ANTENNA DESIGN COURSE

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CHAPTER 4

ANTENNA ARRAY DESIGN

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4.1 Fundamentals on Patch Antenna Design

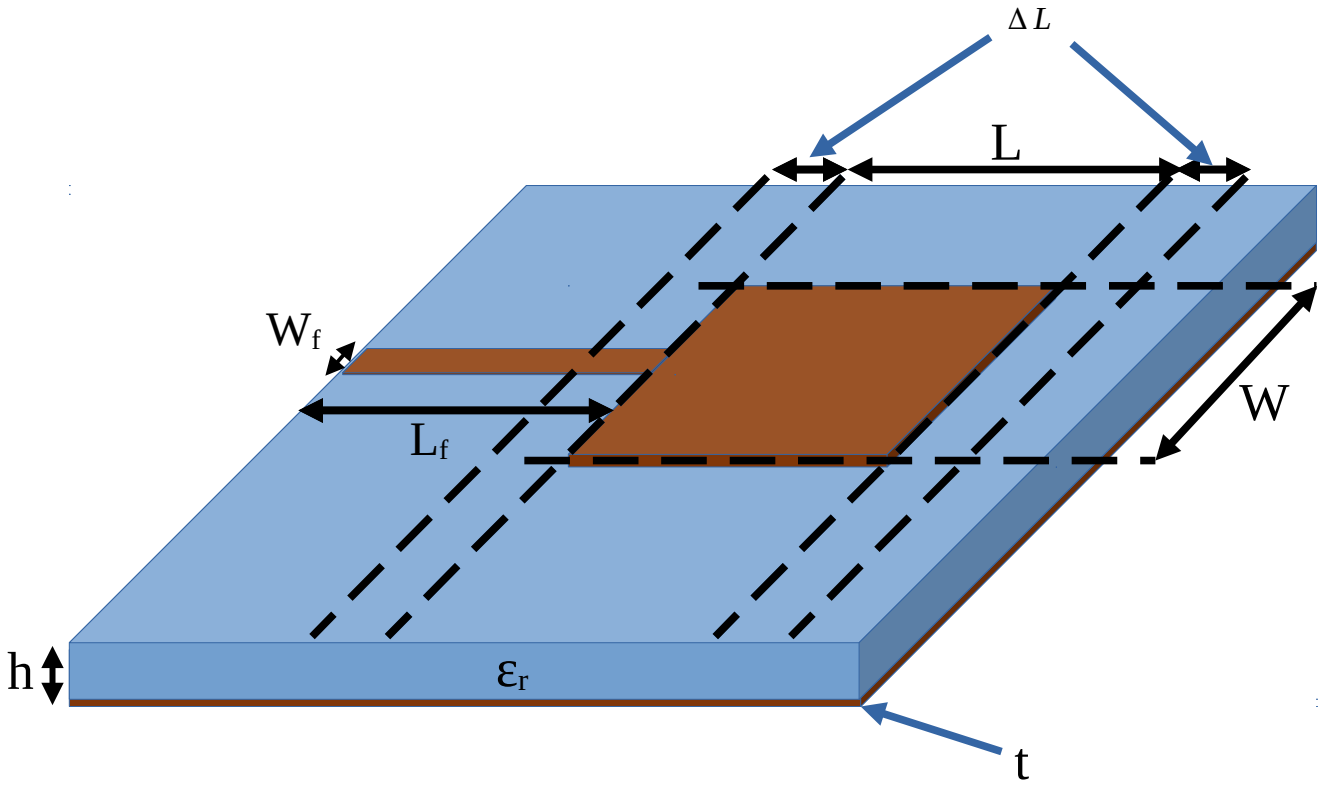


Fig. 1: Schematic of a patch antenna.

4.1.1 Basic Equations

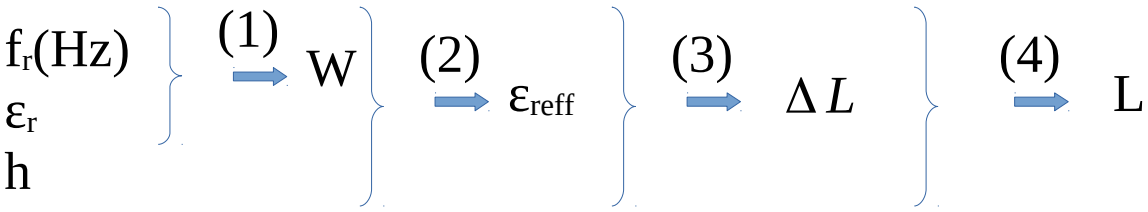
$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \cdot \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2 f_r} \cdot \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

$$\varepsilon_{r_{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \left[1 + 12 \cdot \frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

$$\Delta L = 0.412\, h \frac{\left(\varepsilon_{r_{eff}} + 0.3\right)\left(W + 0.264\, h\right)}{\left(\varepsilon_{r_{eff}} - 0.258\right)\left(W + 0.8\, h\right)} \qquad (3)$$

$$L = \frac{v_0}{2 f_r \sqrt{\varepsilon_{r_{eff}}}} - 2\Delta L \qquad \textbf{(4)}$$

