ANTENNA DESIGN: 2x1 S-BAND PATCH ANTENNA ARRAY AND UHF DIPOLES

1. ***2x1 Patch Array Antennas at Left- and Right-side of CubeSat structure:*** S-Band rectangular 2x1 patch antenna, for operation at 2.4GHz, at Left- and Right-side of CubeSat structure. Design stage performed without 2.4 m Wire Antennas or UHF dipoles. Simulations performed with CST Studio Suite 2017 ©. 2x1 array is modified with respect to the model shown on previous report for a resonance shift from 2.451GHz down to 2.4 GHz.

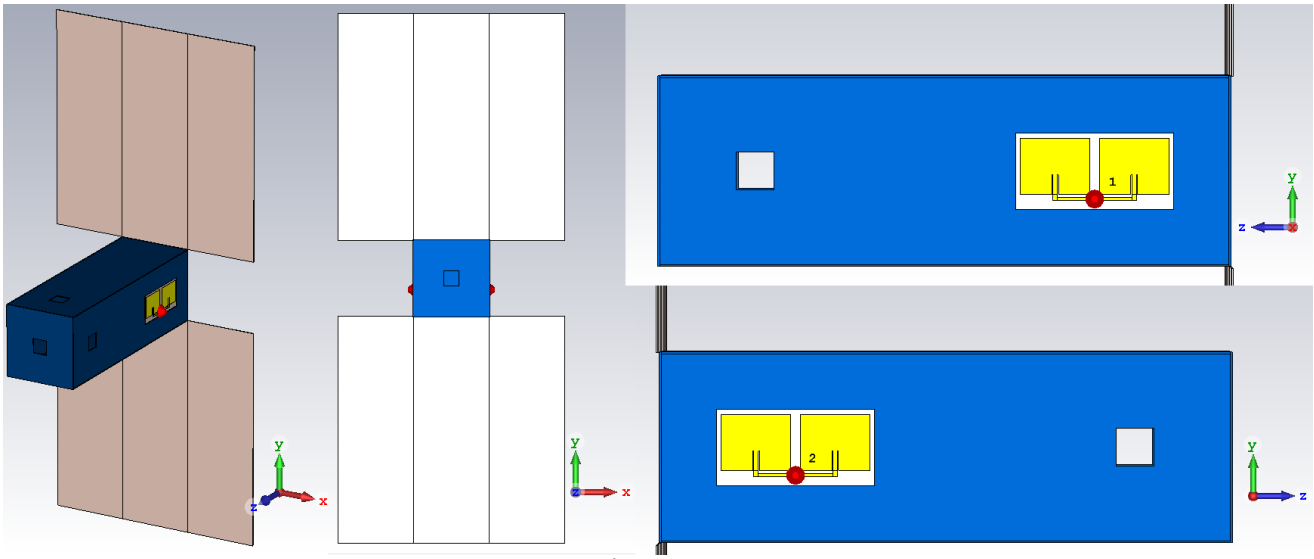

Figure 1. 1. Cube-Sat structure. Perspective, Front, Left- and Right-side Views

Parameter List

Name	Expression	Value	Description	Type
f	2.4	2.4	Frequency [GHz]	Frequency
Hbox	10	10	Box Height (Y Axis) [cm]	Length
Hpan	10	10	Panel Height/Width (X Axis) [cm]	Length
Lambda	12.5	12.5	Wavelength [cm]	Length
LambdaG	6.1808	6.1808	Guided Wavelength [cm]	Length
Lbox	30	30	Box Length (Z Axis) [cm]	Length
Lpan	30	30	Panel Length (Y Axis) [cm]	Length
MPHole	2	2	Wire Antenna Box Hole	Length
Tbox	0.1	0.1	Box Thickness [cm]	Length
Tpan	0.08	0.08	Panel Thickness [cm]	Length
Tpatch	0.005	0.005	Patch Thickness (X Axis) [cm]	Length
Tsubs	0.16	0.16	Substrate Thickness (X Axis) [cm]	Length
Wposc	Hbox/2	5	Wire Antena Central Position [cm]	Length
Gpatch	3	3	Distance From Box Edge to Patch [cm]	Length
Lpatch	2.935705	2.935705	Patch Length (Y Axis) [cm] (Orig = 2.8579)	Length
Lsubs	4	4	Substrate Length (Y Axis) [cm]	Length
Wconn	2*Wstrip/3	0.16666...	Width - Connector Strip between Patches [cm]	Undefined
Wpatch	3.65779	3.65779	Patch Width (Z Axis) [cm] (Orig = 3.5593)	Length
Wstrip	0.25	0.25	Feed Strip Width (X Axis) [cm]	Length
Wsubs	2*(2*Wstrip + Wpatch)	8.31558	Substrate Width (Y Axis) [cm]	Length
x0	0.05	0.05	Space between Patch & Feed Strip (X Axis) [cm]	Length
y0	1.025	1.025	Space between Patch & Feed Strip End (Y Axis) [cm]	Length

Figure 1. 2. Parameter List for Structure design

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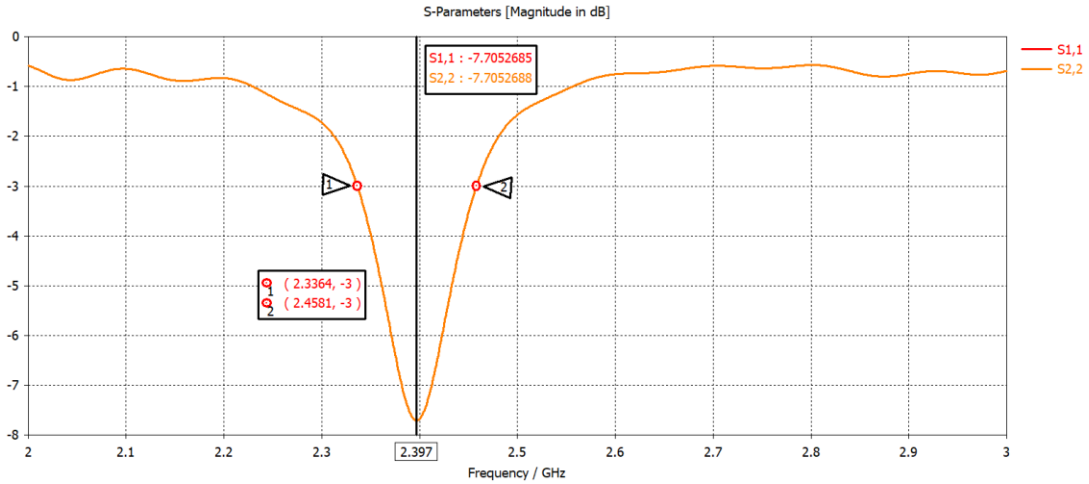

Figure 1. 3. Input reflection coefficients (S11 and S22 Parameters) for both 2x1 S-Band Patch Array Antennas

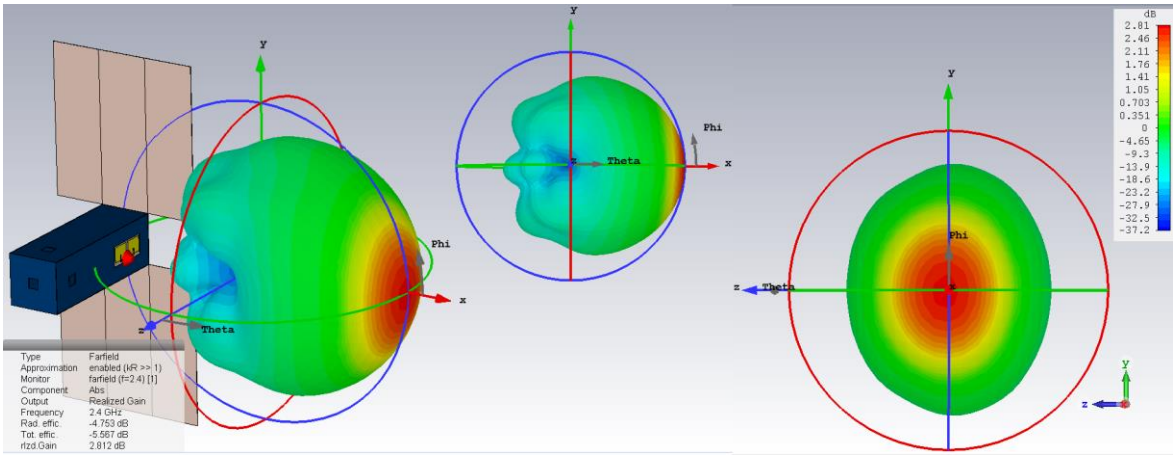

Figure 1. 4. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.

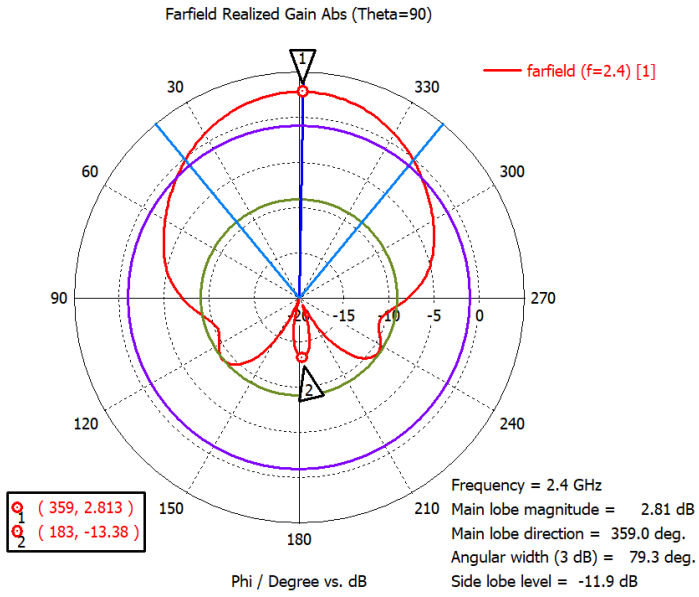

Figure 1. 5. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

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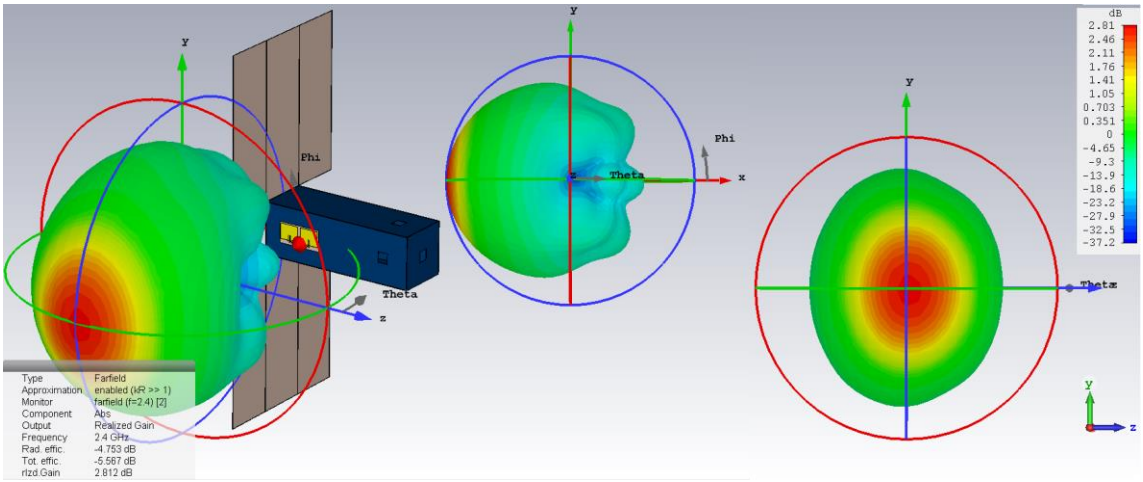

Figure 1. 6. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.

