CST RFCA Project 2

94927104 3
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1) Coaxial Cable Design

TOP VIEW

$2a = 1mm$

$a = 0,5mm$

$\lambda = \frac{c}{f} = 42,857mm$

$l = 85,714mm = 2\lambda$

$\boxed{\text{Screen 0}}$

$\varepsilon = \varepsilon_0 \varepsilon_r$ ← 2,1 (Teflon)

$120\pi = \sqrt{\mu_0/\varepsilon_0}$

$$Z = 50\,\Omega = \sqrt{\frac{\mu}{\varepsilon}}\,\frac{\ln(b/a)}{2\pi}$$

$$b = a e^{(5/6)\sqrt{2,1}} = 1,673\,mm$$

We choose a and b to get matching with the characteristic impedance
~~So~~ in theory we shouldn't get any losses.
But in practice, the modelisation gets power absorbed by the coaxial cable
- mismatch losses
- ohmic losses
→ dielectric losses

We normalize the S-Parameters to 50Ω (SET UP SOLVER)

$\boxed{\text{Screen 1,2}}$ → S_{21}, S_{12} around 0dB → no significant losses

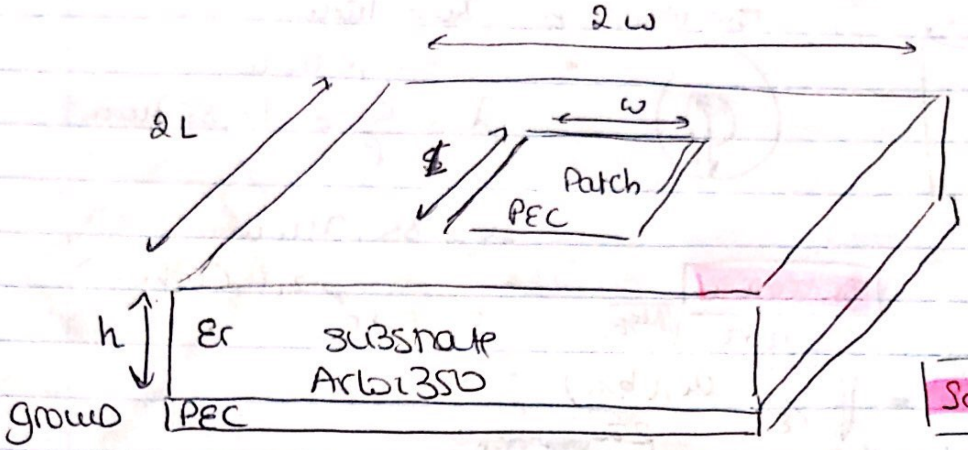
$\boxed{\text{Screen 3,4}}$ → S_{11}, S_{22} OPTIMIZED Below -25dB

insertion loss @ freq $f = 7GHz$ → $\boxed{\text{Screen 5}}$
$S_{21}(f = (7GHz)) \simeq 0dB$

/1

S Parameters optimized cable → min insertion loss → matching $\boxed{\text{Screen 1-5}}$

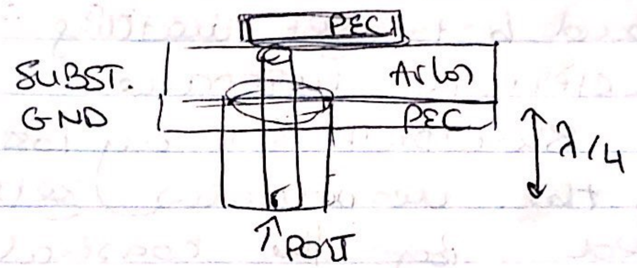
2)



$\boxed{\text{Screen 6}}$

$\boxed{\text{Screen 6bis}}$

SIDE VIEW



According to theory:

$\varepsilon_r = 3{,}5 \leftarrow$ Arlon 350 Permittivity const

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

$$L = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad \varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

$$\Delta L = 0{,}412\,h\,\frac{(\varepsilon_{reff} + 0{,}3)\left(\frac{W}{h} + 0{,}264\right)}{(\varepsilon_{reff} - 0{,}258)\left(\frac{W}{h} + 0{,}8\right)} =$$

$$x_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} - \text{location of pin.}$$

$\varepsilon_{r,eff}$ → Because of fringing effect of the electric field → ε_r of substrate and ε_0 of the air combine to ε_{reff}
↳ lower than ε_r, dielectric substrate

We can also change a and b radius of the coaxial cable to get matching as long as their ratio doesn't change