4.1.2 Design Procedure Summary



To see a complete description of this procedure, read Section 14.2.1 in [CABAL]

4.2 Patch Antenna Design in CST

4.2.1 Modeling

Open CST,

Create Project Template,

Microwaves & RF / Optical,

Antennas, Next, Planar (Patch, Slot, etc.), Time Domain Next,

Unit configuration (mm, GHz, ns, Kelvin, V, A, Ohm, S, nH, pF), Next,

Frequency Min.: 2 GHz, Frequency Max.: 3 GHz.

Monitors: mark all.

Define at: 2; 2.4525; 3 GHz, Next. Finish.

Modeling

Parameter List,

W¨=37.2 mm, L=28.8 mm, Wf=3 mm, Lf=28.6 mm, h=1.6 mm. t=0.1 mm, Wg=2*W=74,4 mm, Lg=L+L/2+Lf=71,8 mm.

WCS, Local WCS to add a local set of coordinates.

Brick, double click, double click, double click, Name: Substrate, Umin: -W, Umax: W, Vmin: -L/2-Lf, Vmax: L, Wmin: 0, Wmax: h, Component: substrate, Material: Load from Material Library, FR-4 (lossy). Load

To make the Ground, Picks, Picks Face, double click in the ground face of the substract, Extrude Face (icon of a plane with an arrow), Name: Ground Plane, Height: t, Material: Copper (annealed), Load.

To make the patch, go to the front of the antenna, select Brick, double click, double click, double click, Name: Patch, Umin: -W/2, Umax: W/2, Vmin: -L/2, Vmax: L/2, Wmin: h, Wmax: h+t, Component: patch, Material: Load from Material Library, Copper (annealed), Load.

To make the Microstrip Feed Line, go to the front of the antenna, select Brick, double click, double click, double click, Name: MicrostripFeedLine, Umin: -Wf/2, Umax: Wf/2, Vmin: -L/2-Lf, Vmax: -L/2, Wmin: h, Wmax: h+t, Component: microstripfeedline, Material: Load from Material Library, Copper (annealed), Load.

Joining the Patch to the Microstrip Feed Line, Select Patch, Boolean, Add, select MicrostripFeedLine, enter, save.

4.2.2 Waveguide Port Placement

Waveguide Port placement, Picks, Pick Face, select the free end of the microstrip feed line, double click, Home, Macros, Solver. Ports, Calculate ports extensions coefficient, Select Microstrip, Dimensions W[mm]=4, h[mm]=1.6, Material Properties Er=4,4, Frequency range: 2 to 3 GHz, Calculate, then k=5.57 (k varies in the range: 3.57 a 5,57), Close. Then define a new parameter, k=5.57, save. Go to Simulation, Waveguide Port, Name 1, Positive, Use picks, Xmin= -1.5 – k*h, Xmax=1.5+k*h, Zin: 1.6-h, Zmax: 1.7+k*h, Xpos: -67.1792458, Distance to ref. plane: 0, Number of modes: 1, OK.

See the bounding box, View, Visibility, click Bounding Box (if it is not clicked), and observe that the Bounding Box includes all the antenna design.

4.2.3 Simulating

Simulation, Setup Solver, Normalize to fixed impedance 50 Ohm, Adaptive mesh refinement, Apply, save, Start.

4.2.4 Results

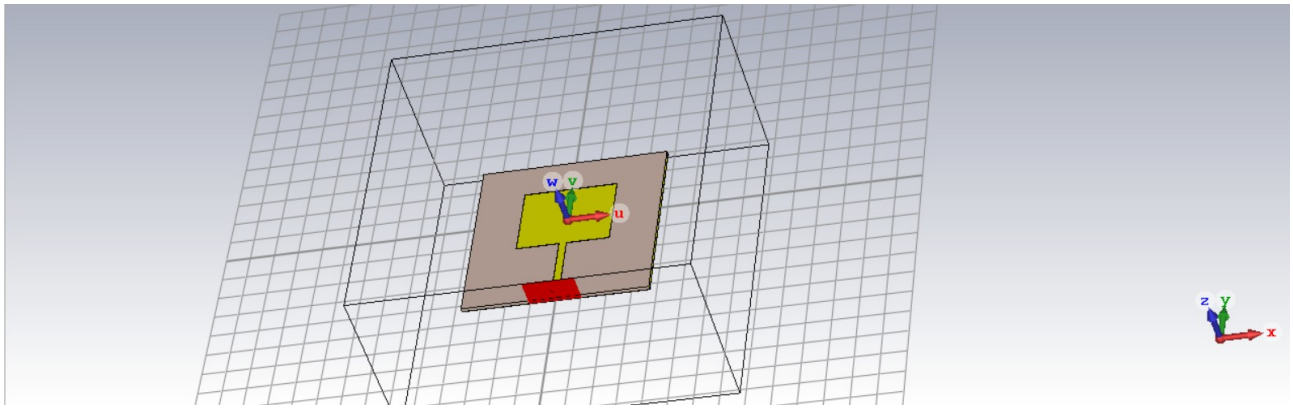


Fig. 2: Patch Antenna Model.