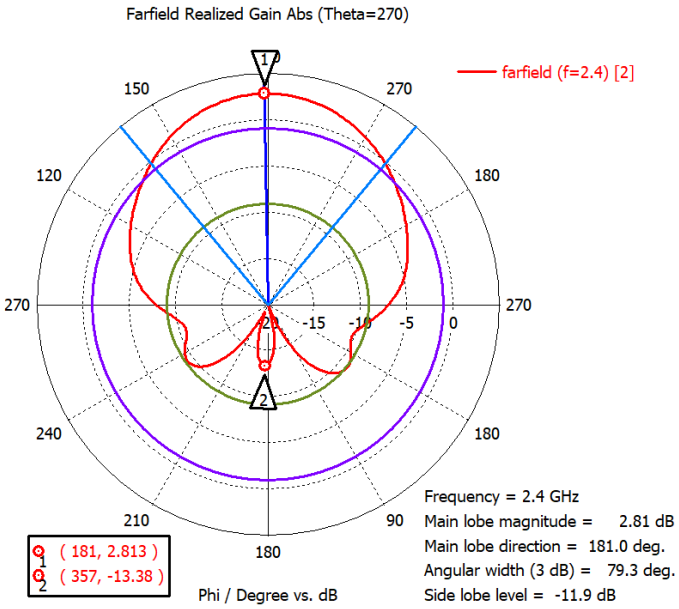

Figure 1. 7. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

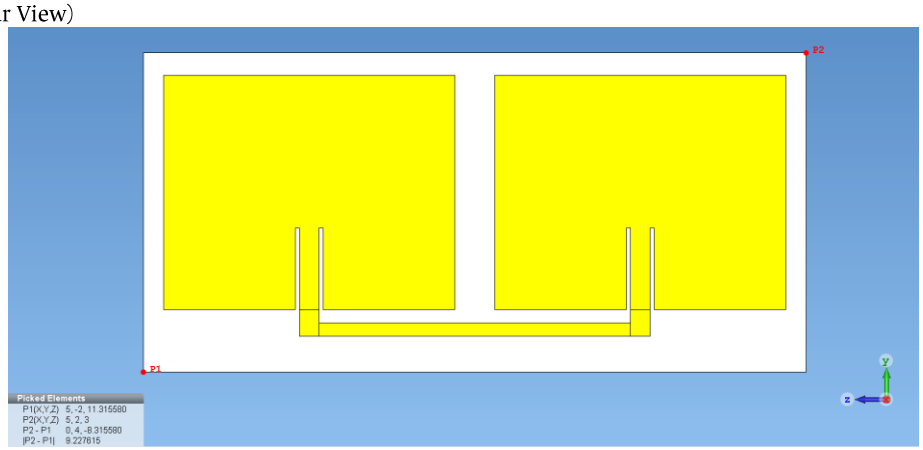

Figure 1. 8. Detail of size for full 2x1 Patch Antenna Array structure: 8.315cm x 4cm.

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2. ***Dipole antennas added to back-side of CubeSat structure:*** UHF Dipoles added to the back-end of at Left- and Right-side of CubeSat structure, the same sides where each of the S-Band rectangular 2x1 patch antenna arrays are located. Dipoles operating at 438MHz. Design stage performed without 2.4 m Wire Antennas. Simulations performed with CST Studio Suite 2017 ©.

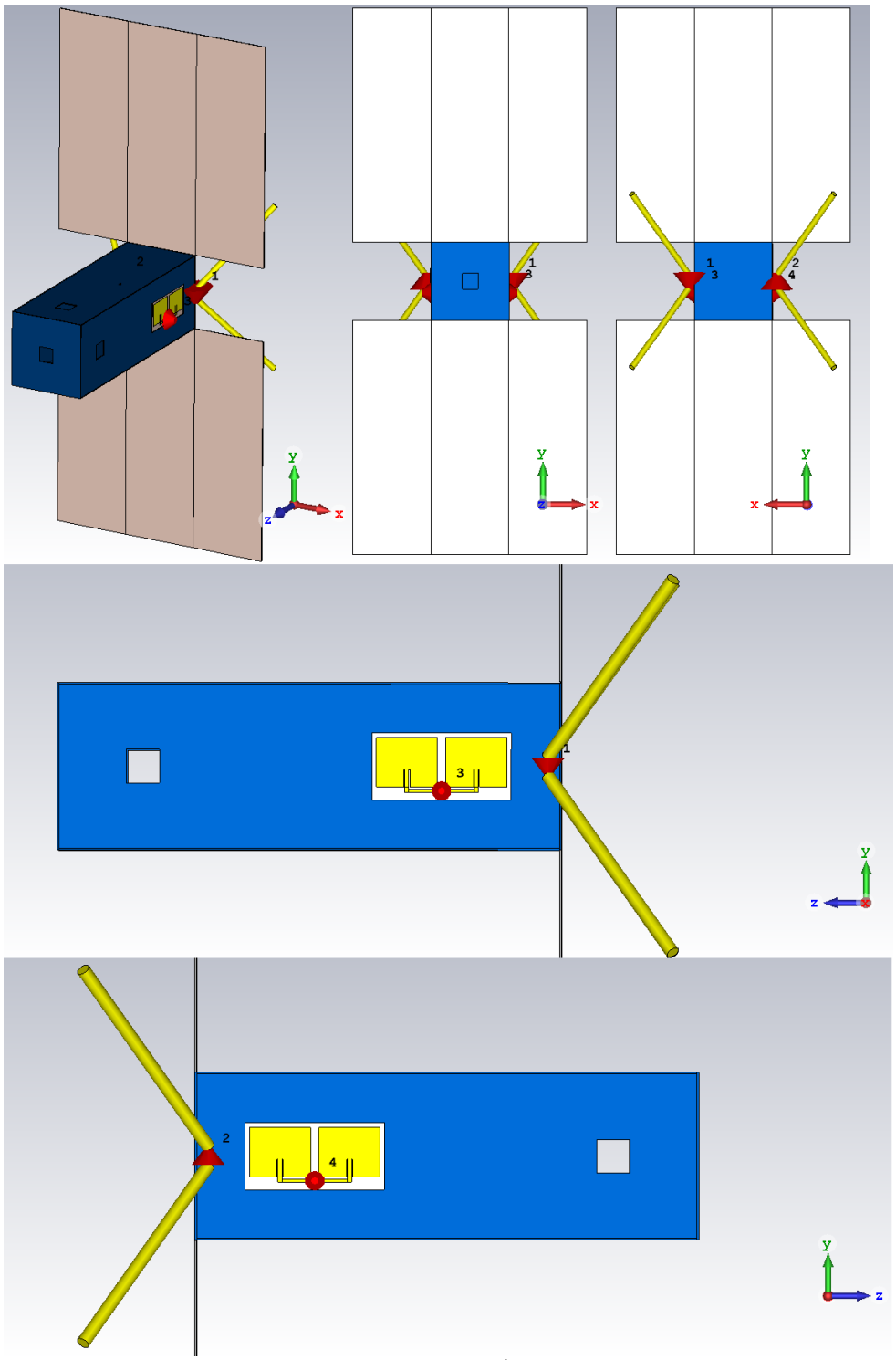

Figure 2. 1. Cube-Sat structure. Perspective, Front, Back, Left- and Right-side Views

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Parameter List

Name	Expression	Value	Description	Type
A	= 2	2	Dipole Axis Shif Factor	Undefined
Bf	= -0.07	-0.07	Factor of Additional Spacing Between CubeSat and Dipole Structure (Over Surface = 0.055)	Undefined
f	= 2.4	2.4	Frequency [GHz]	Frequency
Gap_dip...	= 0	0	Gap between Dipole Arms [mm]	Length
Hbox	= 10	10	Box Height (Y Axis) [cm]	Length
Hpan	= 10	10	Panel Height/Width (X Axis) [cm]	Length
Lambda	= 68.49315	68.49315	Wavelength [cm]	Length
Lbox	= 30	30	Box Length (Z Axis) [cm]	Length
Lpan	= 30	30	Panel Length (Y Axis) [cm]	Length
Lwire	= 240	240	Wire Antenna Length [cm]	Length
L_dipole	= Lambda/4 -2.2	14.9232...	Dipole Length [mm]	Length
MPHole	= 2	2	Wire Antenna Box Hole	Length
Rwire	= 0.016	0.016	Wire Antenna Radius [cm]	Length
R_dipole	= 0.4	0.4	Dipole Radius [mm]	Length
Tbox	= 0.1	0.1	Box Thickness [cm]	Length
Tpan	= 0.08	0.08	Panel Thickness [cm]	Length
Tpatch	= 0.005	0.005	Patch Thickness (X Axis) [cm]	Length
Tsubs	= Tbox	0.1	Substrate Thickness (X Axis) [cm]	Length
Wposc	= Hbox/2	5	Wire Antena Central Position [cm]	Length
Gpatch	= 3	3	Distance From Box Edge to Patch [cm]	Length
Lpatch	= 2.935705	2.935705	Patch Length (Y Axis) [cm] (Orig = 2.8579)	Length
Lsubs	= 4	4	Substrate Length (Y Axis) [cm]	Length
Wconn	= 2*Wstrip/3	0.16666...	Width - Connector Strip between Patches [cm]	Undefined
Wpatch	= 3.65779	3.65779	Patch Width (Z Axis) [cm] (Orig = 3.5593)	Length
Wstrip	= 0.25	0.25	Feed Strip Width (X Axis) [cm]	Length
Wsubs	= 2*(2*Wstrip + Wpatch)	8.31558	Substrate Width (Y Axis) [cm]	Length
x0	= 0.05	0.05	Space between Patch & Feed Strip (X Axis) [cm]	Length
y0	= 1.025	1.025	Space between Patch & Feed Strip End (Y Axis) [cm]	Length