We chose the following parameters

$W = 13{,}33$ mm $\varepsilon_{reff} = 3{,}05$ $x_f = 2{,}86$ mm
$L = 9{,}994$ mm $\Delta L = 0{,}729$ mm $r_{out} = b = 0{,}873$
$h = 1{,}6$ mm $r_{in} = a = 0{,}25$
ground height = ~~[illegible]~~ = 0,02 mm   coax length: $\lambda/4$
patch height = 0,5 mm ≈ $h/3$ $\lambda = 40$ mm

input matching over $0{,}7f : 1{,}3f$ → 4,9 → 9,1 GHz
$\boxed{\text{Screen 7}}$ → 6,86 → 7,14 GHz freq. range has return loss better than −10 dB!

We got the size patch according to the theoretical results. Small deviations can be explained by fine tuning parameters due to practical losses!   Theory match w/ (7,5GHz)

3D far field RP of the patch antenna @ $f = 7$ GHz
$\boxed{\text{Screen 8}}$

RP YZ plane: Elevat° RP | Screen 9 a,b

RP XZ plane: Azimuth RP | Screen 10 a,b

We can see that our Patch antenna has a maximum of 7,21 dBi which is very comparable to an ideal patch 7,5dBi. The difference can be explained by practical losses.

- Direction of Peak gain: Z-direction

Peak gain: 7,05 | Screen 11

Directivity: 7,22 | Screen 12

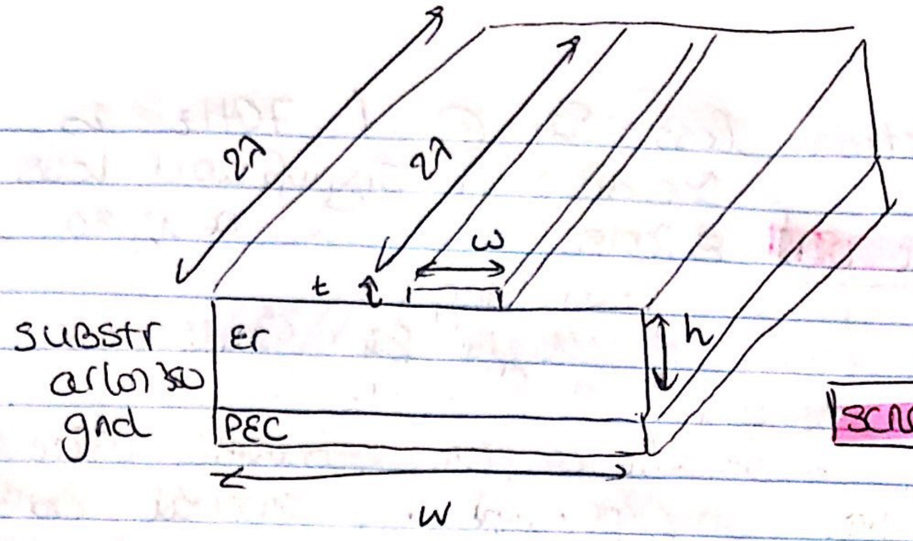
$\eta = G/D = 97,65\%$

- Surface currents on Patch antenna | Screen 13

- Surface currents on the ground Plane | Screen 14

As expected from theory, we can see from the last 2 screens that the highest current comes from the port (@ the edge of the coaxial cable) and then spreads up to the ground plane and to the patch antenna through the inner pin of the coaxial cable (PEC) since we extended the inner pin up to the point between substrate and patch antenna.

3)



screen 15

$l = 2l = 80$ mm
$W = 13{,}\cancel{33}$ mm
$w = 0{,}312$ mm
$h = 1{,}6$ mm
$t = 0{,}5$ mm

t is chosen ~~as~~ the same height as the Patch antenna
while w is calculated for 100 Ω impedance matching

⚠ Simulate > Setup Solver > normalize to fix impedance : 100 Ω.
we place ports @ edges of microstrip line.

$$w = \frac{7{,}48h}{e^{\left(Z_0 \frac{\sqrt{\varepsilon_r + 1{,}41}}{87}\right)}} - 1{,}25t$$

when using W from the patch antenna we were matching f = 7,2GHz instead of 7GHz
So we tuned our model in order to get matching @ f By modifying W = 14 mm

- S_{11} screen 16 → −35 dB @ f = 7GHz
  S_{22} screen 17 → " " "