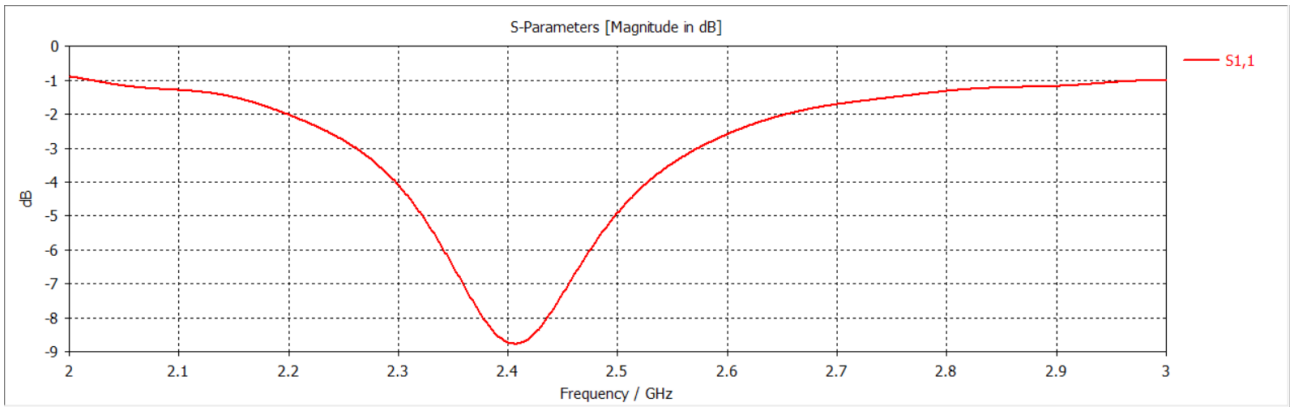


Fig. 3: S11 Parameter for the patch antenna.

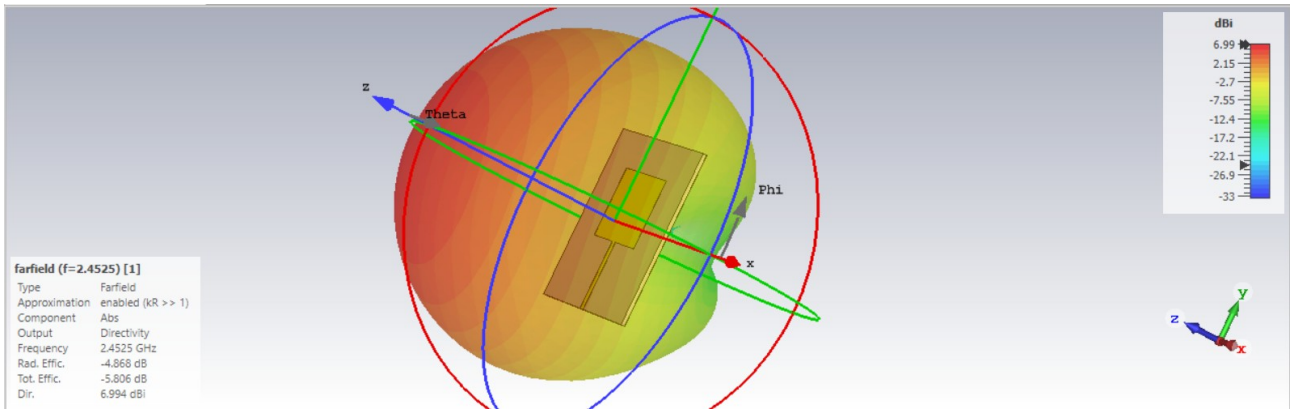


Fig. 4: Radiation Pattern for the patch antenna.

Trying to improve the S11 parameter in Fig. 3, the following simulation is done with optimized parameters as the one used in [REC01].

Modeling

Parameter List,

W¨=53 mm, L=28 mm, Wf=3 mm, Lf=30 mm, h=1.6 mm. t=0.1 mm, Wg=2*W=106 mm, Lg=L+L/2+Lf=72 mm.