Figure 2. 2. Parameter List for Structure design

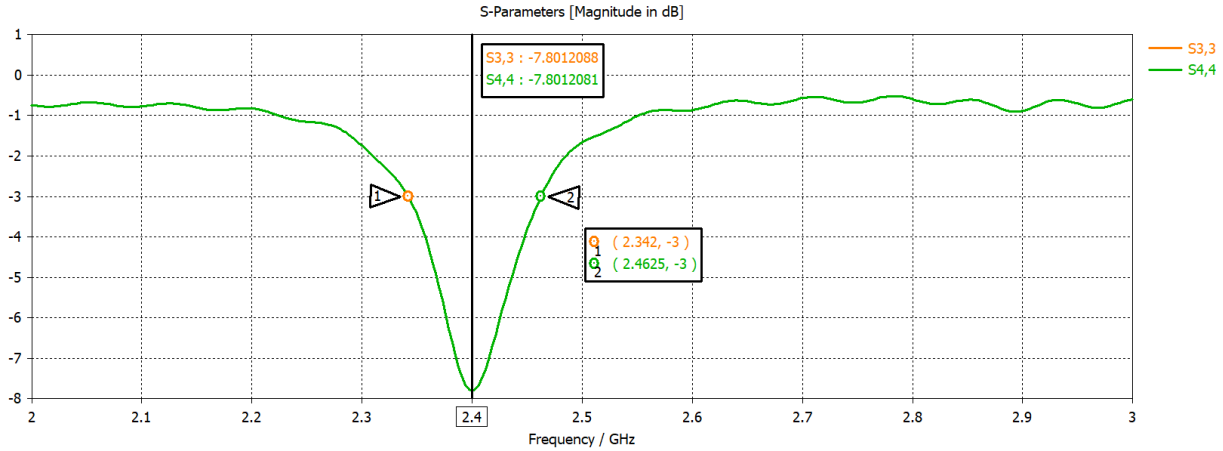

Figure 2. 3. Input reflection coefficients (S11 and S22 Parameters) for both 2x1 S-Band Patch Array Antennas

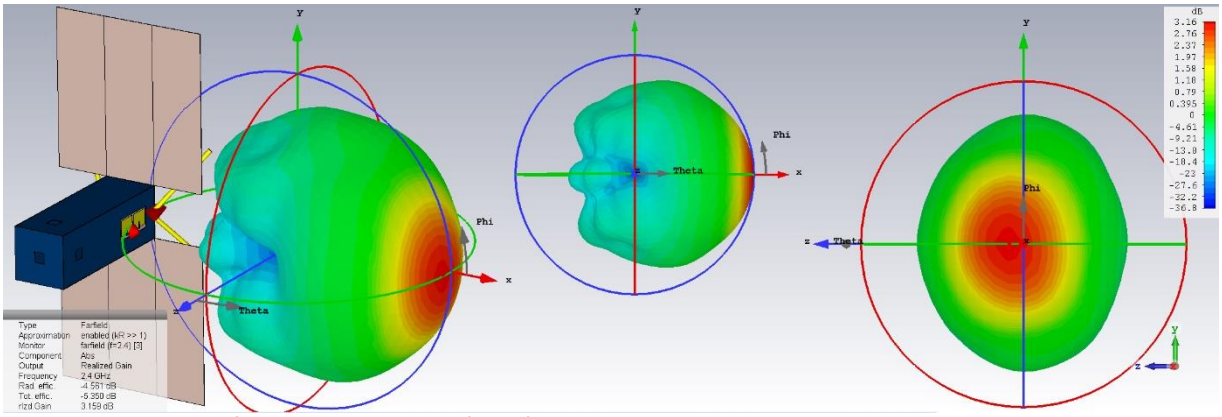

Figure 2. 4. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.

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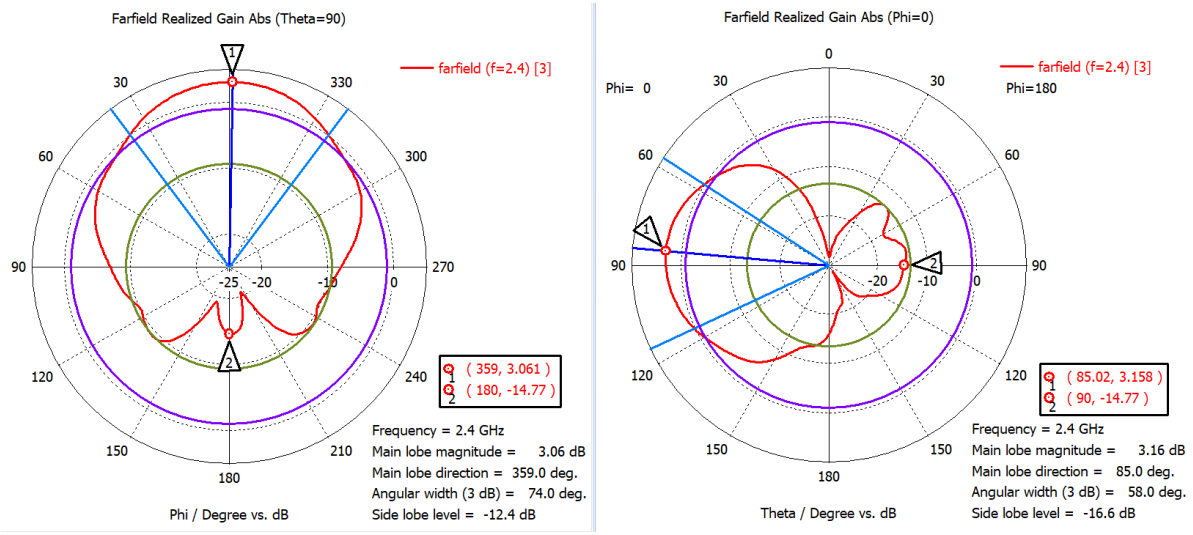

Figure 2. 5. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

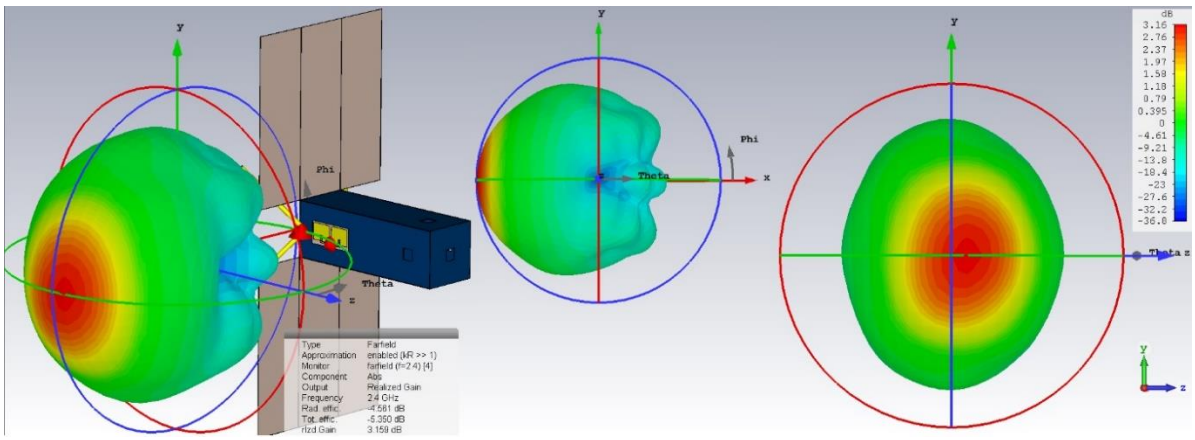

Figure 2. 6. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.

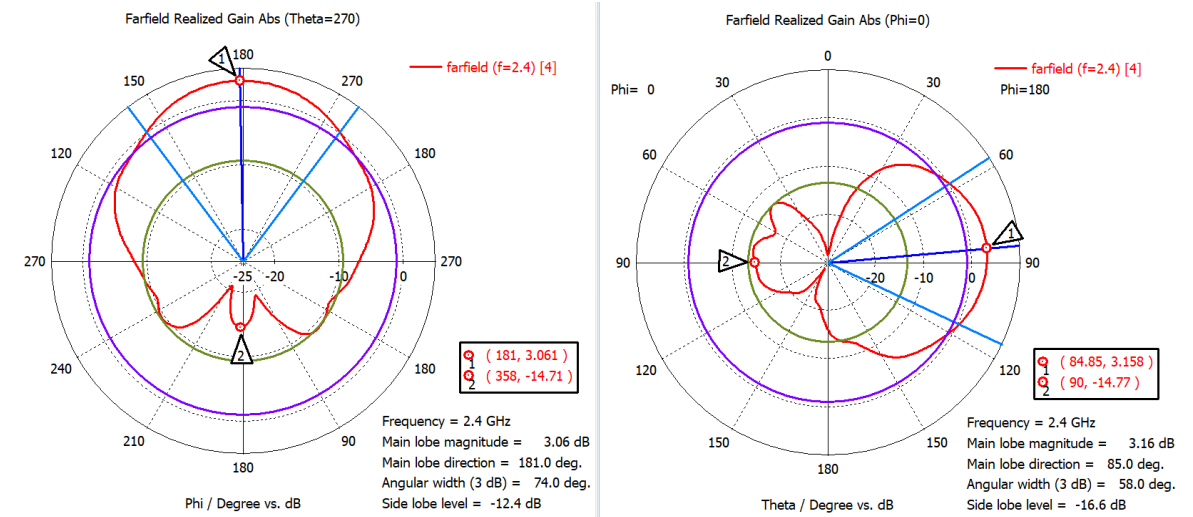

Figure 2. 7. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

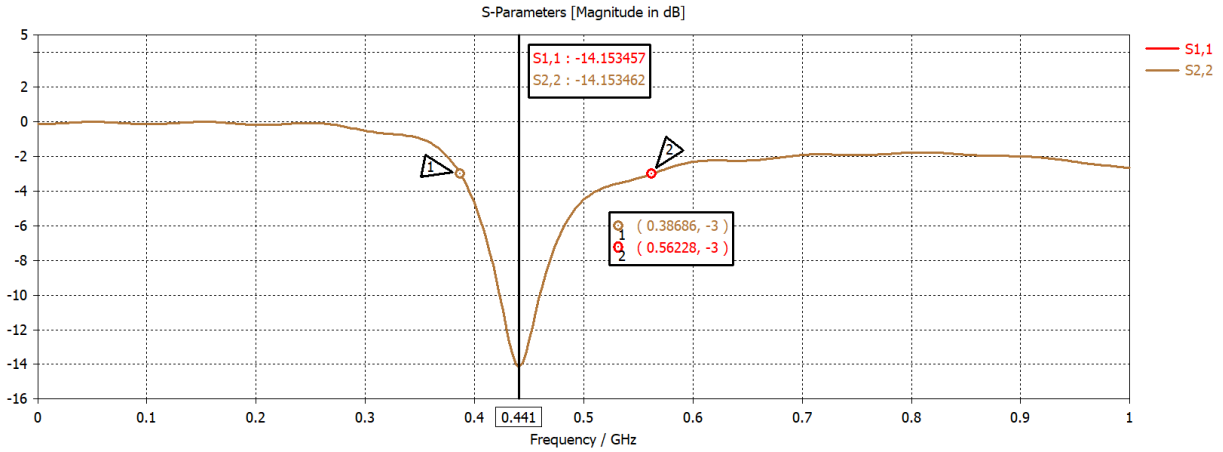

Figure 2. 8. Input reflection coefficients (S11 and S22 Parameters) for both UHF Dipole Antennas