↳ Below −25 dB ✓

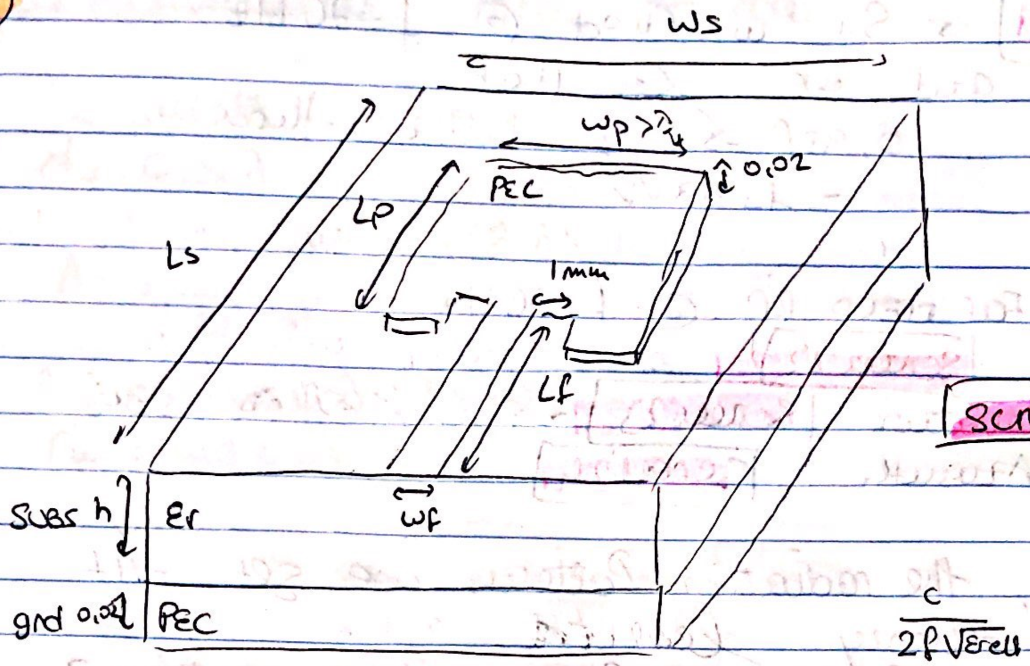
- The insertion loss S_{21} @ $f = 7GHz$ is $\simeq 0dB$ → no significant loss

$\boxed{\text{Screen 18, 19}}$ expected since we designed for matching!

A coaxial cable of length 27 would have "better" insertion loss.

Stripline depending on its geometry usually is slightly higher than coaxial cable in loss ($\simeq \times 10$)

4)



screen20

$$\lambda = \frac{c}{f} = 41{,}38 \qquad W_p = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad L_p = \underbrace{L_{eff}}_{\frac{c}{2f\sqrt{\varepsilon_{reff}}}} - 2\Delta L$$

$$h = \frac{0{,}0606\lambda}{\sqrt{\varepsilon_r}} \qquad L_s = L_p + 6h \qquad W_s = W_p + 6h$$

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}} \qquad L_f = \frac{\lambda_g}{4} \qquad W_f = \frac{7{,}48\,h}{e^{\left(Z_0 \frac{\sqrt{\varepsilon_r+1{,}41}}{87}\right)}} - 1{,}25t$$

Because our dialectric substrate is not that high we used other matching options of the Patch antenna to the line By tuning the above parameters: and we used the following values (f=7,25G)

$W_p = 13{,}79$mm $\qquad \varepsilon_{reff} = 3{,}099$

$h = 1{,}34$ mm $\qquad L_p = 10{,}492$mm

$W_s = 21{,}83$mm $\qquad L_s = 18{,}532$mm

$L_f = 5{,}88$ mm $\qquad W_f = 0{,}76$mm

Note: the impedance of the line remains 100Ω!

SCREEN 21 → S_{11} matched @ $f = 7GHz$
and we see that
$0,98f \rightarrow 1,02f$ Better than
$-10\ dBW$

- 3D Far FIELD RP @ $f = 7GHz$
SCREEN 22
  - Elevation SCREEN 23
  - Azimuth SCREEN 24

Again, the radiation Patterns we get fit the theory learned
We get similar shape as in section 3
with directivity direction: z-axis

5). Normalized Array Factor

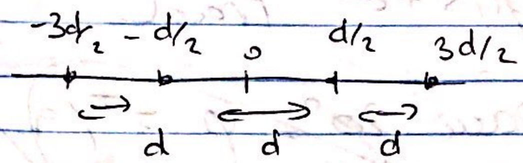
4 elements along x-axis

$d = 0{,}5\lambda$ $\quad N=4$

$$AF = \frac{1}{N}\sum_{m=1}^{N-1} e^{j(\hat{r}\cdot\vec{r_m})k}$$

$\hat{r} = \sin\theta\cos\varphi\,\hat{x} + \sin\theta\sin\varphi\,\hat{y} + \cos\theta\,\hat{z}$

