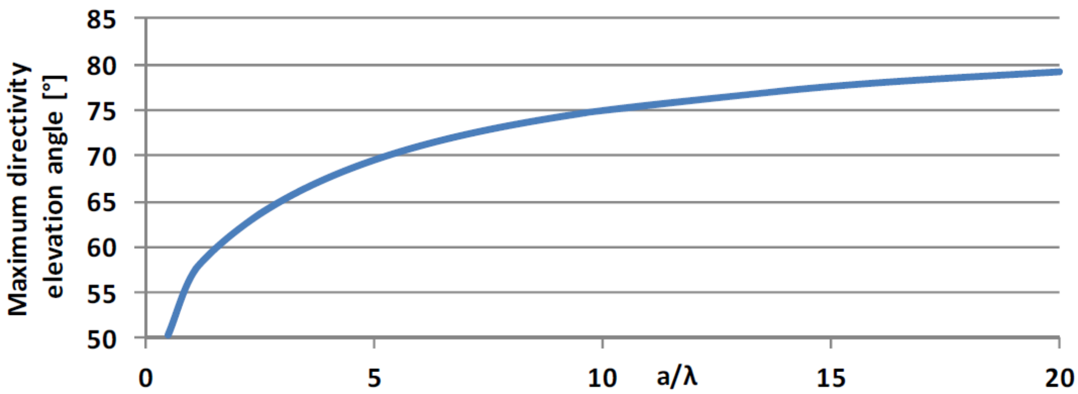


Fig-6.2: Angle of Peak Radiation Vs. relative Ground Size ……from [2]

6.3 UHF Quarter wave on the IITMSat Structure:

The 435MHz Quarter wave pole on the IITMSat structure mounted in the center (without payload material) has shown the peak of the radiation to be 40° below the horizontal. It is equivalent to mounting a monopole on a finite (λ_t/2.4) small (41% of λt) cuboidal ground plane.

As per the concepts in sections 6.1 and 6.2, this problem can be analyzed by applying the geometrical theory of diffraction from the edges (top face) and also diffraction of the fields grazed on the surface (along -Z) of the vertical faces of the satellite and the bottom face.

The total field is the superposition of the edge diffracted fields and the surface grazed fields and the field of the monopole on an infinite ground plane.

Though no exact theoretical solution is attempted to this problem, it has been observed in the simulations (see fig-3.4) that the peak of the radiation changes its angle as we increase the size of the top face ground plane. This could be due to the reduction in the diffraction of the surface grazed field with the increase in the ground size. i.e. as the size of the ground is increased, the peak of the radiation shifts upwards as per the figure-6.2.

Conclusion

The IITMSat design requirements and specifications have been precisely brought out as per the requirements of the project. The project limitations and constraints were understood clearly and the antennas were designed adhering to these constraints.

The simulator results were validated by comparison with the antenna properties for the monopole antenna with finite radius on an infinite ground plane from literature.

Initially quarter wave pole configuration was studied for IITMSat. However, as simulations showed that length of the poles should be 205mm because of the mutual coupling and as the peak of the radiation was 40° below the horizontal, this configuration was dropped from considering for IITMSat Project.

The design configuration using IFA at 435 MHz and 145 MHz was studied and found that placing the four IFAs at the centers of the solar panel faces of the satellite gives a desirable bi-directional peak radiation pattern.

The receiver antenna configuration using IFA and an additional U bend was studied on IITMSat using single and two antennas. As the two antennas were giving nulls in axial directions, the design was limited to use a single antenna only. Simulations showed that the height of the receiver antenna should be at least 100mm to achieve return loss > 10dB with appropriate stub offset.

Finally, four design configurations were proposed for the IITMSat project. The merits and de-merits of each configuration has been studied in detail.

An attempt has been made to theoretically understand the finite ground effects on the antenna radiation patterns using the geometrical theory of diffraction.

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[1] Ramo and Whinnery – Fields and Waves for Communication Systems PP-602-603 ; John Wiley and Sons, New York

[2] Zlatko, Damir, Christof Bodendorf, Jacek Skrzypczynski, Antonio "Radiation pattern and impedance of a quarter wavelength monopole antenna above a finite ground plane" IEEE Transactions on Antenna and Propagation

[3] Andrew T. Gobien, "Investigation of Low Profile Antenna Designs for Use in Hand-Held Radios", Chapter-3, pp:50 - 84, M.S. Thesis 1997, Virginia Polytechnic Institute and State University

[4] Alfred R Lopez, "The Geometrical Theory of Diffraction Applied to Antenna Pattern and Impedance Calculations" IEEE Transactions on A&P, January 1966

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[6] Joseph B. Keller, "Geometrical Theory of Diffraction", Journal of the Optical Society of America, volume 5, Number 2, February, 1962

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[8] Timothy Pratt, Charles Bostain, Jeremy Allnut, "Satellite Communications" 2nd Edition, John Wiley and Sons, New York

APPENDIX

A1: Quarter Wave Pole Simulation Results

The Quarter wave pole on the finite cube was simulated with single pole at the center and also at the corner/face edge of the cube. The Simulation results are provided as below.

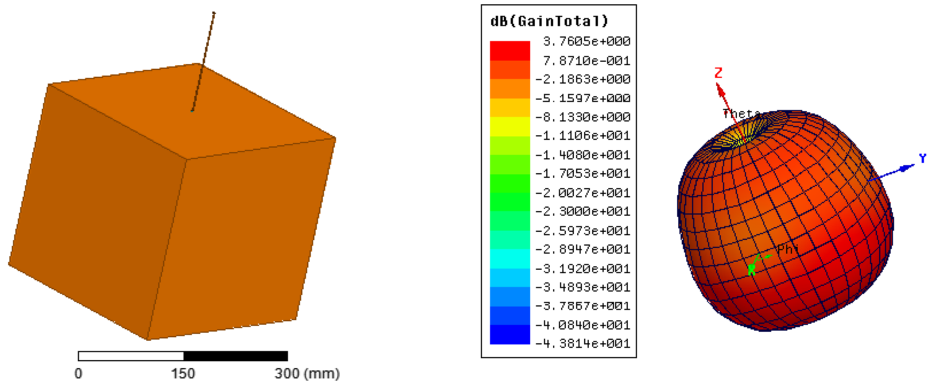


Fig-A1.1 : Single Pole at the center with its radiation pattern

The center mounted pole gives the peak of the radiation 40° below the horizontal. This is due to the diffraction of the fields at the satellite cube edges. The corner mounted pole has distorted non Omni pattern.