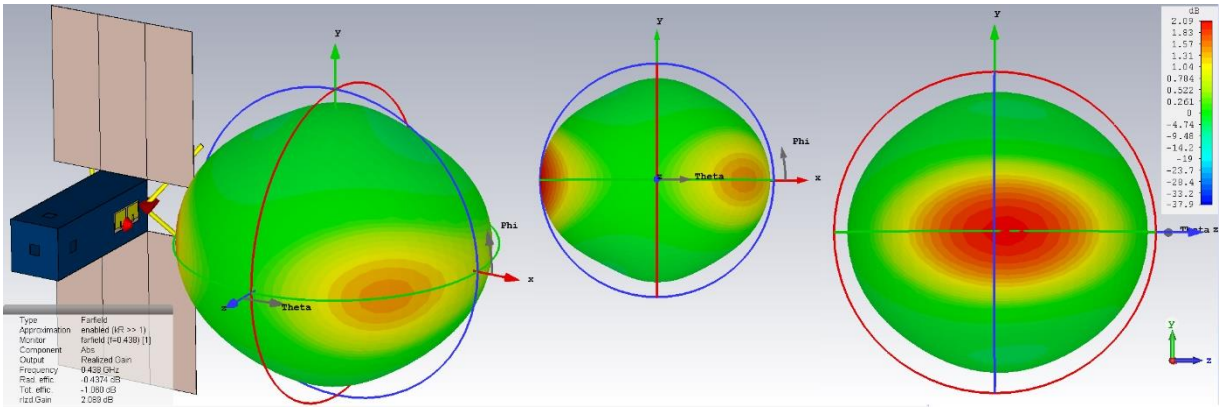

Figure 2. 9. Far-field Radiation Pattern for Left-Side UHF Dipole Antenna Design at 438MHz. Realized Gain.

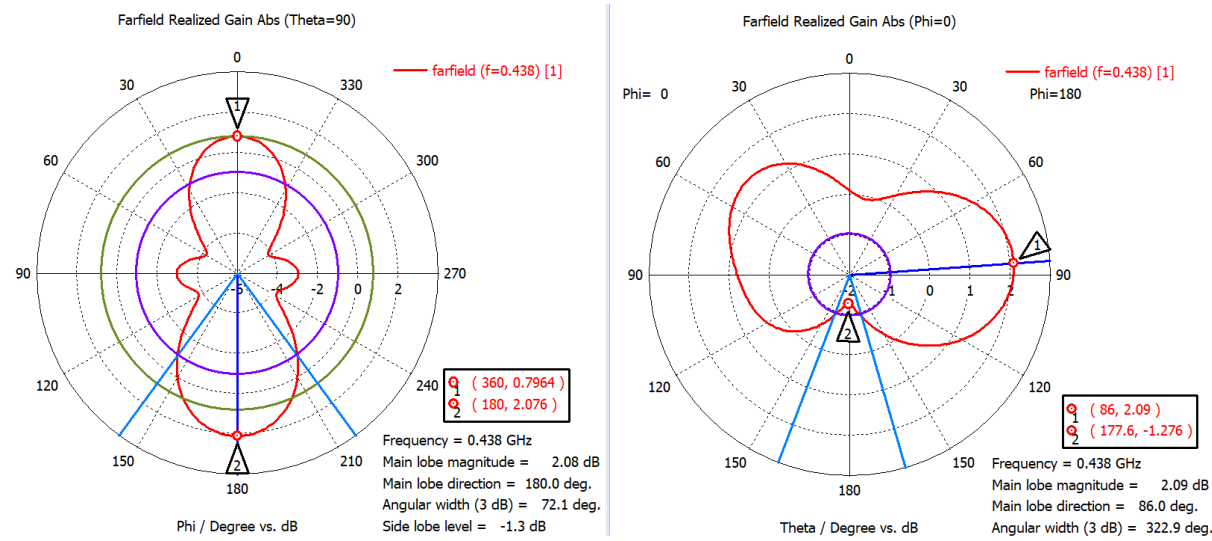

Figure 2. 10. Far-field Radiation Pattern for Left-Side UHF Dipole Antenna Design at 438MHz. Realized Gain. (Polar View)

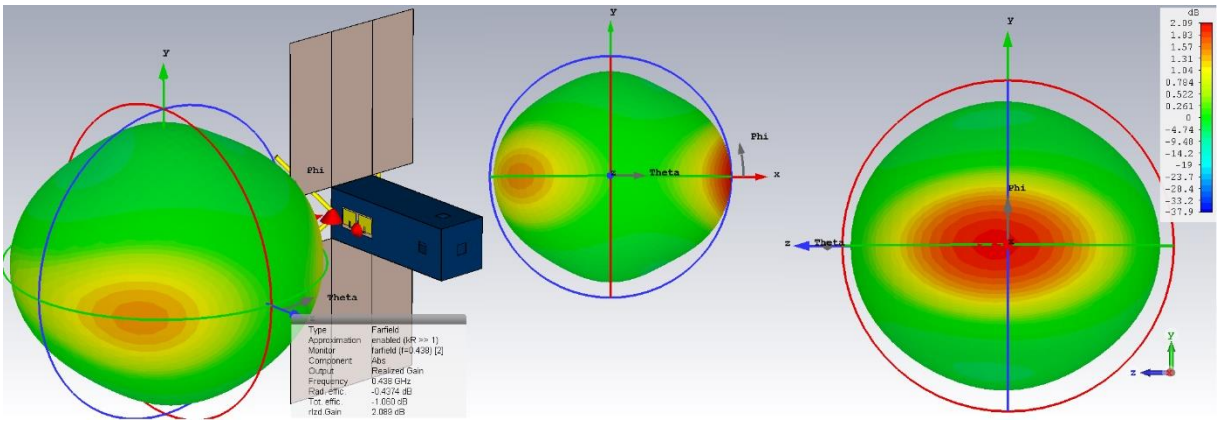

Figure 2. 11. Far-field Radiation Pattern for Right-Side UHF Dipole Antenna Design at 438MHz. Realized Gain.

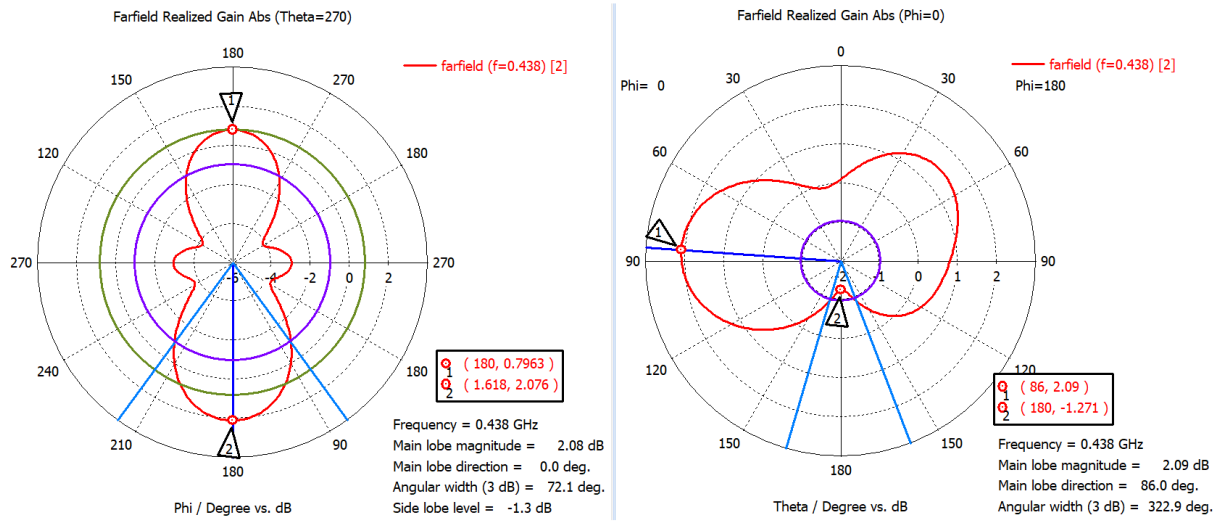

Figure 2. 12. Far-field Radiation Pattern for Right-Side UHF Dipole Antenna Design at 438MHz. Realized Gain. (Polar View)

At this design stage, for each of the dipoles located on the sides of the CubeSat structure, we see that the maximum gain lobes are directed 180° from the antenna axis of desired directivity, i.e., the point of maximum gain is directed towards the opposite side of CubeSat. This interference may be caused by the S-Band patch array antennas as well as the panels and the rest of CubeSat structure. Full results comparison can be seen on tables 1.1 and 1.2 at the end of this document.

3. ***2.4m Wire Antennas added to front-side of CubeSat structure:*** 2.4 m Wire Antennas added to the front of CubeSat structure, on Front-, Top-, Bottom-, Left- and Right-sides of Cube. Wire antennas are designed for operation from 0 to 20 MHz, however they are not yet energized. Simulations performed with CST Studio Suite 2017 ©.