$\vec{r_m} = md\,\hat{x}$



$$AF = \frac{1}{4}\left[e^{j\sin\theta\cos\varphi\frac{kd}{2}} + e^{-j\sin\theta\cos\varphi\frac{kd}{2}} + e^{j\sin\theta\cos\varphi\frac{3dk}{2}} + e^{-j\sin\theta\cos\varphi\frac{3kd}{2}}\right]$$

$$AF = \frac{1}{2}\left[\cos\left(\sin\theta\cos\varphi\frac{\pi}{2}\right) + \cos\left(\sin\theta\cos\varphi\frac{3\pi}{2}\right)\right] \quad //$$

$kd = \pi$ $\quad \Delta\varphi = 0$ $\quad \boxed{\text{Screen } 25+26}$

We get a sinc shaped as expected from the Theory.

$\psi = \sin\theta\cos\varphi\, kd - \Delta\psi$

- Array Directivity

$$D = \frac{2\pi}{P_{rad}} \qquad P_{rad} = \int_{\theta=0}^{\pi/2} \int_{\varphi=0}^{2\pi} U(\theta,\varphi) \sin\theta \, d\varphi \, d\theta$$

$U(\theta,\varphi) = AF^2$ using Matlab Numerical solver

$$D = 4 = \frac{2\pi}{1{,}57a} \; P_{rad}$$

- Steer Beam $\theta = 20° = \pi/9 \simeq 0{,}35$ rad

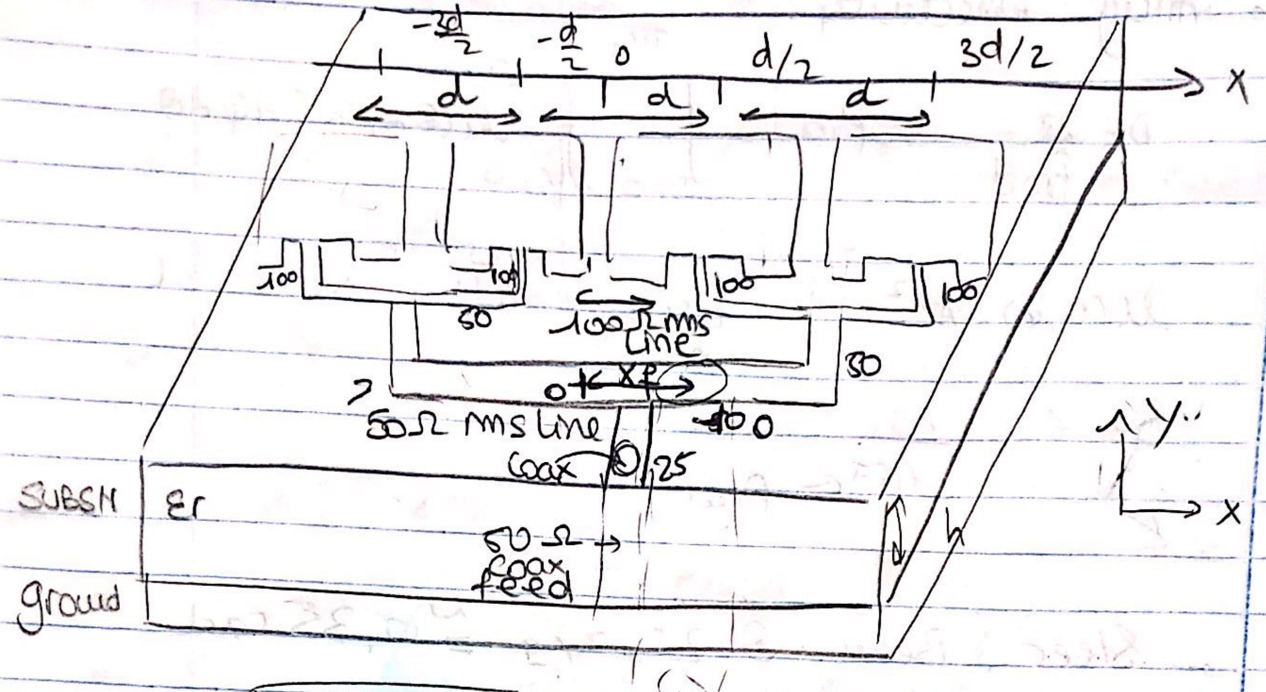
$$\psi = \frac{kd}{\pi} \cancel{\cos}(0°) \sin(\theta) - \Delta\phi = 0$$