Simulations with the Two and three poles at the corners also showed the non-omnidirectional radiation patterns.

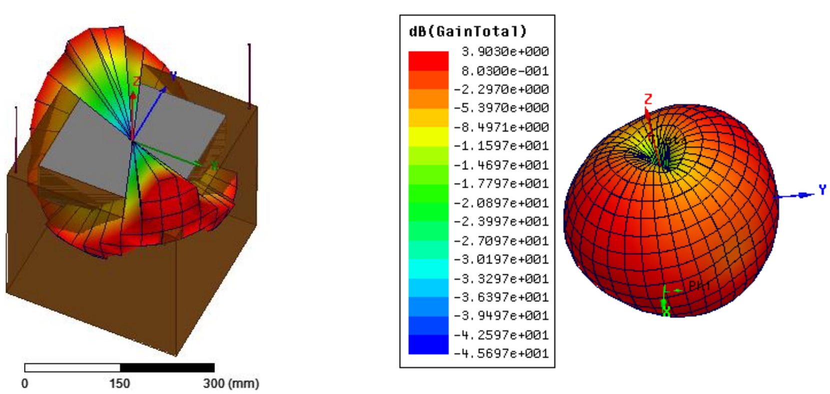


Fig-A1.2 : Two Poles at the corner with its radiation pattern

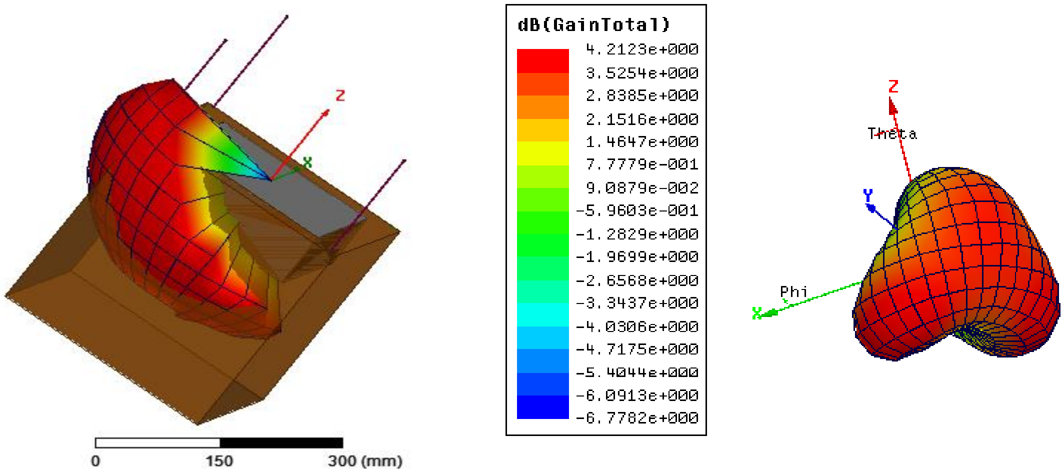


Fig-A1.3 : Three Poles at the corner with its radiation pattern

Thus either single or two or three poles at the cube corners are not suitable for IITMSat mission. Henceforth, four poles are considered for simulation

Simulation results showed that four poles in the edge corners doesnot give a proper resonance return loss characteristics. However the four poles at the face edge centers give good return loss and also omni directional radition pattern in the azimuth.

Simulations were done by tilting the poles inside and also outside, but the peak did not change its direction from 40° below.

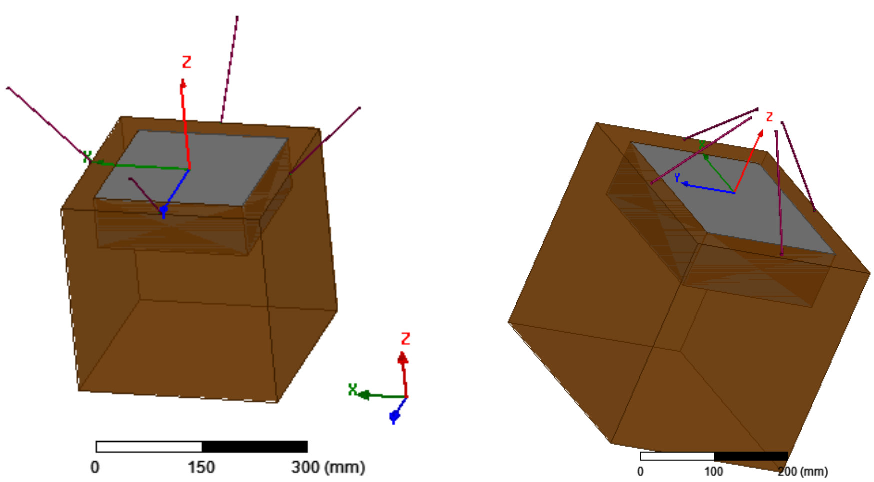


Fig-A1.4 : Pole orientations showing the tilts (inward and outward)

Insulating the ground plane of the monopoles using a 2mm Teflon sheet between the poles ground plane and the satellite top face also did not change the direction of the peak.