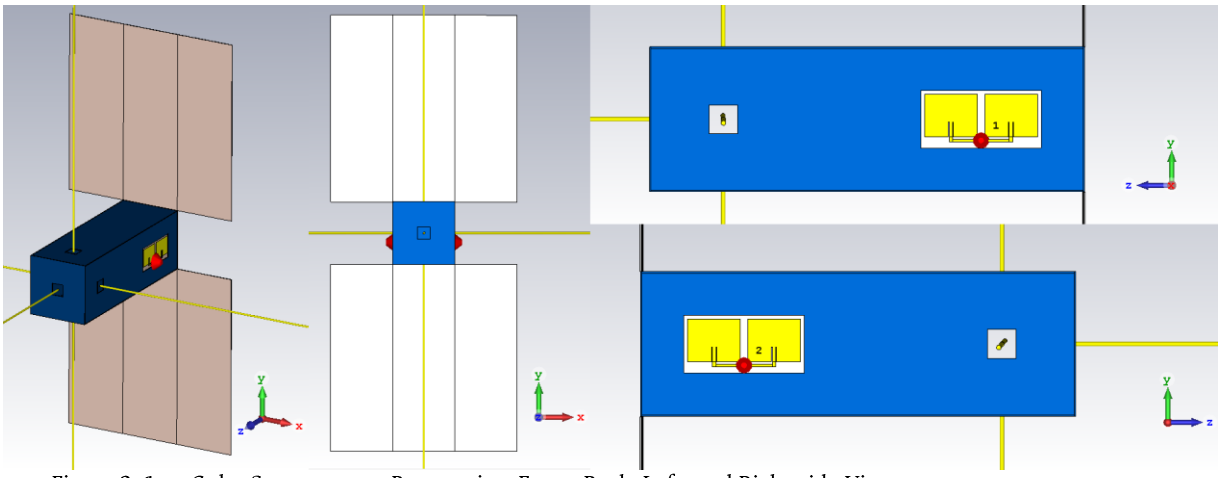

Figure 3. 1. Cube-Sat structure. Perspective, Front, Back, Left- and Right-side Views

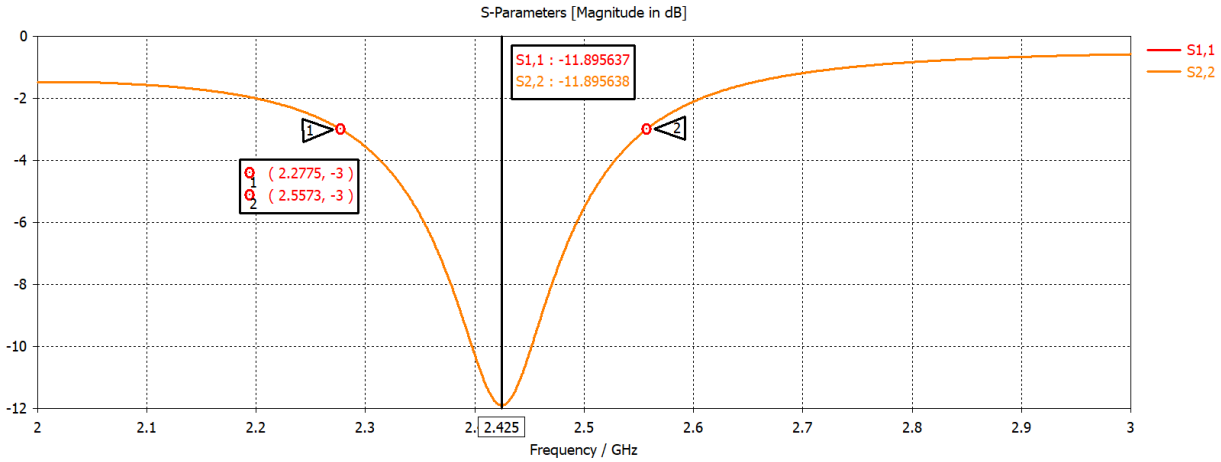

Figure 3. 2. Input reflection coefficients (S11 and S22 Parameters) for both 2x1 S-Band Patch Array Antennas

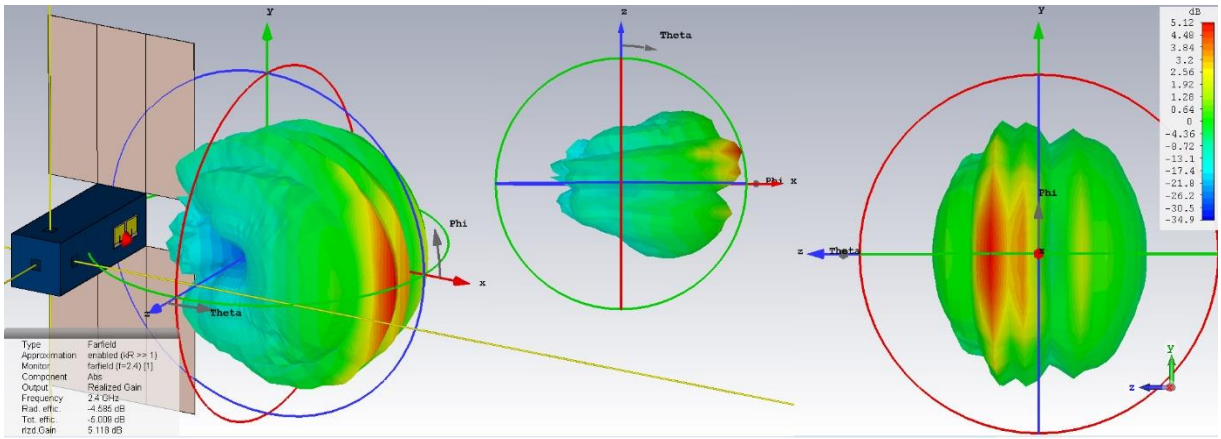

Figure 3. 3. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.

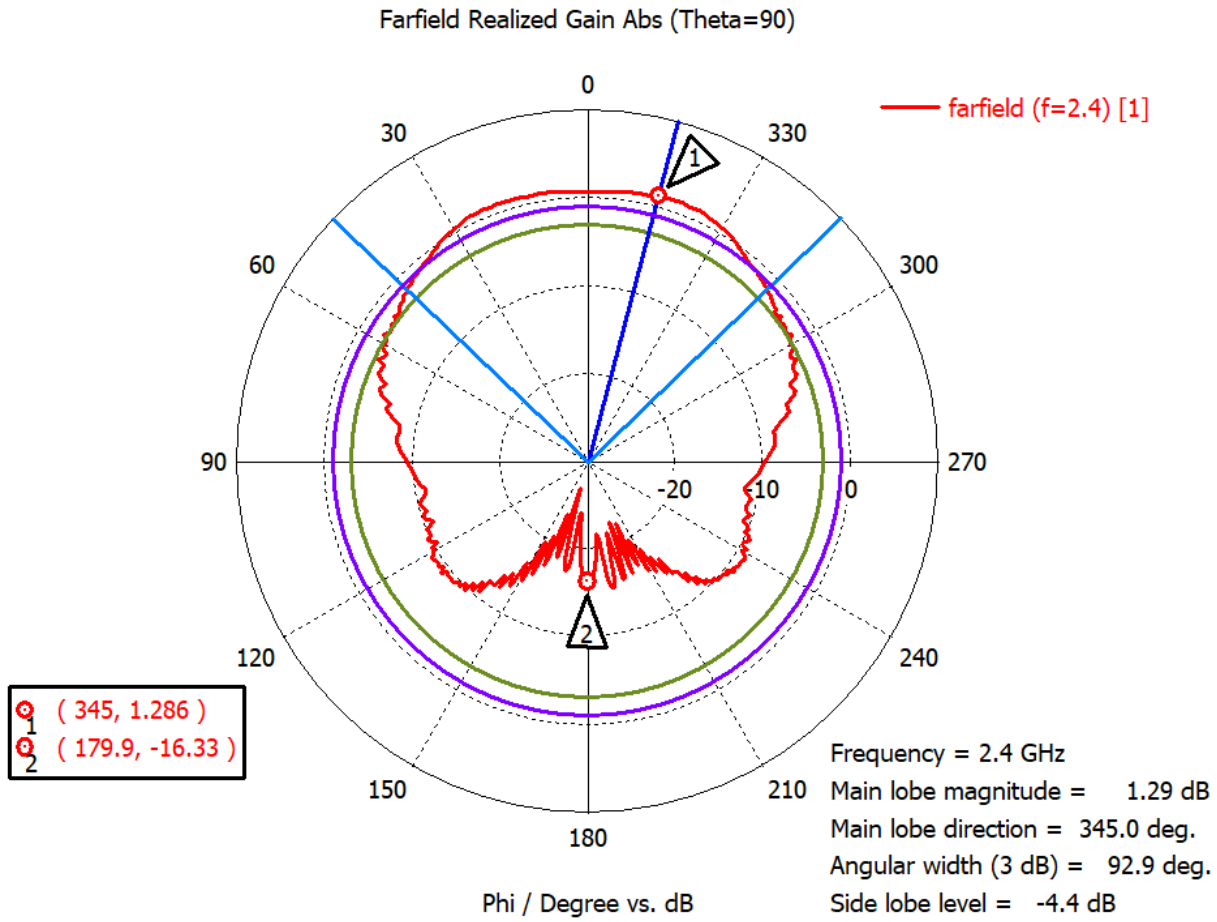

Figure 3. 4. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

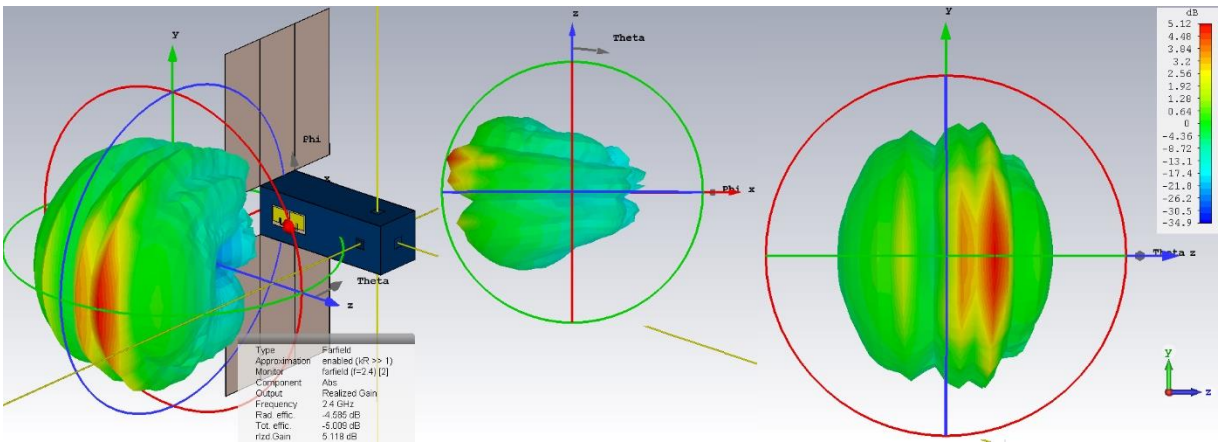

Figure 3. 5. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.