$$\Rightarrow \Delta\phi = \pi \sin\left(\frac{\pi}{9}\right) = 1{,}074$$

$$\psi = kd \sin\theta - \Delta\phi$$

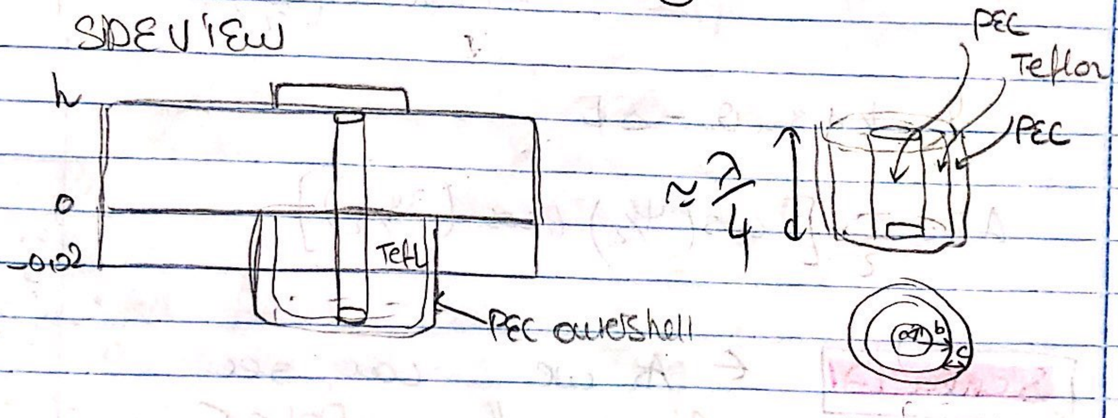
$$AF = \frac{1}{2}\left[\cos(\psi/2) + \cos(3\psi/2)\right]$$

~~Screen 27~~ ← As we can see from the polar representation, get ~~we~~ a pattern directed towards $\theta \simeq 20°$. Moreover the cartesian representation shows maximas at $\theta = 0{,}35$ rad $= 20°$ as expected



SCREEN 28,29 4 elements array along the x axis

SIDE VIEW



4 elements x axis $d=0,5\lambda$
vertical Polarization $\theta=0$ $E=E_0\hat{y}$

The array configuration narrows the Radiation Pattern in the φ plane

The physics of the array does not depend on the arbitrary chosen axis System

100 to 50 ohms width transformers were calculated thanks to the following formula

$$W_{50} = \frac{7{,}48h}{e^{Z_0 \sqrt{\frac{\varepsilon_r + 1{,}41}{87}}}} - 1{,}25t = 1{,}63$$

$W_{100} = 0{,}76\,mm = W_f$ $\qquad d = \lambda/2 \qquad \lambda = 41{,}38\,mm$

$L_f = 5{,}88\,mm$ $\qquad W_S = 21{,}63\,mm$

$h = 1{,}34\,mm$ $\qquad L_S = 18{,}532\,mm$

$r_{out} = 0{,}35\,mm$ $\qquad W_p = 13{,}79\,mm$

$r_{in} = 0$ $\qquad L_p = 10{,}492\,mm$

x_f = dist of the coaxial cable on the $\hat{x}$-axis from the origin.

↳ middle of a 100 Ω line → 50 Ω

We can take the formulas developped in class for array along the z axis and replace θ by φ

⚠ this is only valid when looking at the yz-plane (for x-array)
ow, one should consider to add correction terms.

We can see that for the centered ($\parallel \hat{x}$-axis) coaxial cable we get matching @ f = 7,6 Hz

| Screen 30 |

S_{11} is matched around our frequency and gets better than -10dB

- Different from section 4 since now 4 patch antennas interact with each other
  ↳ coupling effect

3D, Polar, 2D RAD Pattern [Screen 31, 32, 33]

" " " Azimuth RP [Screen 34, 35, 36]

" " " Elevation [Screen 37, 38, 39]

- We get expected Radiation Pattern since for an array we have

$$RP_{array} = RP_{\substack{\text{single}\\\text{element}\\\text{(patch)}}} * AF$$

and as expected, most of the radiation happens around the origin (coax cable)

Peak Directivity: 11,87 [Screen 40]

gain: 11,82 [Screen 41]