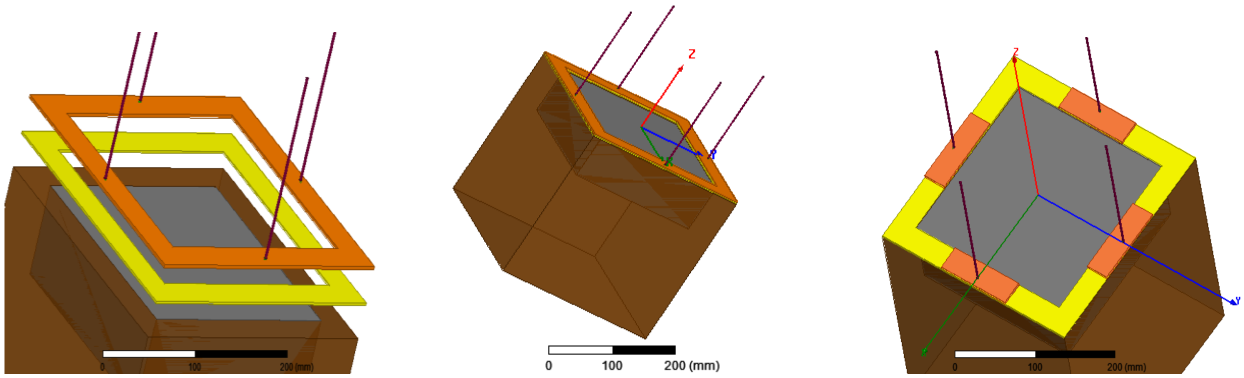


Fig-A1.5 : Insulated Ground (Top Orange) of the poles using 2mm (yellow) Teflon sheet

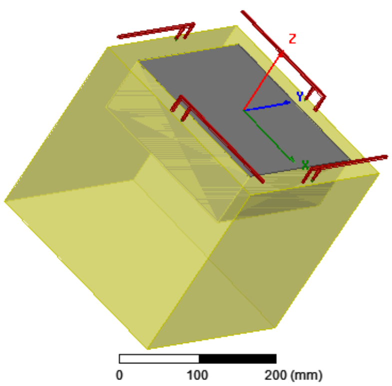
A2: IFA Simulation Results for 435 MHz UHF Antenna

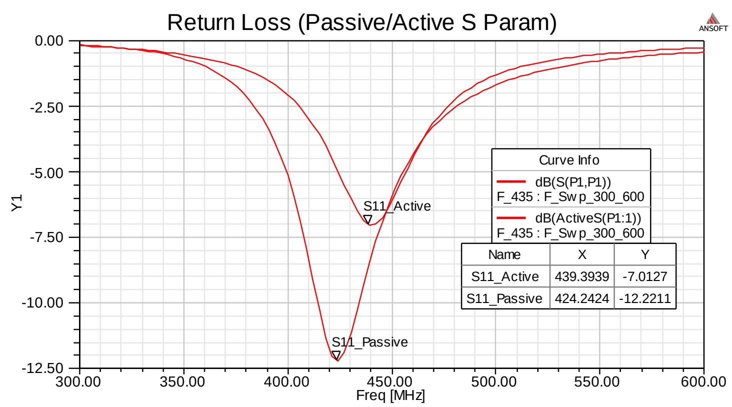
The configurations of IFAs for 435 MHz were simulated and following are the observations. When a single IFA was used on the top face of the satellite, the radiation pattern obtained was distorted and not omnidirectional in the horizontal plane. In order to obtain omni pattern, at least four IFAs have to be used along the edges of the satellite faces.

The results using the four IFAs at 435 MHz are given below briefly.

A2.1 Four 435 MHz IFAs on the Top face of the satellite

Two different cases with the Heights of the antenna being 25mm and 75 mm are given below.