Results

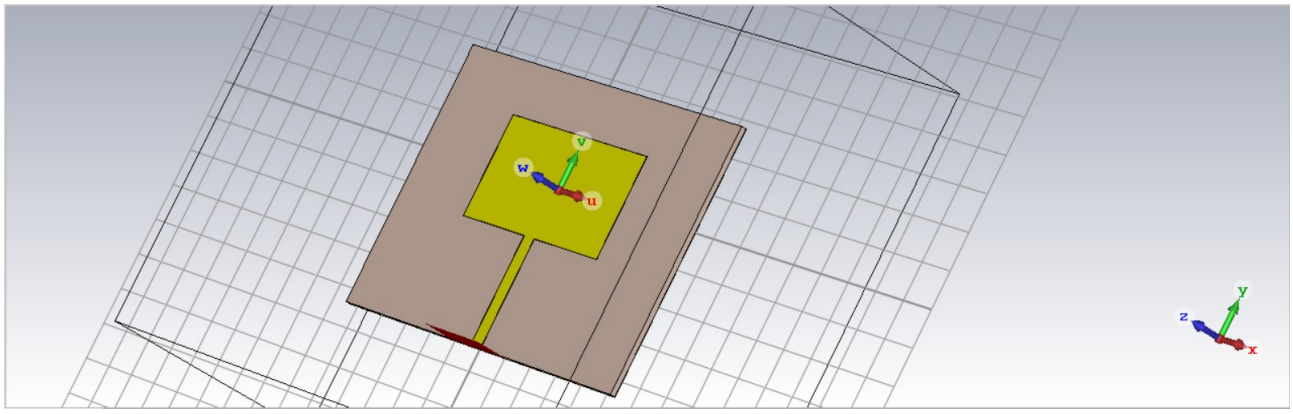


Fig. 5: Improved Patch Antenna Model.

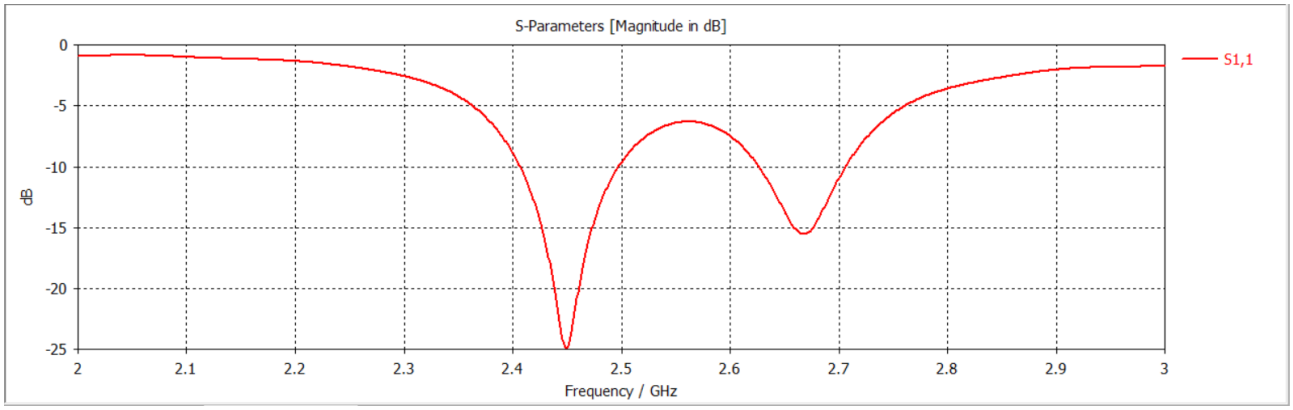


Fig. 6: S11 Parameter for the improved patch antenna.

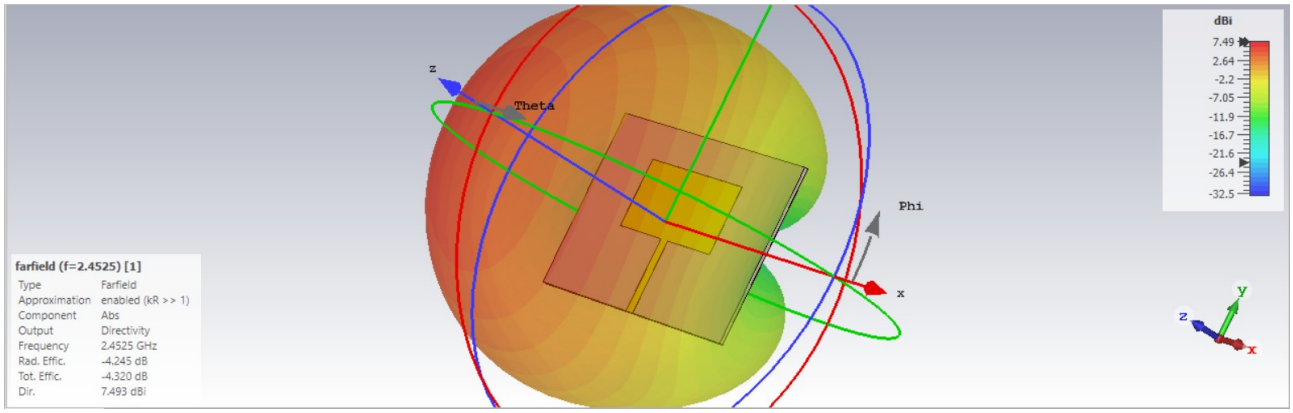


Fig. 7: Radiation Pattern for the improved patch antenna.