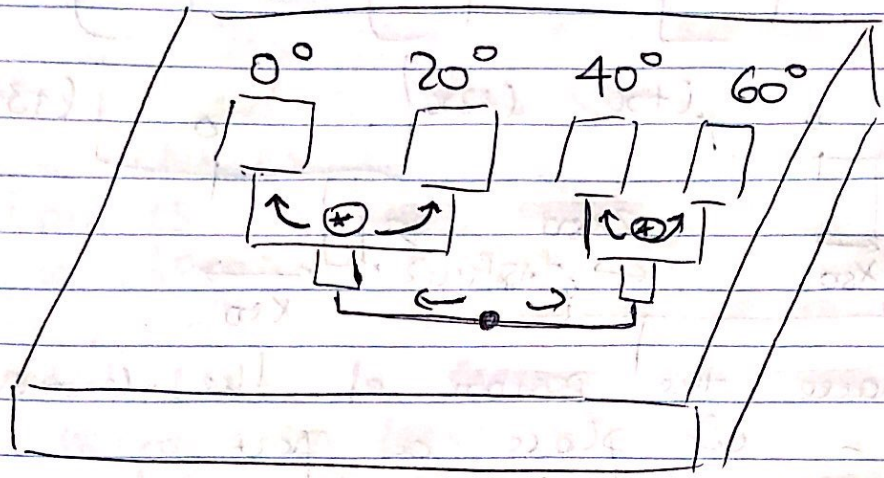
η = 99,9% efficiency @ f = 7GHz.

We can see that we get very high efficiency.

- Difference from matlab comes from the fact that we used the following approximation

$M \approx (AF)^2$

- Beam Steering -



↓ prop const

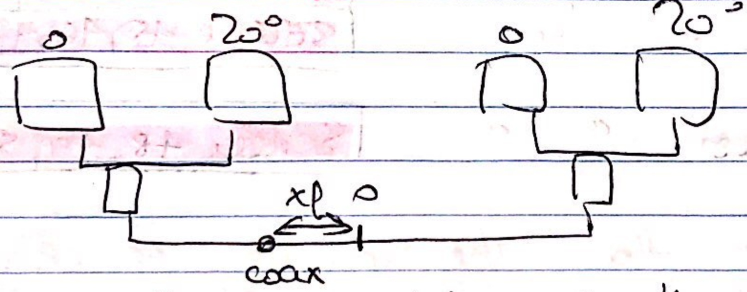
$\beta l = \Delta\phi$ $\qquad$ $\beta(l_1 - l_2) = \Delta\phi$

↑ total length

we should create an offset Bw ∀ 2 patch antennas (transformer λ/4 should not be centered) (to the left)

But the 2 groups of 2 patch antennas won't be delayed between them

ie



to create the phase delay of the first picture we'll also need to move the feeding point = coaxial cable