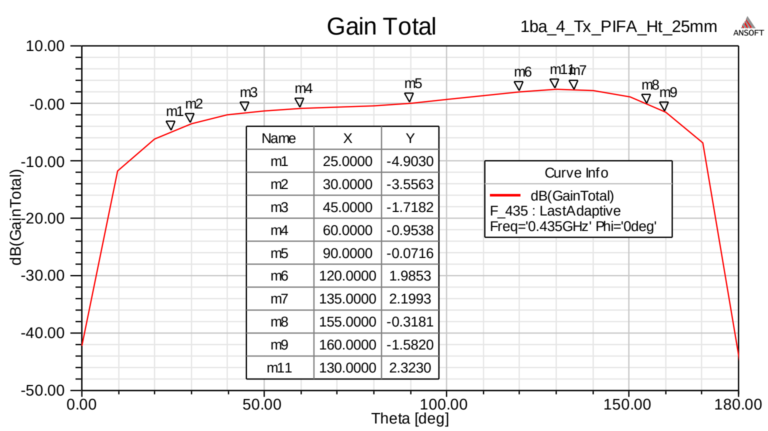


Fig-A2.1: Four IFAs on top face at 435 MHz with 25mm Ht of the each IFA

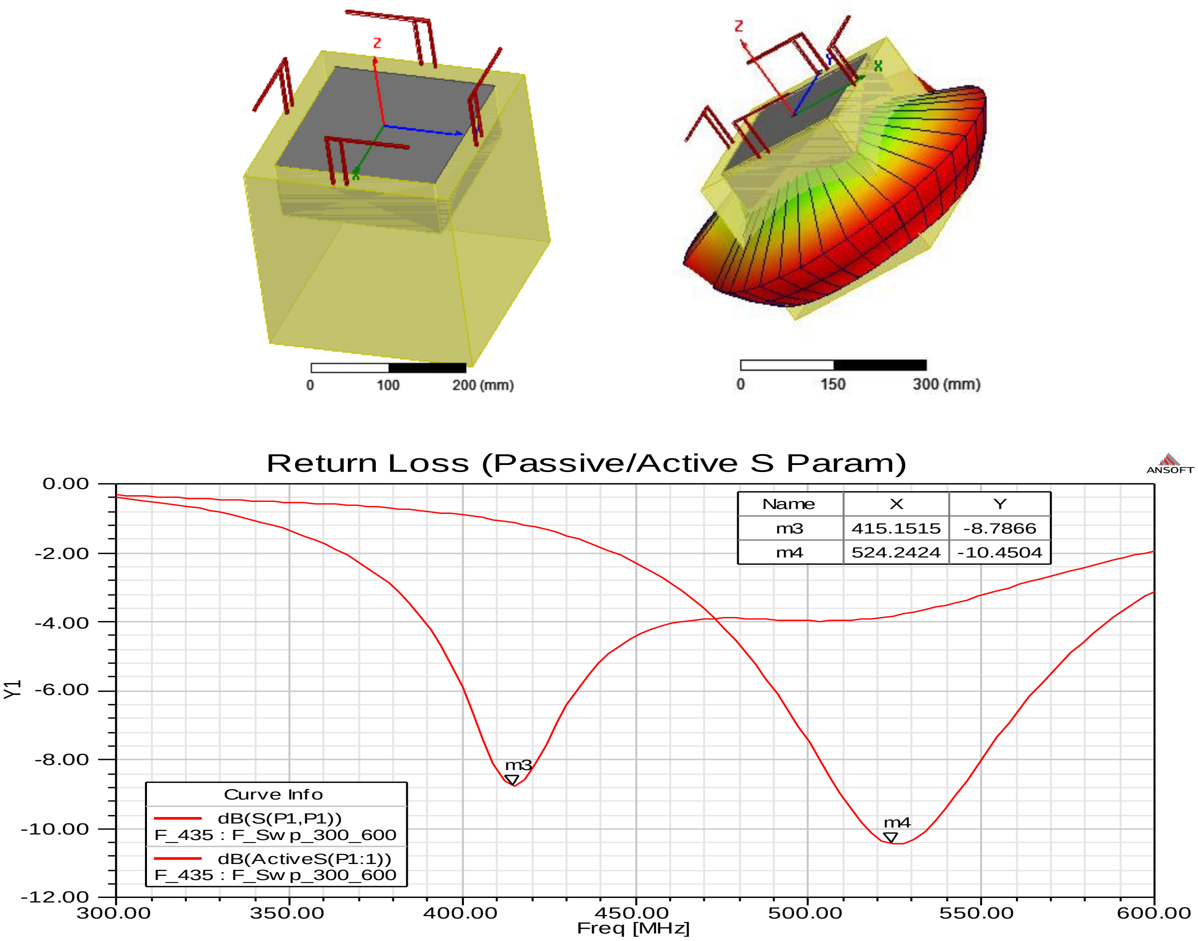


Fig-A2.2: Four IFAs on top face at 435 MHz with 75mm Ht of the each IFA

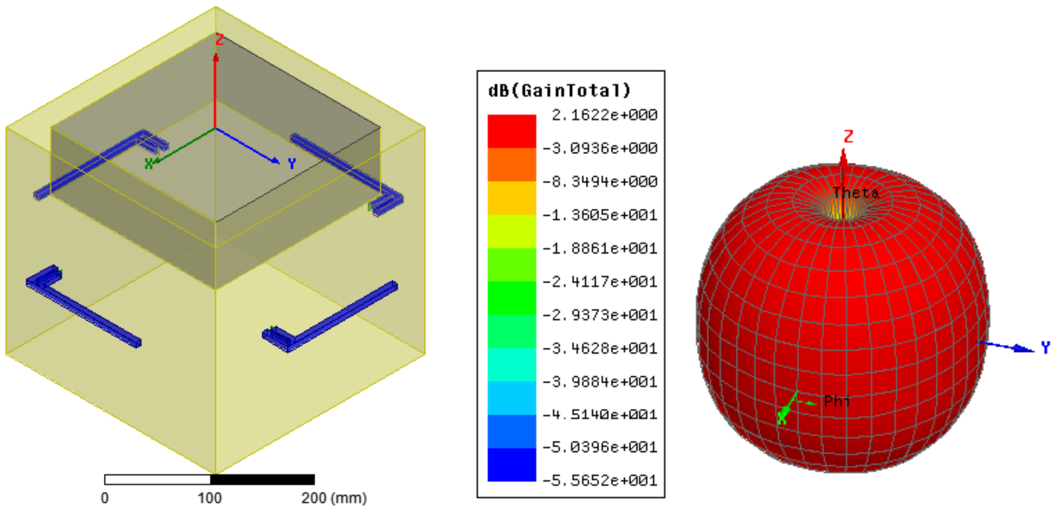
From the above two cases, it can be observed that

I. The peak of the radiation will be 40° below the horizontal if IFAs are on the top face
II. The larger height of the IFA causes the active S to be far away making it necessary to increase the length of the antenna for resonance at 435 MHz. i.e. larger the height, mutual coupling effects are more dominant.

In order to change the peak of the radiation being below and also to minimize mutual coupling effects, the IFAs are mounted as shown below on the four sides of solar panel faces. This configuration gives the bi-directional peak which is desirable and also the mutual coupling effects are minimized.