In this case the S11 parameter has an improvement of 16 dB.

4.3 Design of a Patch Antenna Array in CST

4.3.1 Modeling

1.- First the size of the substrate is increased from (2W)x(1.5L+Lf) to (6W)x(2L+Lf). To do this: make double click over Subtrate, Define brick, Umin:-3*W, Umax:3*W, Vmin:- L– Lf, Vmax:L, Componet: substrate, Material: FR-4 (lossy), enter. The Ground Plane was automatically extended.

2.- The patch antenna will be copied and translated. Select patch, copy and paste, rename the component as partch01 and Patch01. Then in the Modeling windows, select patch01, click over the icon Transform, Translate, Translation vector U:-2*W, V:0, W:0. Apply, Ok. Repit the same procedure to place the third path antenna of the array. At the end, rename the original patch antenna (which is placed in the center of the array) as patch02 and Patch02.

3.- Delete the microstripfeedline microwave port. Later it will be added in its new position. Also delete the k parameter (k=5.57). Go to Ports in the meu at the left, select Ports, and delete Port1.

4.- Put a common feed line. Modelling, brick, clic, click, click, Name: CommonFeedLine, Umin: -2*W-Wf/2, Umax: 2*W+Wf/2, Vmin: -L/2 -Lf – Wf, Vmax:-L/2 -Lf, Wmin: h, Wmax: h+t. Component: commonfeedline, Material: Cooper (annealed). Preview, Ok. Save.

5.- Add the common feed line to to the feed of each antenna. Select CommonFeedLine, Boolean, Add, select Patch01, enter. Repit the same process for Patch02 and Patch03 and save.

6.- Add the feed input. Modelling, brick, clic, click, click, Name: FeedInput, Umin: -Wf/2, Umax: Wf/2, Vmin: -L-Lf, Vmax: -L/2 -Lf – Wf, Wmin: h, Wmax: h+t. Component: feedinput, Material: Cooper (annealed). Preview, Ok. Save.

7.- Add the feed input to the commonfeedline. Select CommonFeedLine, Boolean, Add, select FeedInput, enter and save.

4.3.2 Waveguide Port Placement

Waveguide Port placement, Picks, Pick Face, select the free end of the microstrip feed line, doble click, Home, Macros, Solver. Ports, Calculate ports extensions coefficient, Select Microstrip, Dimensions W[mm]=3, h[mm]=1.6, Material Properties Er=4,4, Frequency range: 2 to 3 GHz, Calculate, then k=5.57 (k varies in the range: 3.57 a 5,57), Close. Then define a new parameter, k=5.57, Parametric Update, save. Go to Simulation, Waveguide Port, Name 1, Positive, Use picks, Xmin= -1.5 – k*h, Xmax=1.5+k*h, Zmin: 1.6-h, Zmax: 1.7+k*h, Xpos: -58, Distance to ref. plane: 0, Number of modes: 1, OK.

See the bounding box, View, Visibility, click Bounding Box (if it is not clicked), and observe that the Bounding Box includes all the antenna design.

4.3.3 Simulating

Simulation, Setup Solver, Normalize to fixed impedance 50 Ohm, Adaptive mesh refinement, Apply, save, Start.

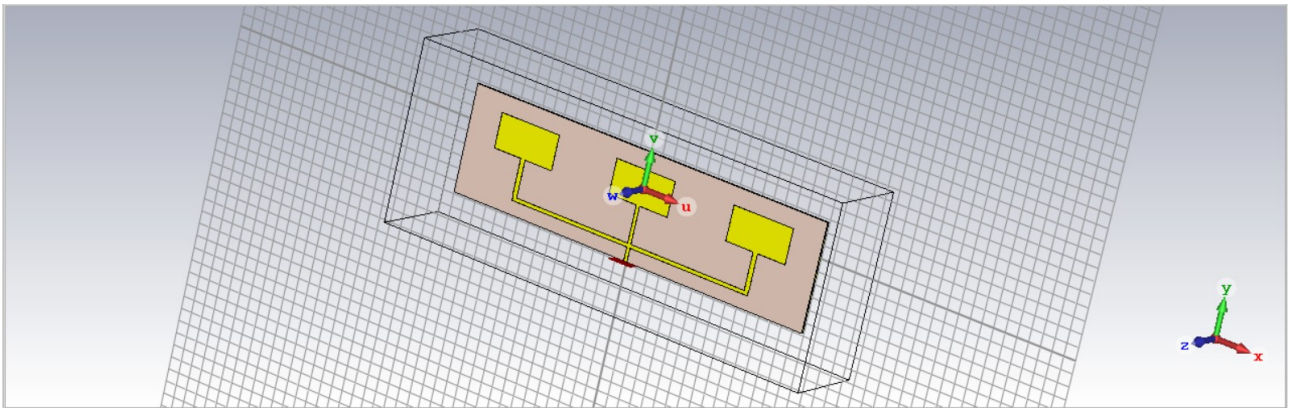


Fig. 8: Array Patch Antenna Model.