$$\beta x_f = \beta\Delta l = \frac{40/2}{180}\pi = \pi/9 = \beta\Delta l$$

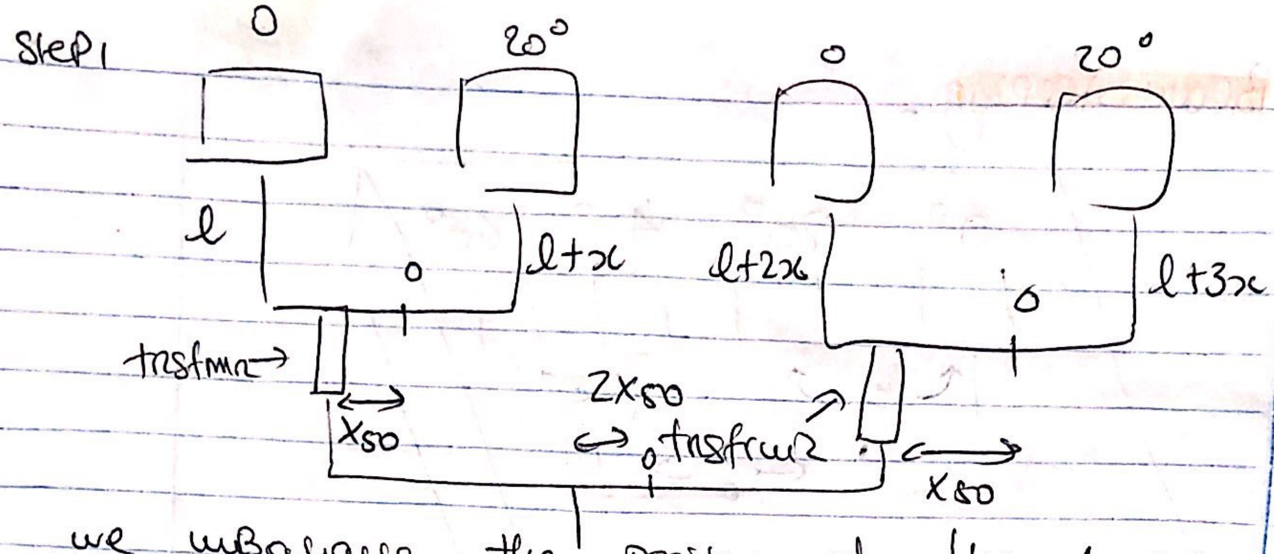
$\pi/9 = 20°$

$$\Delta l = x_f = \frac{\pi}{9\beta} = \frac{\pi}{9}\frac{\lambda}{2\pi} = \frac{\lambda}{18} = 2x_{50}$$

$$x_{50} = \frac{\Delta l}{2} = \frac{\lambda}{36}$$

$$\beta d = \frac{2\pi}{\lambda}\frac{\lambda}{2} = \pi = 180°$$

Step 1



we unbalance the position of the λ/4 (?) transformer. We place a port on each antenna and check the phase of the S_{ij} parameters where $j=1$ is the coaxial port

So S_{21}, S_{31}, S_{41}, S_{51}

- Absolute RP. (3D, 2D, Polar) $\boxed{\text{Screen 42, 43, 44}}$
- Azimuth " " $\boxed{\text{Screen 45, 46, 47}}$
- Elevation " " $\boxed{\text{Screen 48, 49, 50}}$

We can see that the radiation pattern got affected / different shape when applied with beam steering and this is expected since the location of the feeding point changes the main lobe direction → for directivity purposes

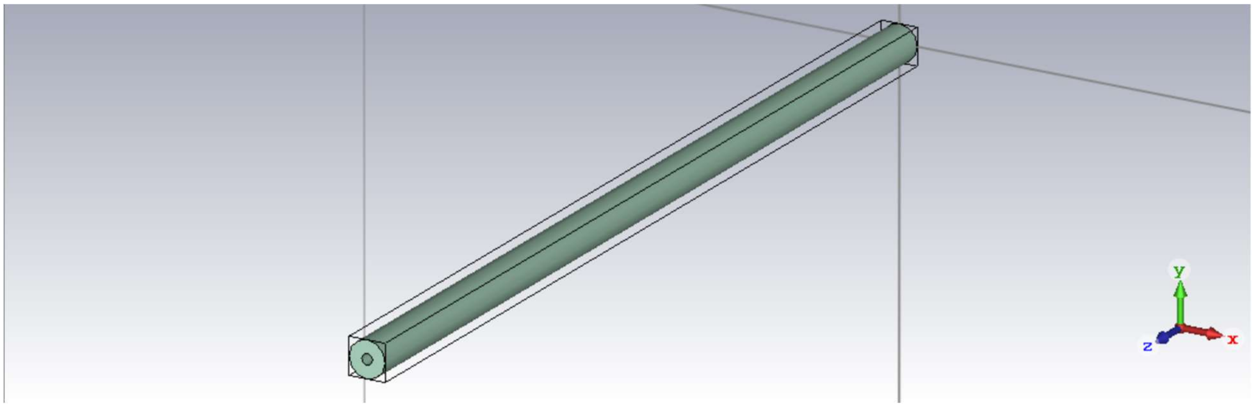
- input matching S_{11} $\boxed{\text{Screen } S_{1}}$

To apply linear phase, we unbalanced our picture and so the input matching also changes.
This is because, when moving the source location (coaxial cable matched to 50Ω) from the middle of the 100Ω horizontal line, you're no longer at exact 50Ω.
This of course affect the Sparameter behaviour.