A2.2 435MHz IFAs on SP Faces with Height 35mm

A2.2.a: IFAs mounted with the horizontal segment in the center on the face



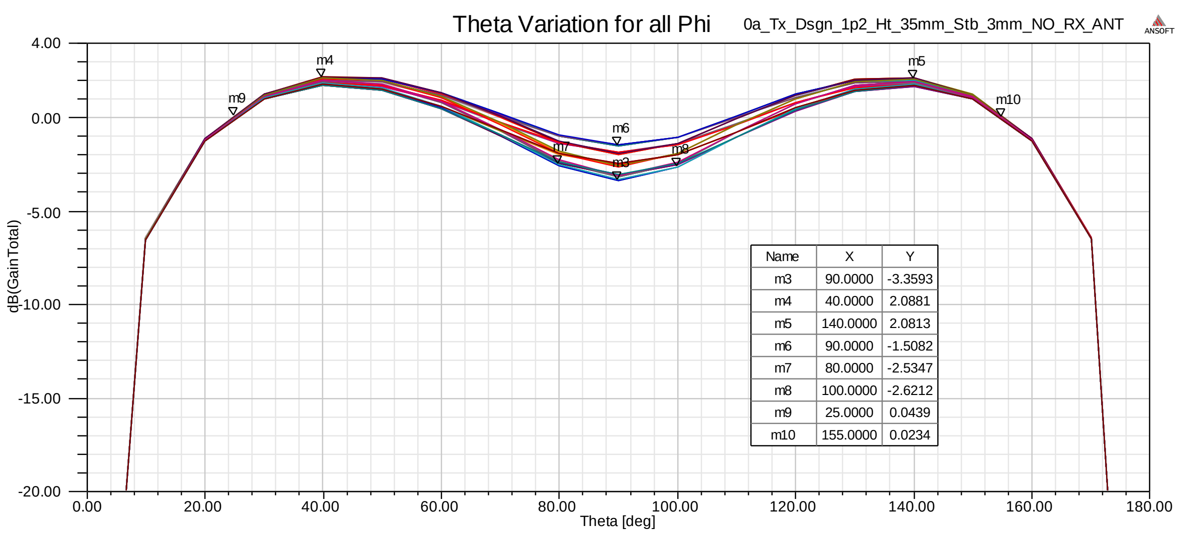
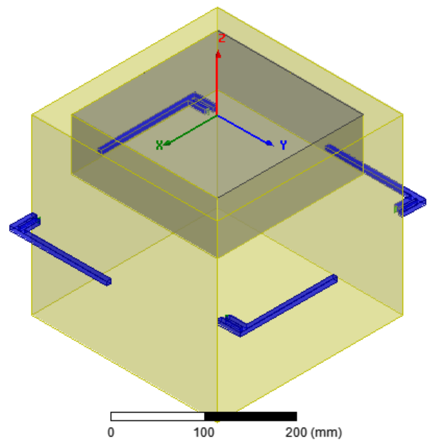
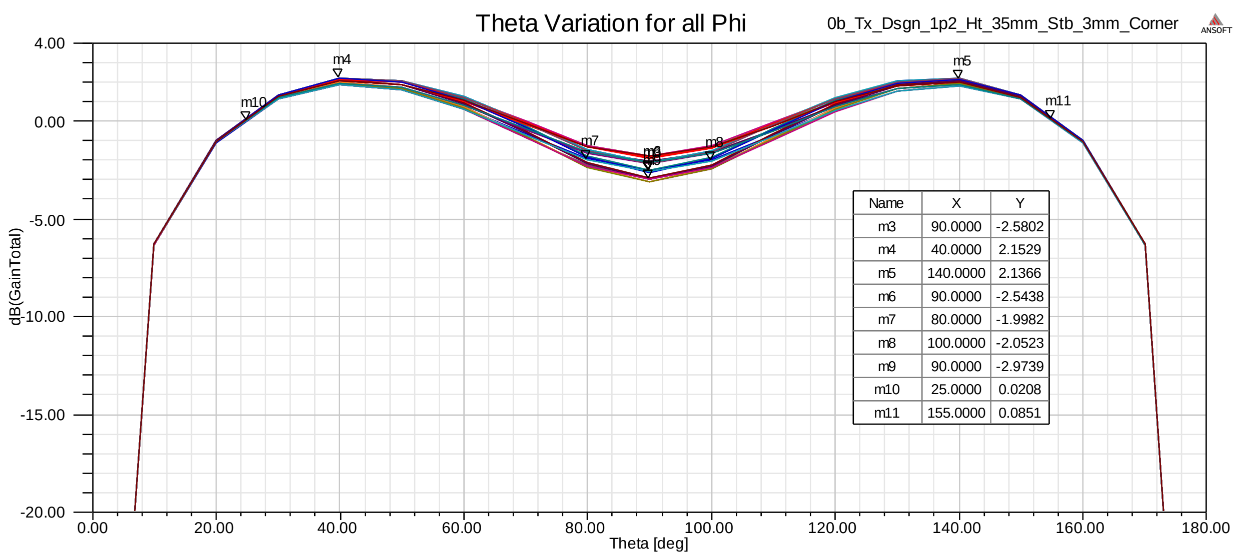


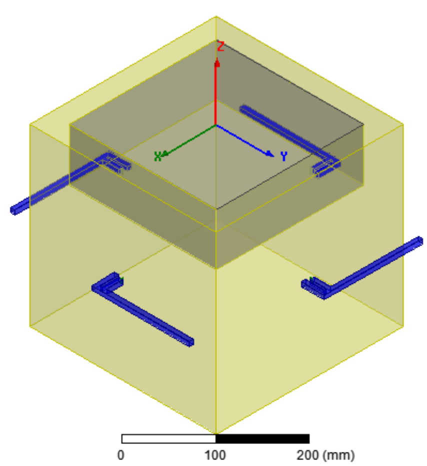
Fig-A2.3: Four IFAs on top face at 435 MHz with 35mm Ht of the each IFA