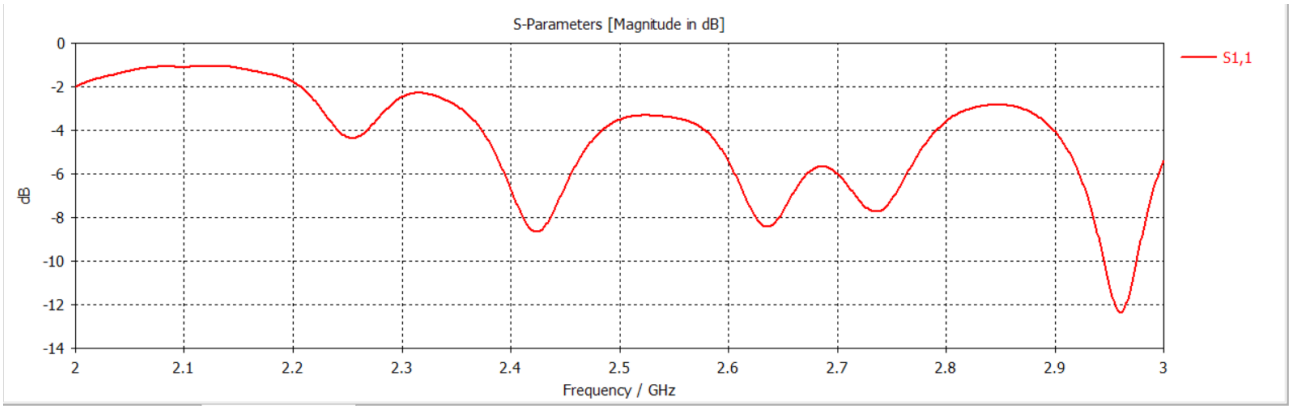


Fig. 9: S11 Parameter for the array patch antenna.

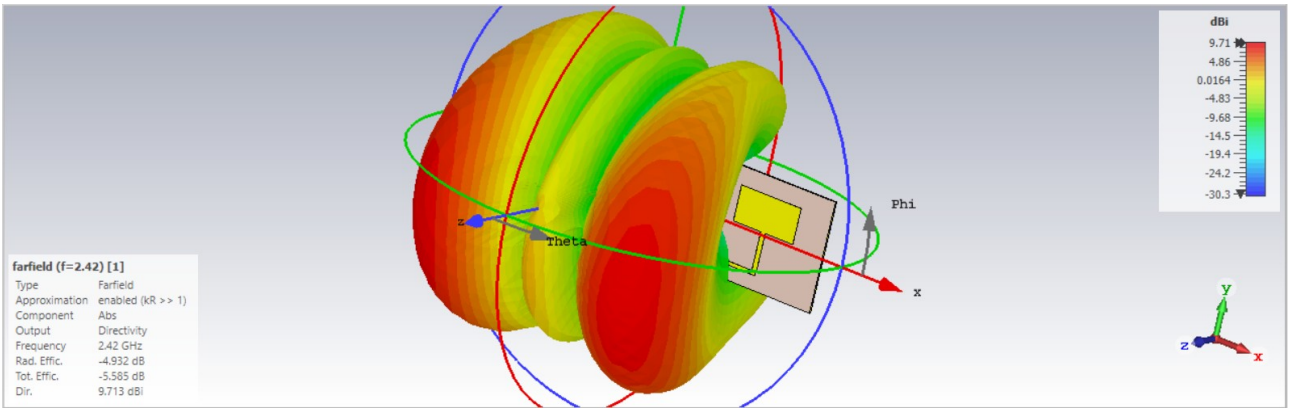


Fig. 10: Radiation Pattern for the array patch antenna at 2,42 GHz.