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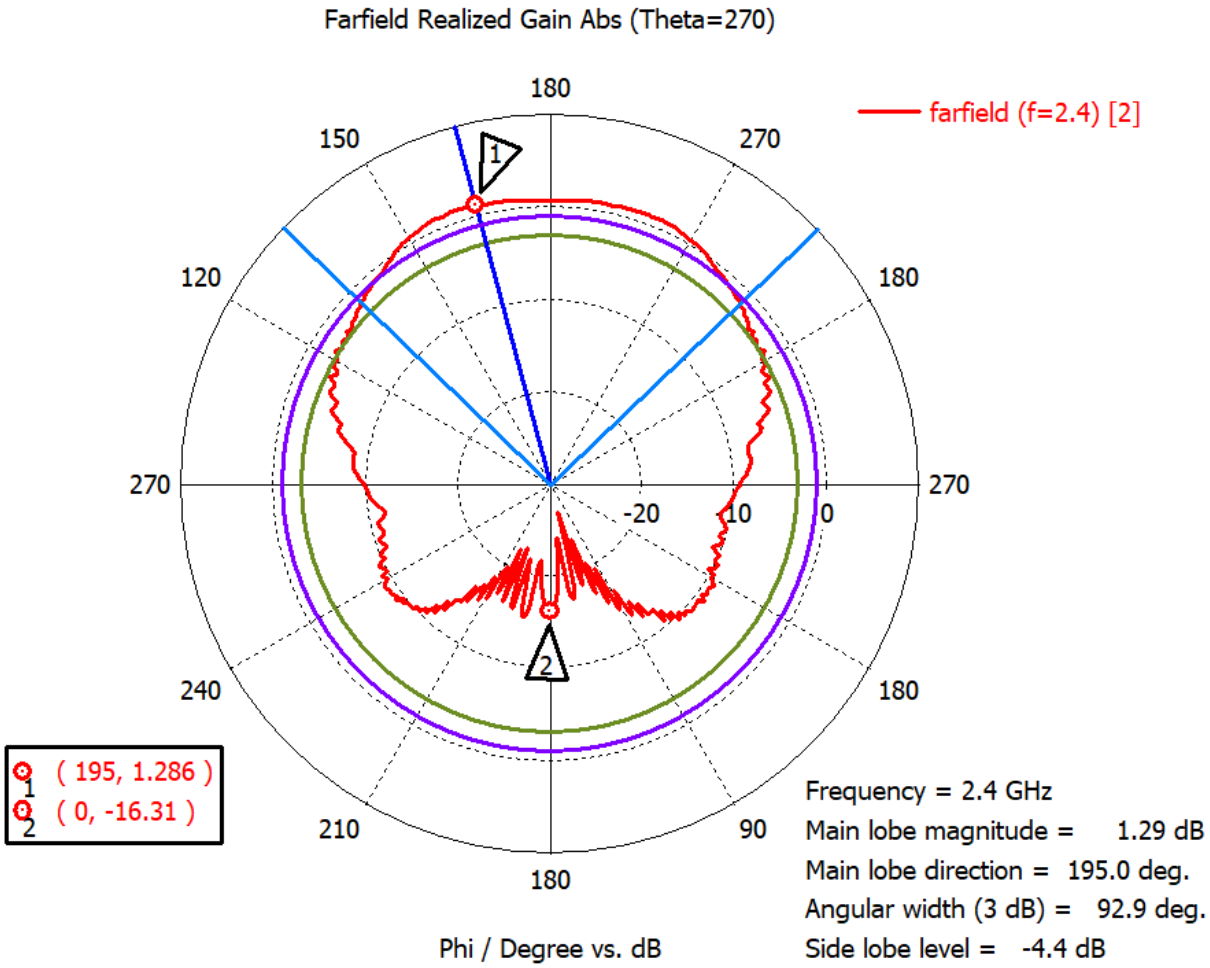


Figure 3. 6. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

S-Band patch antennas present an interference on their Farfield characteristic, affecting the direction of maximum gain, mainly due to the presence of the 2.4m Wire antennas at the front of the CubeSat. Main lobe magnitude is lower in comparison to the previous design stage, however the integrated realized gain for each 2x1 patch antenna array seems higher. Full results comparison can be seen on tables 1.1 and 1.2 at the end of this document.

4. ***2.4m Wire Antennas added to front-side and UHF Dipoles added to Back-side of CubeSat structure:*** UHF Dipoles added to the back-end of at Left- and Right-side of CubeSat structure, the same sides where each of the S-Band rectangular 2x1 patch antenna arrays are located, as previously shown. Dipoles operating at 438MHz. 2.4 m Wire Antennas added to the front of CubeSat structure, on Front-, Top-, Bottom-, Left- and Right-sides of Cube, as previously shown. 2.4m antennas are not yet energized. Simulations performed with CST Studio Suite 2017 ©.

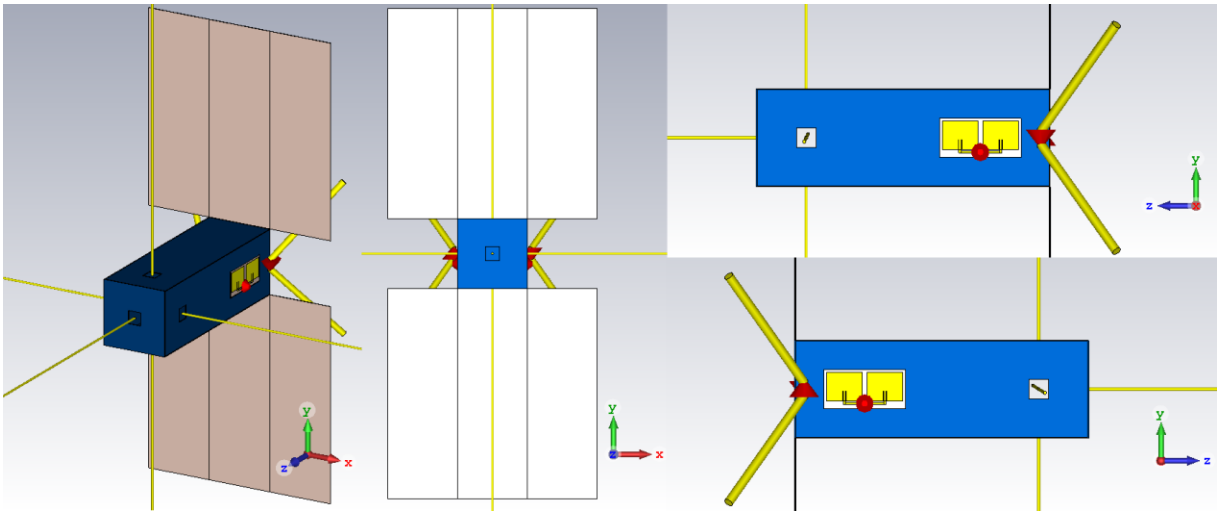
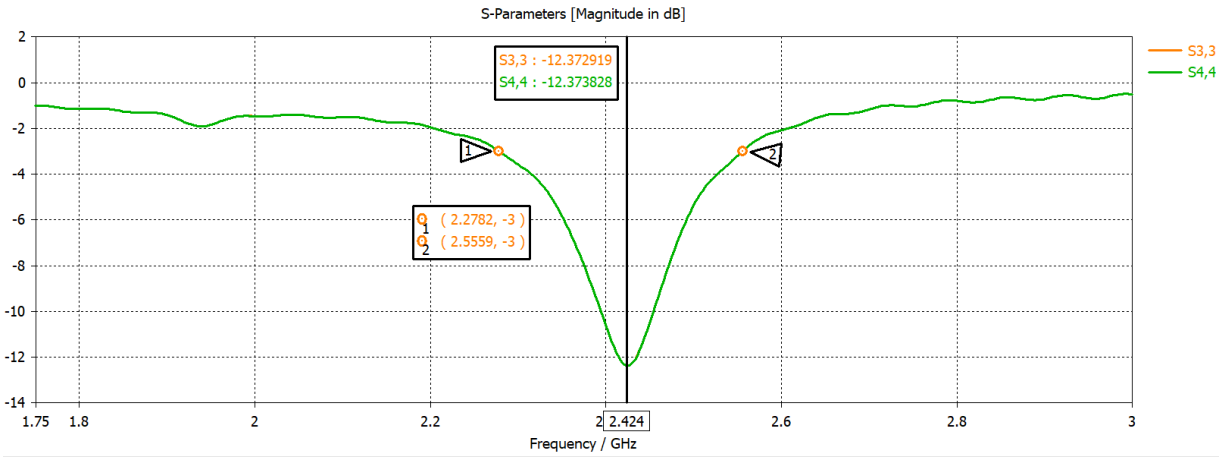


Figure 4. 1. Cube-Sat structure. Perspective, Front, Back, Left- and Right-side Views

Parameter List

Name	Expression	Value	Description
A	2	2	Dipole Axis Shif Factor
Bf	-0.07	-0.07	Factor of Additional Spacing Between CubeSat and Dipole Structure...
f	2.4	2.4	Frequency [GHz]
Gap_dipole	0	0	Gap between Dipole Arms [mm]
Gpatch	3	3	Distance From Box Edge to Patch [cm]
Hbox	10	10	Box Height (Y Axis) [cm]
Hpan	10	10	Panel Height/Width (X Axis) [cm]
Lambda	68.49315	68.49315	Wavelength [cm]
Lbox	30	30	Box Length (Z Axis) [cm]
Lpan	30	30	Panel Length (Y Axis) [cm]
Lpatch	2.935705	2.935705	Patch Length (Y Axis) [cm] (Orig = 2.8579)
Lsubs	4	4	Substrate Length (Y Axis) [cm]
Lwire	240	240	Wire Antenna Length [cm]
MPHole	2	2	Wire Antenna Box Hole
Rwire	0.016	0.016	Wire Antenna Radius [cm]
Tbox	0.1	0.1	Box Thickness [cm]
Tpan	0.08	0.08	Panel Thickness [cm]
Tpatch	0.005	0.005	Patch Thickness (X Axis) [cm]
Tsubs	Tbox	0.1	Substrate Thickness (X Axis) [cm]
Wconn	2*Wstrip/3	0.166666...	Width - Connector Strip between Patches [cm]
Wpatch	3.65779	3.65779	Patch Width (Z Axis) [cm] (Orig = 3.5593)
Wposc	Hbox/2	5	Wire Antena Central Position [cm]
Wstrip	0.25	0.25	Feed Strip Width (X Axis) [cm]
Wsubs	2*(2*Wstrip + Wpatch)	8.31558	Substrate Width (Y Axis) [cm]
x0	0.05	0.05	Space between Patch & Feed Strip (X Axis) [cm]
y0	1.025	1.025	Space between Patch & Feed Strip End (Y Axis) [cm]
L_dipole	Lambda/4 -1.7	15.4232875	Dipole Length [mm]
R_dipole	0.475	0.475	Dipole Radius [mm]