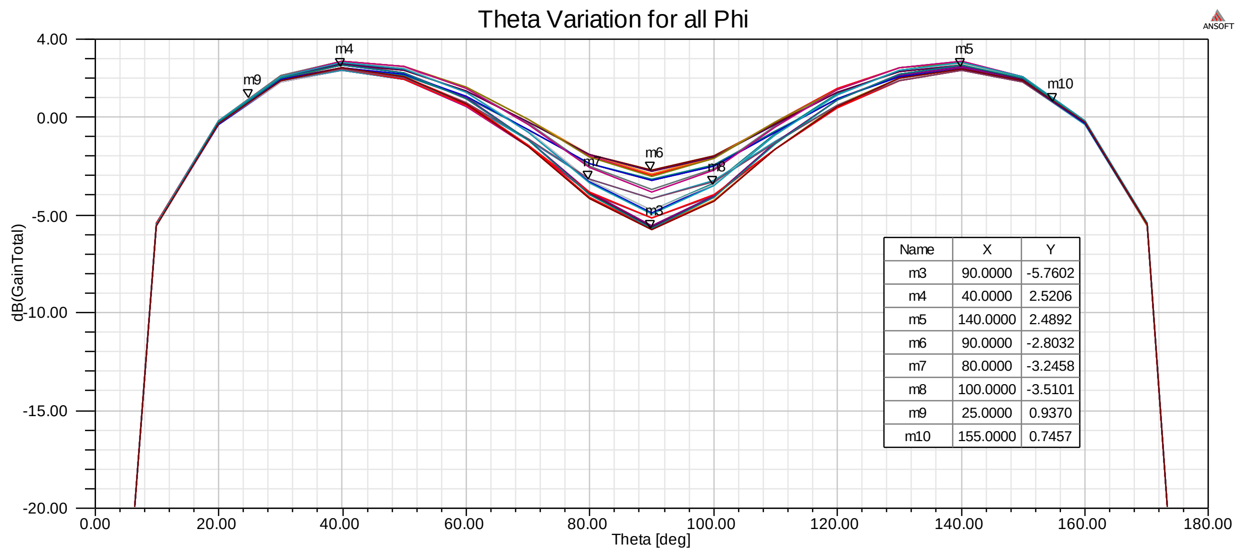
A2.2.b: IFAs mounted in the center left corner





A2.2.b: IFAs mounted with the feed in the center:



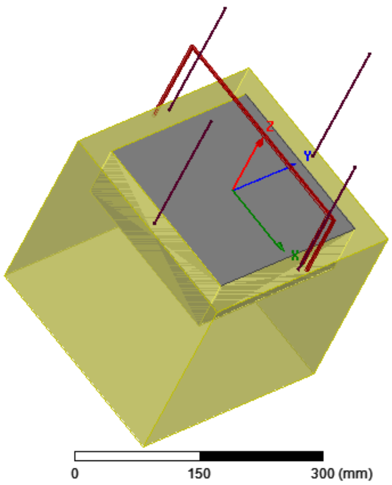


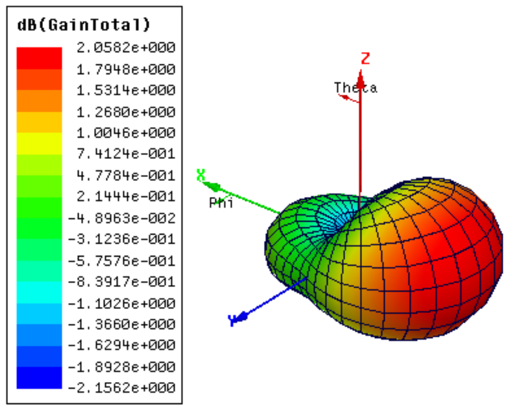
The observations from the IFAs mounted on the solar panel faces are summarized below.

1. Mounting the IFAs in the vertical centers of the face gives a bi-directional peak of the radiation
2. Each IFA being on the different face, mutual coupling is minimal and hence the active S and the passive S are closely equal. This means there will be minimal increase in length of the antenna (from lambda/4) to achieve active resonance at 435 MHz

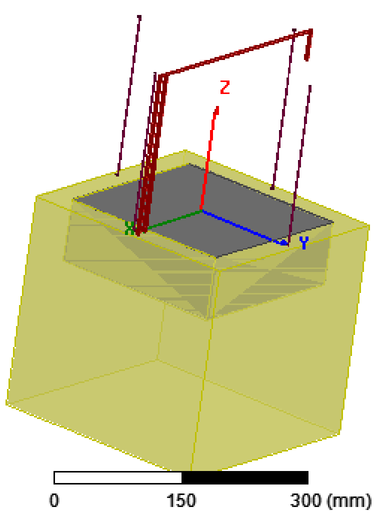
A3: IFA Simulation Results for 145 MHz VHF Antenna

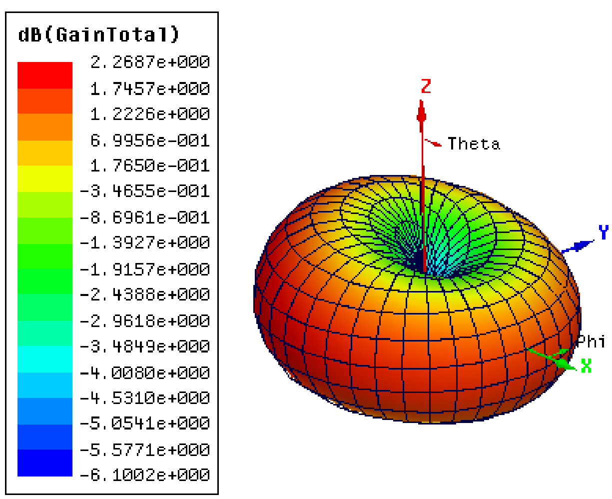
A3.1: 100mm Ht Rx IFA across the face Centre



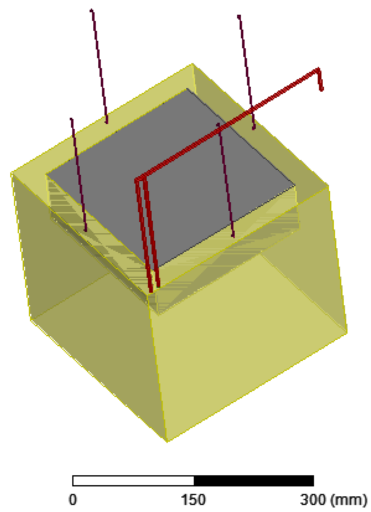


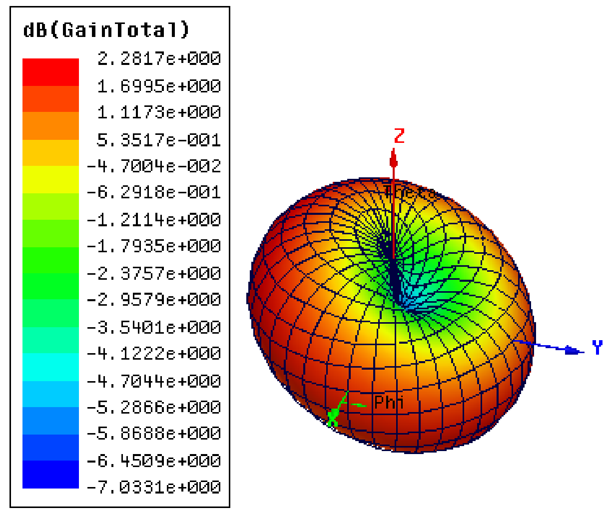
A3.2: 205mm Ht Rx IFA across the face Centre