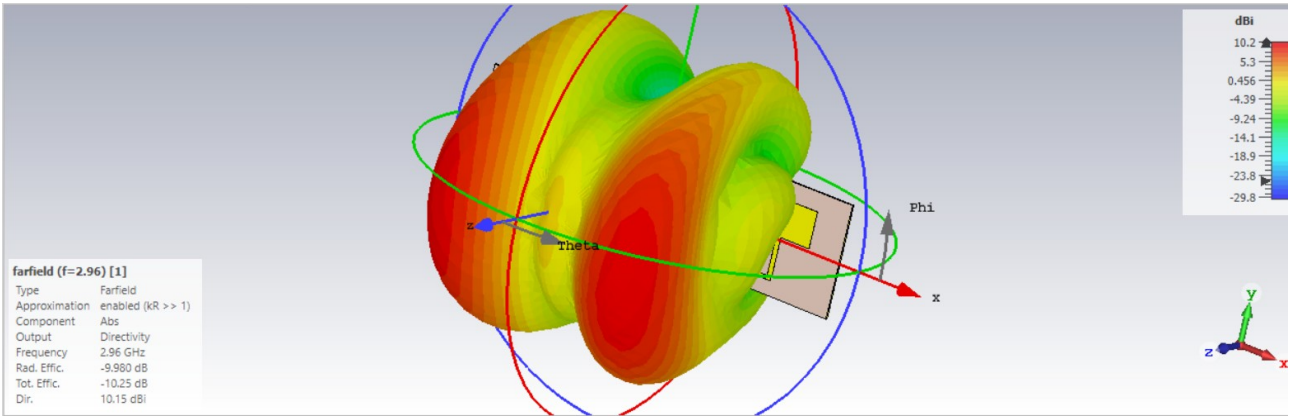


Fig. 11: Radiation Pattern for the array patch antenna at 2,96 GHz.

Now the idea is to move the position of the feeding line and observe the variations in the antenna array parameters.

4.3.4 Modeling

1.- Delete the feed input to relocate it. Modelling, brick, click, click, click, Name: Vacuum, Umin:-Wf/2, Umax: Wf/2, Vmin: -L-Lf, Vmax: -L/2 -Lf – Wf, Wmin: h, Wmax: h+t. Component: vacuum, Material: vacuum. Preview, Ok. Save. Then select FeedInput, Boolean, Substract, select, Vacuum, enter, save.

2.- Add the feed input 01. Modelling, brick, click, click, click, Name: FeedInput01, Umin:W-Wf/2, Umax:W+Wf/2, Vmin: -L-Lf, Vmax: -L/2 -Lf -Wf, Wmin=h, Wmax: h+t. Component: feedinput, Material: Cooper (annealed). Preview, Ok. Save.

3.- Add the feed input 01 to the commonfeedline. Select CommonFeedLine, Boolean, Add, select FeedInput01, enter and save.

4.- Delete the microwave port1. Later it will be added in its new position. Also delete the k parameter (k=5.57). Go to Ports in the menu at the left, select Ports, and delete Port1.

4.3.5 Waveguide Port Placement

Waveguide Port placement, Picks, Pick Face, select the free end of the microstrip feed line, double click, Home, Macros, Solver. Ports, Calculate ports extensions coefficient, Select Microstrip, Dimensions W[mm]=3, h[mm]=1.6, Material Properties Er=4,4, Frequency range: 2 to 3 GHz, Calculate, then k=5.55 (k varies in the range: 3.57 a 5,57), Close. Then define a new parameter, k=5.57, Parametric Update, save. Go to Simulation, Waveguide Port, Name 1, Positive, Use picks, Xmin= -51.5 – k*h, Xmax=54.5+k*h, Zin: 1.6-h, Zmax: 1.7+k*h, Xpos: -58, Distance to ref. plane: 0, Number of modes: 1, OK.

See the bounding box, View, Visibility, click Bounding Box (if it is not clicked), and observe that the Bounding Box includes all the antenna design.

4.3.6 Simulating

Simulation, Setup Solver, Normalize to fixed impedance 50 Ohm, Adaptive mesh refinement, Apply, save, Start.

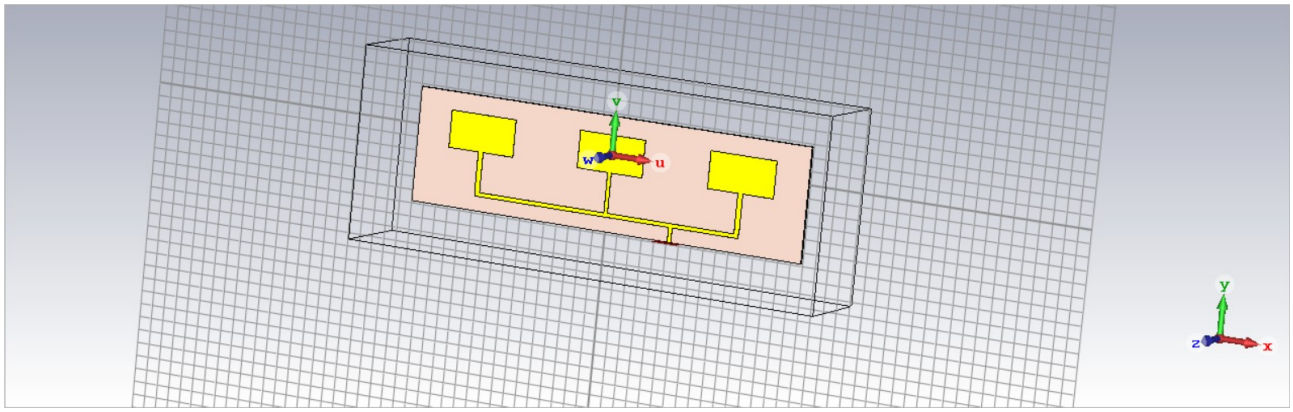


Fig. 12: Array Patch Antenna Model.