Figure 4. 2. Parameter List for Structure design



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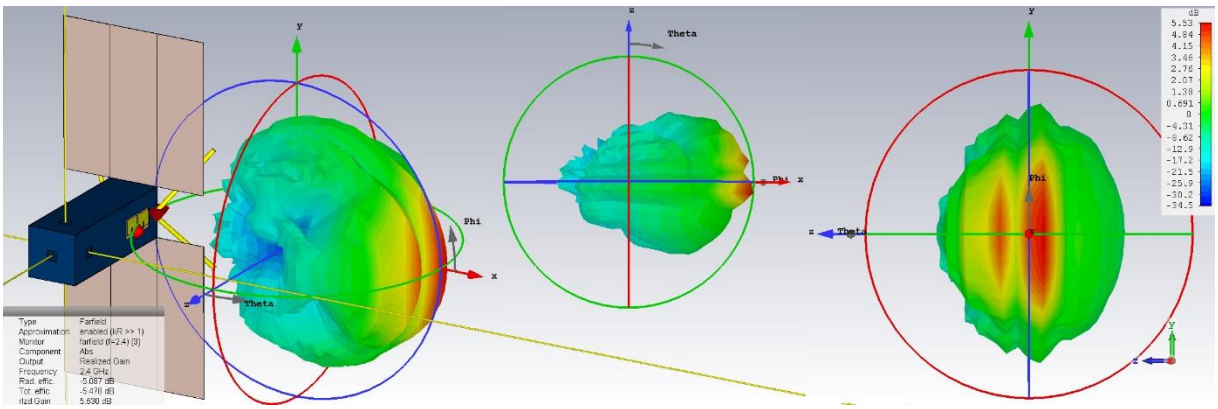
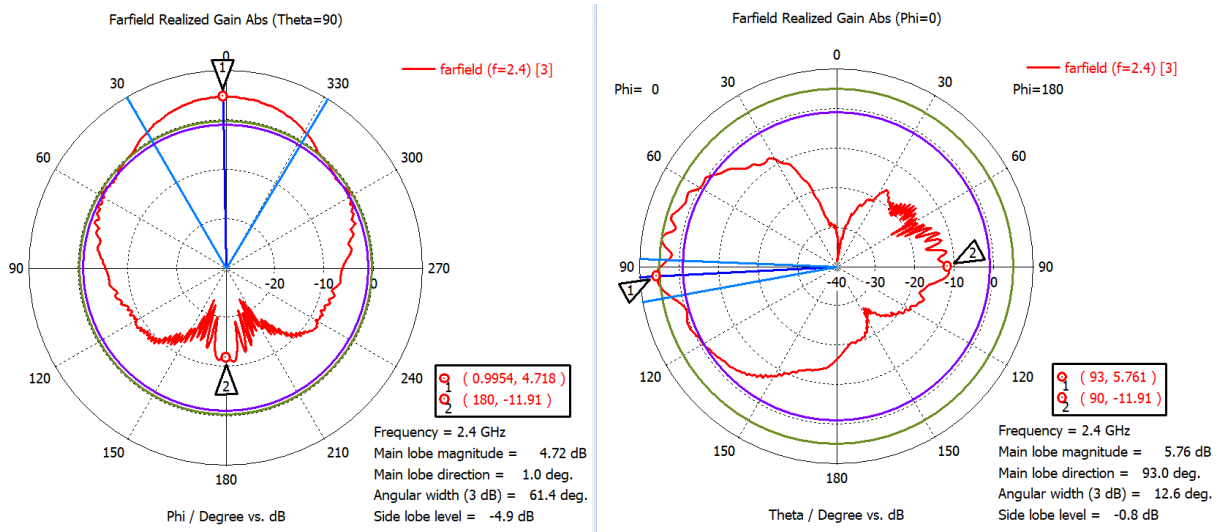


Figure 4. 4. Far-field Radiation Pattern for Left-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain.



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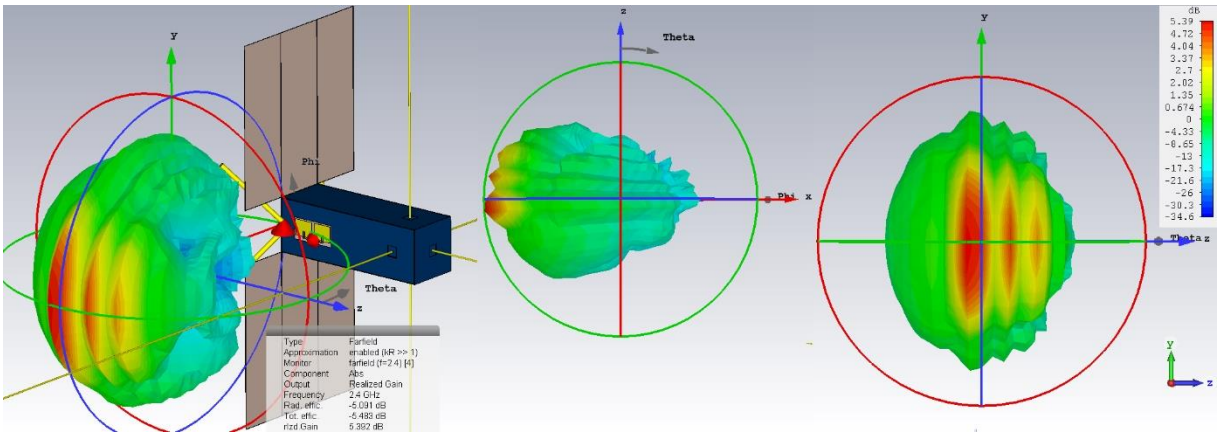

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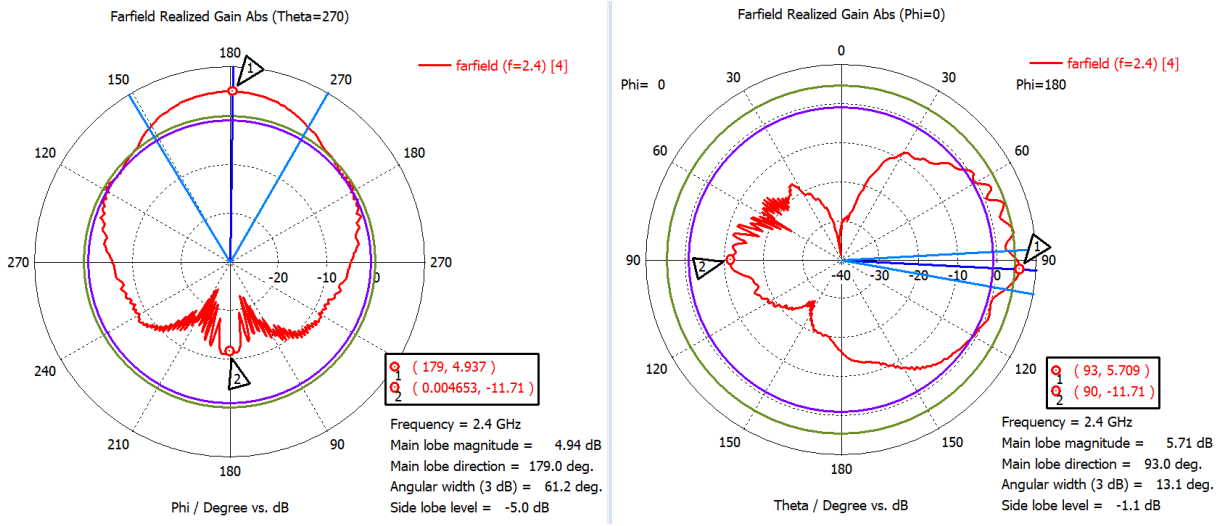

Figure 4. 7. Far-field Radiation Pattern for Right-Side 2x1 Patch Array Antenna Design at 2.45 GHz. Realized Gain. (Polar View)

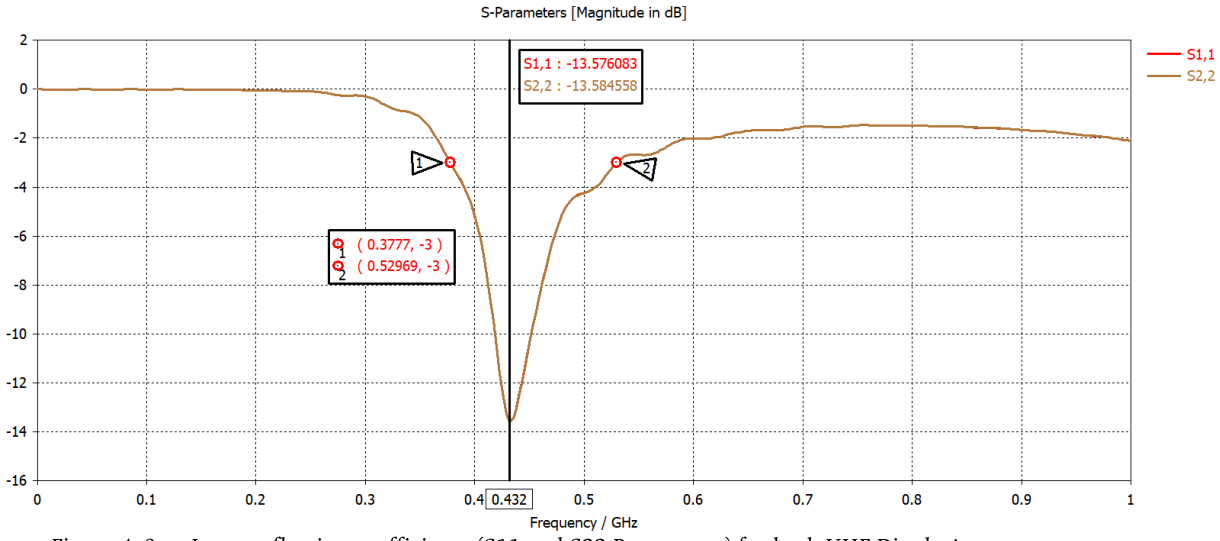

Figure 4. 8. Input reflection coefficients (S11 and S22 Parameters) for both UHF Dipole Antennas

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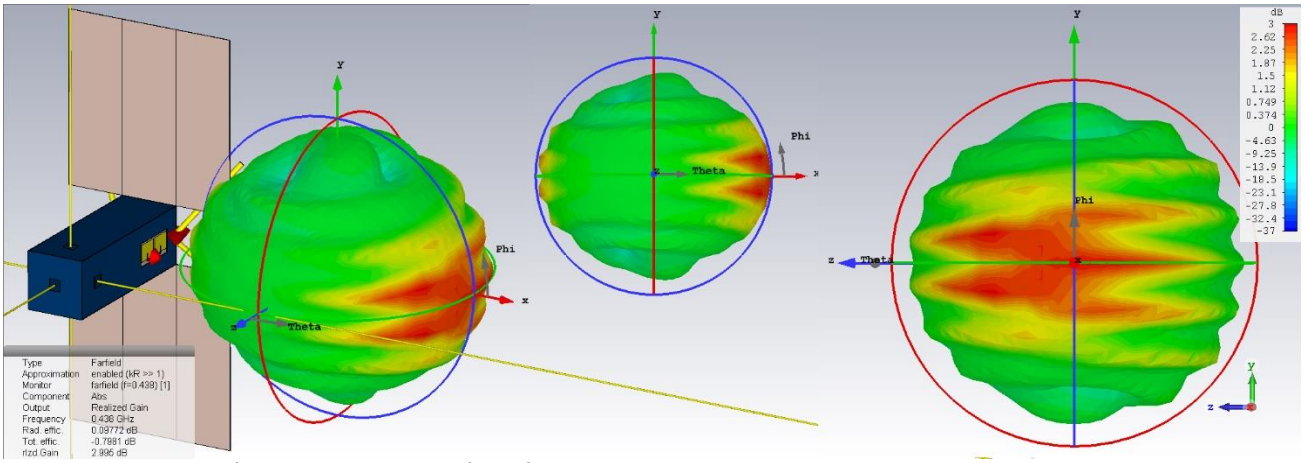

Figure 4. 9. Far-field Radiation Pattern for Left-Side UHF Dipole Antenna Design at 438MHz. Realized Gain.