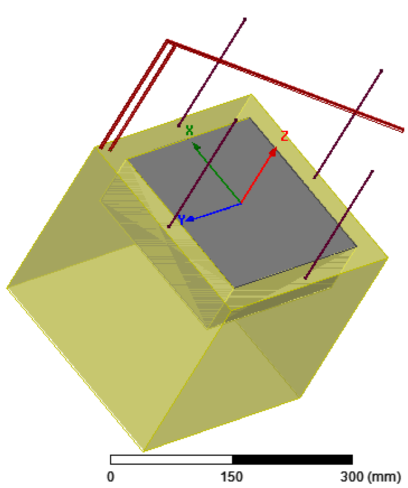


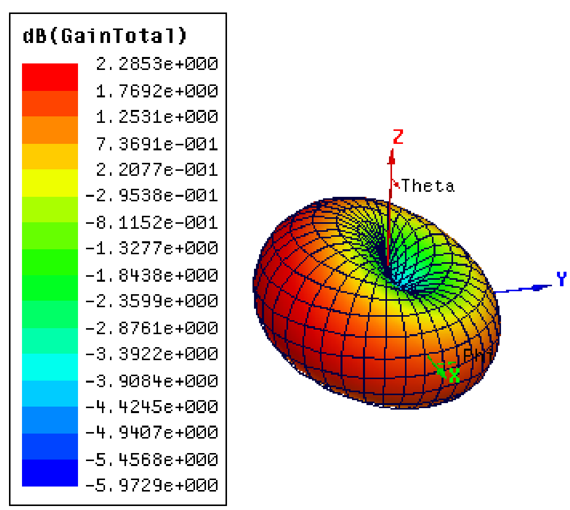
A3.3: 205mm Ht Rx IFA across the face edge