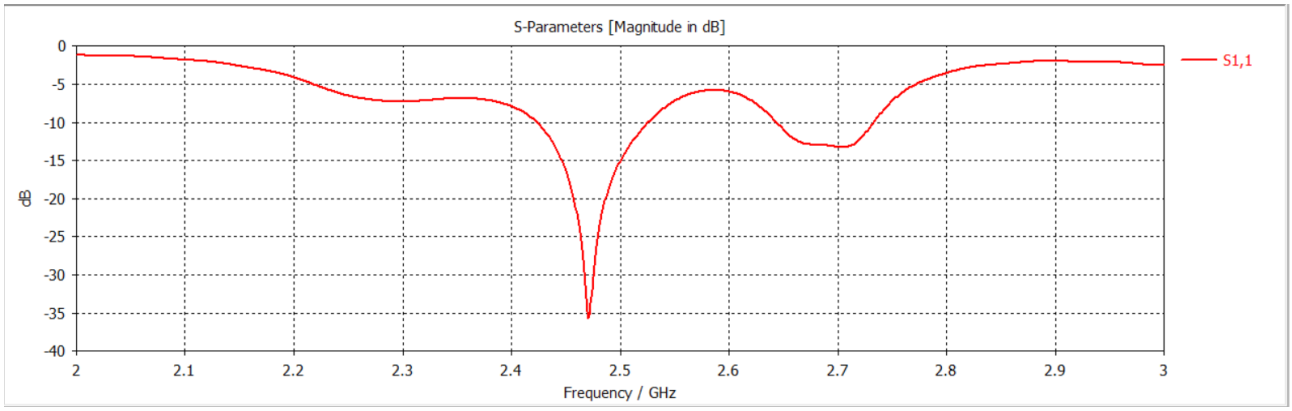


Fig. 13: S11 Parameter for the array patch antenna.

In this case the S11 parameter is very good.

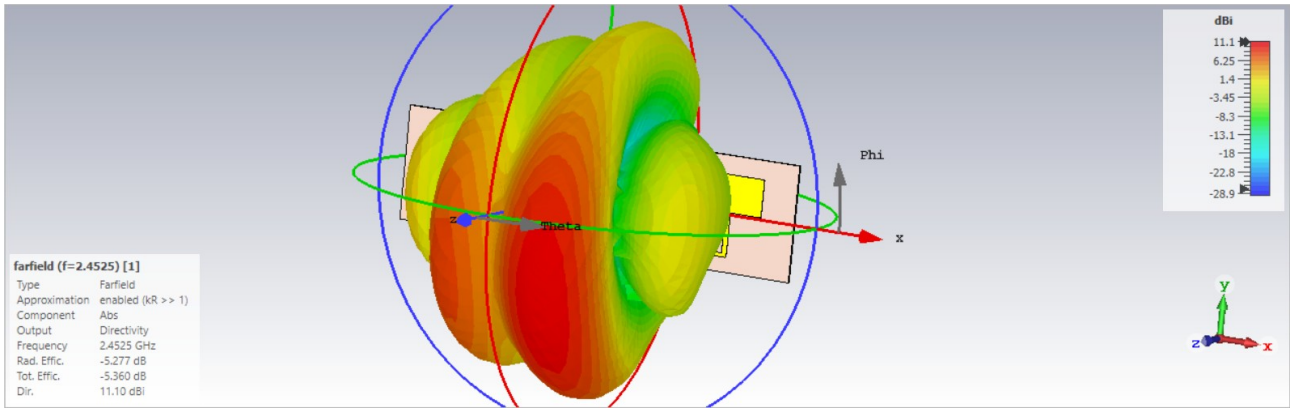


Fig. 14: Radiation Pattern for the array patch antenna at 2,4525 GHz.

In this last three figures important variations in the antenna parameters can be observed, just by changing the location of the feed line. By varying this location, is varied mainly the phase with each antenna element is fed, which produces the observed variations.

REFERENCES

CHAPTER 4 REFERENCES

CABAL: C. A. Balanis, ANTENNA THEORY Analysis and Design, 1997
REC01: Andry Contreras, Benigno Rodríguez, Leonardo Steinfeld, Javier Schandy, Mariana Siniscalchy, Design of a Rectenna for Energy Harvesting on Wi-Fi at 2.45 GHz, 2020

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