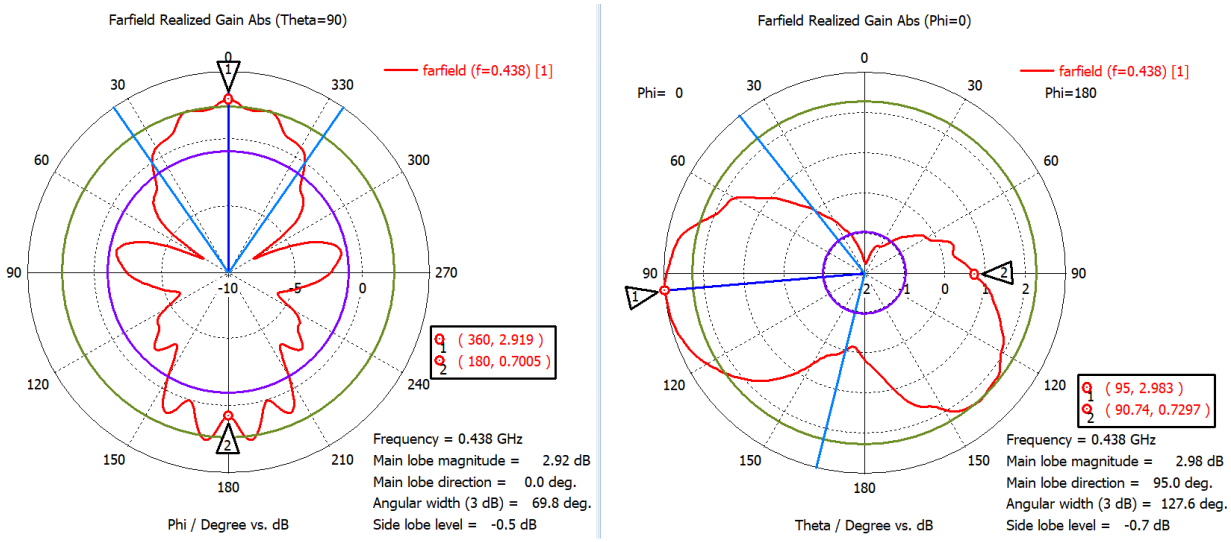

Figure 4. 10. Far-field Radiation Pattern for Left-Side UHF Dipole Antenna Design at 438MHz. Realized Gain. (Polar View)

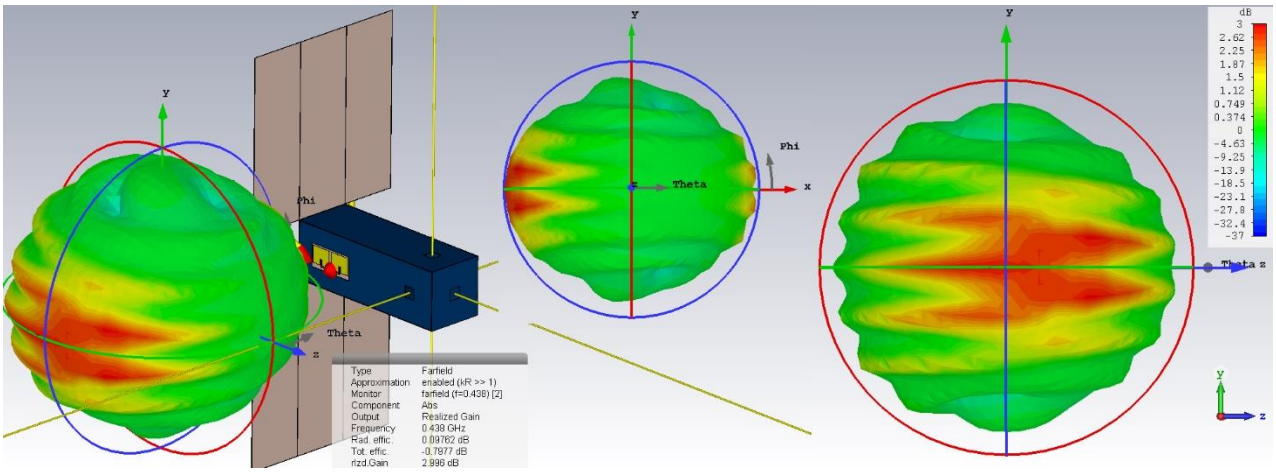

Figure 4. 11. Far-field Radiation Pattern for Right-Side UHF Dipole Antenna Design at 438MHz. Realized Gain.

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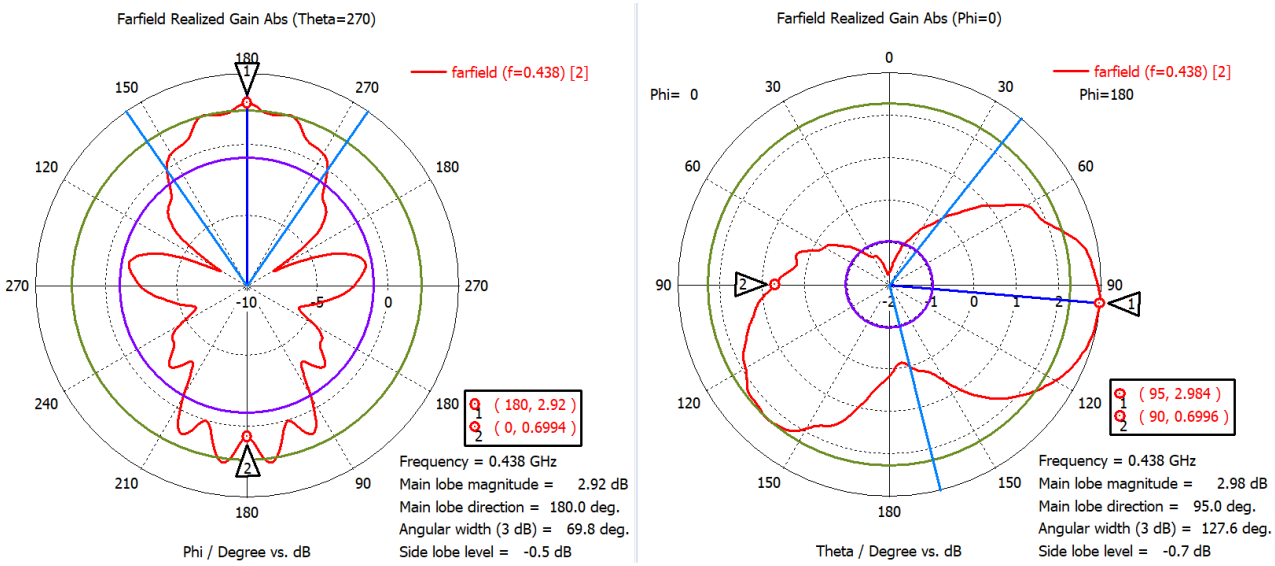

Figure 4. 12. Far-field Radiation Pattern for Right-Side UHF Dipole Antenna Design at 438MHz. Realized Gain. (Polar View)

At this final stage, including two S-Band 2x1 rectangular patch antenna arrays (at left- and right-side of CubeSat), two UHF Dipoles (at left- and right-side of CubeSat), and five 2.4m Wire antennas (at the front end of the CubeSat structure), we see that the farfield characteristic (radiation pattern) of each antenna is very different from the ideal behavior (Farfield for isolated antennas, or with minimum interference from surrounding elements), but the realized gain and directivity for all antennas is effectively higher. Also, compared with previous simulation designs, this configuration of S-Band 2x1 patch array has a higher gain and better directivity

The angle covered with each 2x1 rectangular patch antenna array is approximately 61° by 13°, directed slightly towards the front-side of the Cube, and for the UHF dipoles, the angle is of approximately 69° by 127°. As shown in figures 4.4 to 4.7 and 4.9 to 4.12, the pattern presents some interferences, but apparently have no negative effect in the integrated realized gain for the antennas over the relatively large angle they cover. Full comparison can be seen below in tables 1.1 and 1.2.

PARAMETER	Simulation without Dipoles or 2.4m Wire Antennas	Simulation adding only UHF Dipoles	Simulation adding only 2.4m Wire Antennas	Simulation adding Dipoles and 2.4m Wire Antennas
Input Reflection Coefficient (S11 Parameter)	**-7.705 dB (at 2.397 GHz)**	**-7.801 dB (at 2.4 GHz)**	**-11.895 dB (at 2.425 GHz)**	**-12.3729 (at 2.424 GHz)**
Half-Power (-3 dB Bandwidth)	121.7 MHz	120.5 MHz	279.8 MHz	277.7 MHz
Directivity	8.379 dBi	8.509 dBi	10.13 dBi	11.01 dBi
Gain (IEEE)	3.626 dB	3.948 dB	5.542 dB	5.922 dB
Realized Gain	2.812 dB	3.159 dB	5.118 dB	5.530 dB
Main lobe Magnitude	2.81 dB	3.06 dB	1.29 dB	4.72 dB
Half-Power Beamwidth (HPBW)	79.3°	74°	92.9°	61.4°
Front-to-Back Ratio	16.193 dB	17.831	17.616 dB	16.628

Table 1.1. Results Summary for 2x1 Patch Array Antenna with different companion antenna configurations (2.4m Wires and UHF Dipoles).

PARAMETER	Simulation of UHF Dipoles + 2x1 Patch Array	Simulation of UHF Dipoles + 2x1 Patch Array and 2.4m Wire Antennas
Input Reflection Coefficient (S11 Parameter)	**-14.1534 dB (at 441 MHz)**	**-13.5760 dB (at 432 MHz)**
Half-Power (-3 dB Bandwidth)	175.42 MHz	251.99 MHz
Directivity	3.149 dBi	3.794 dBi
Gain (IEEE)	2.712 dB	3.891 dB
Realized Gain	2.089 dB	2.995 dB
Main lobe Magnitude	2.08 dB	2.92 dB
Half-Power Beamwidth (HPBW)	72.1°	69.8°
Front-to-Back Ratio	2.8724	2.2185

Table 1.2. Results Summary for UHF Dipoles with different companion antenna configurations (S-Band 2x1 Patch Arrays and 2.4m Wires).