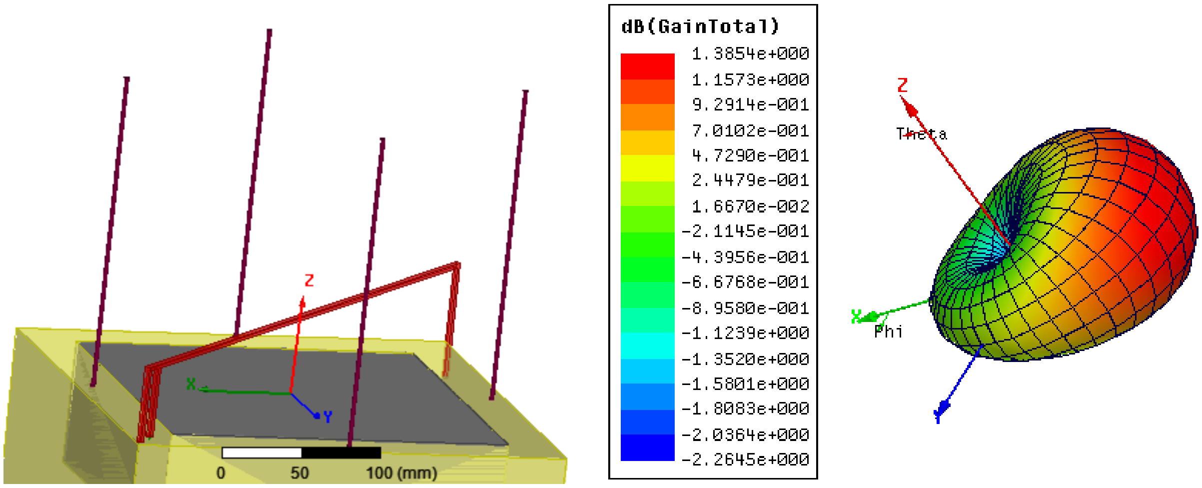


A3.4: 205mm Ht Rx IFA across the face diagonal

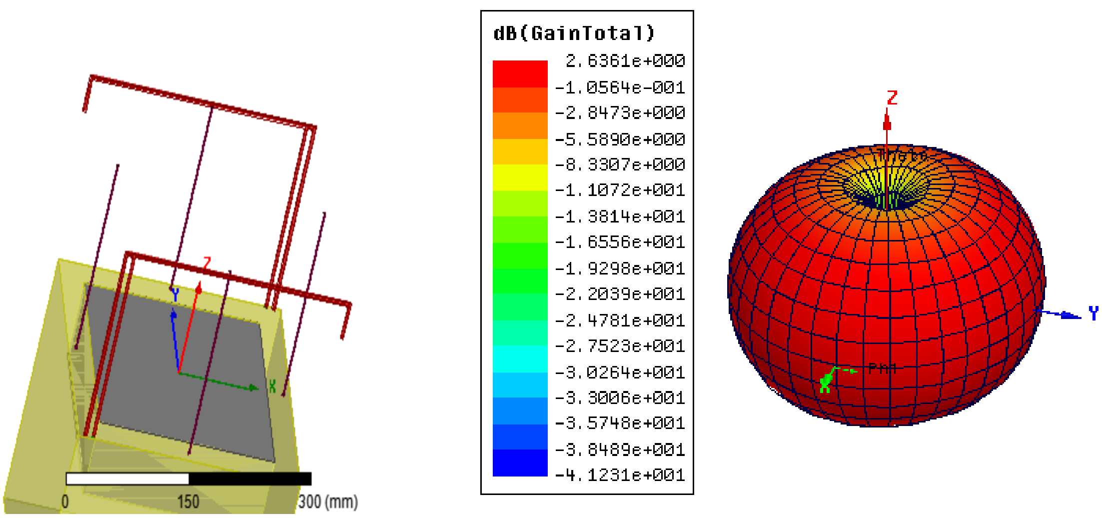




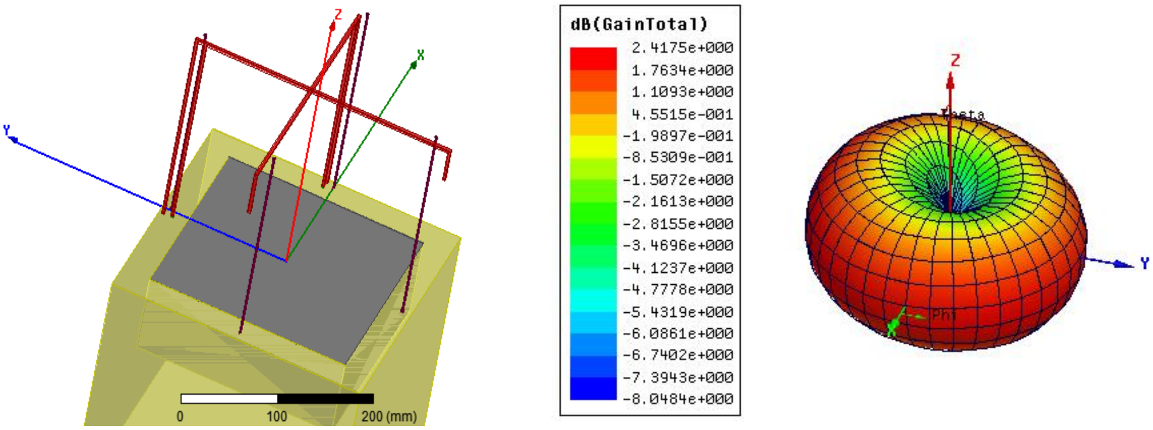
A3.5: 50mm Ht Rx IFA across the face diagonal



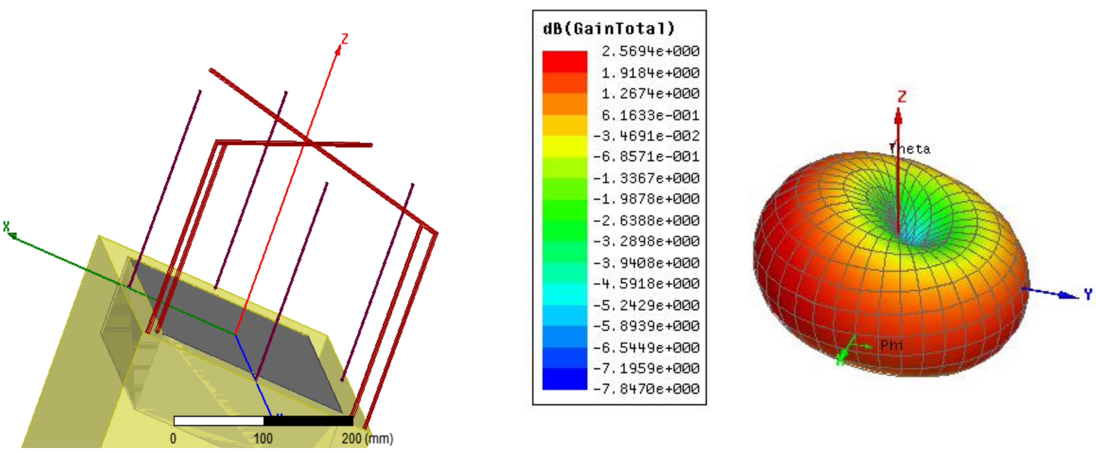
A3.6: 205mm Ht Two Rx IFA across the face edges



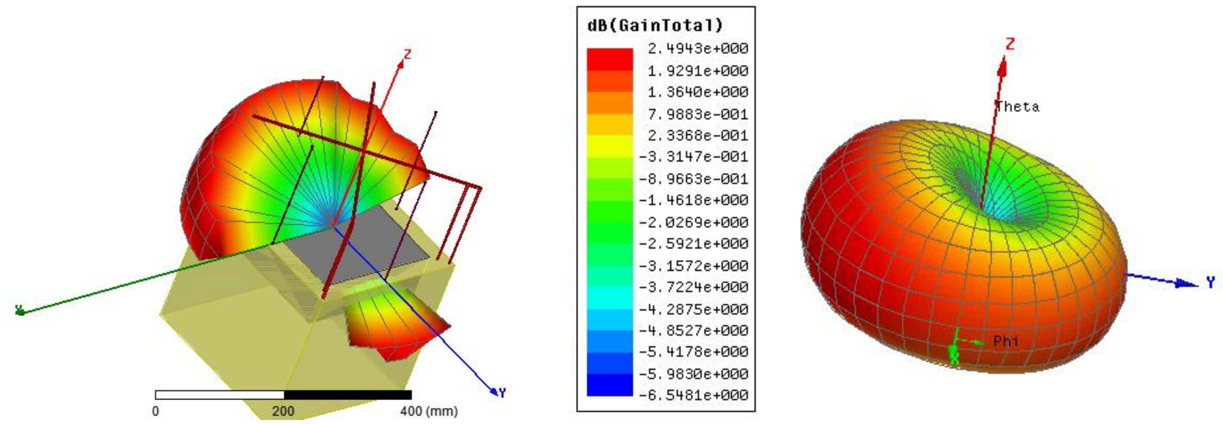
A3.7: 205mm Ht Two Rx IFA crossed along face centers



A3.8: 205mm Ht Two Rx IFA diagonal along the face



A3.9: 150mm Ht Two Rx IFA diagonal along the face



A3.10: 30mm Ht Two Rx IFA along the face edges