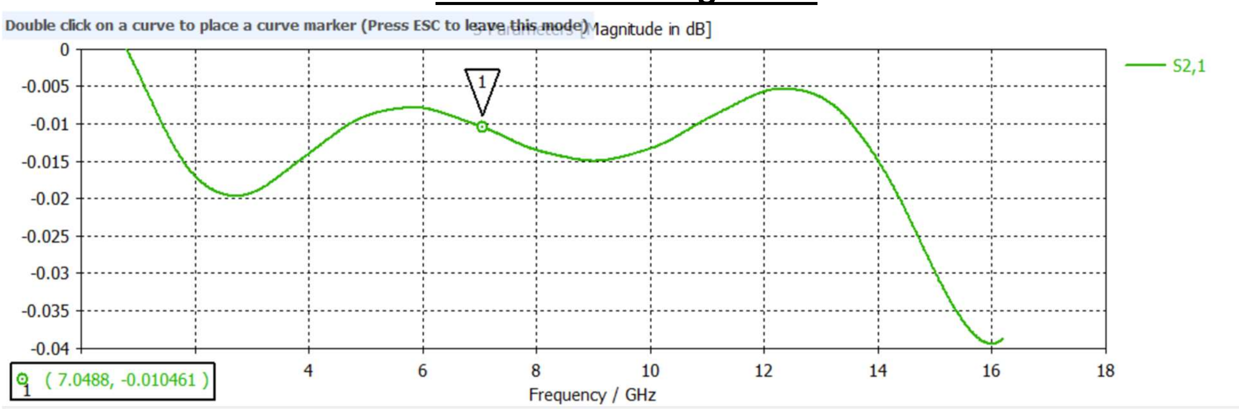
However, our undirected R.P was already close to 20° so we didn't have to use a big distance so that's the reason why our input matching pattern is still valid.

PART 1: COAXIAL CABLE

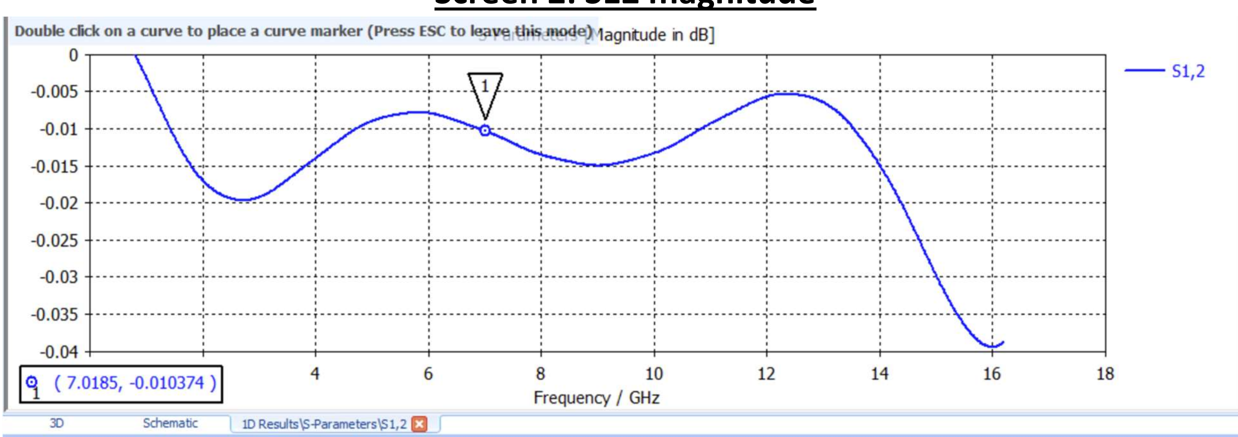
Screen 0: coaxial cable



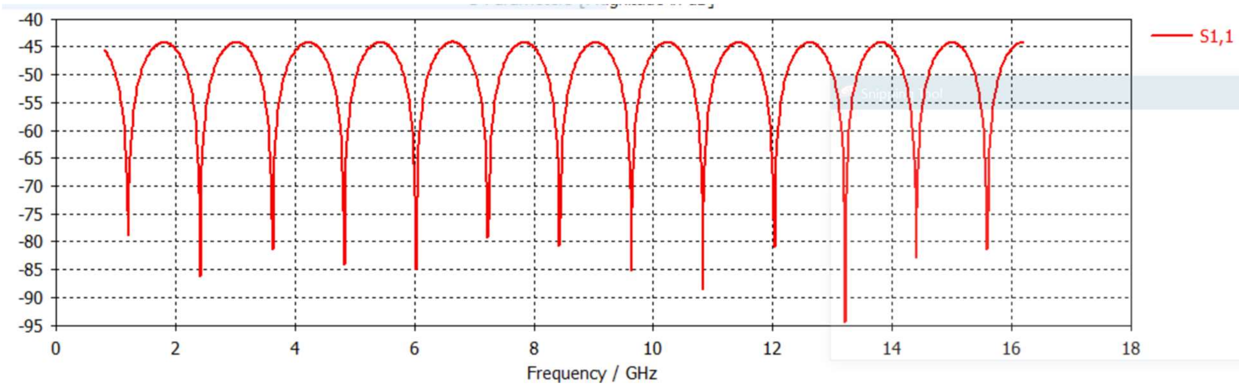
Screen 1: S21 magnitude



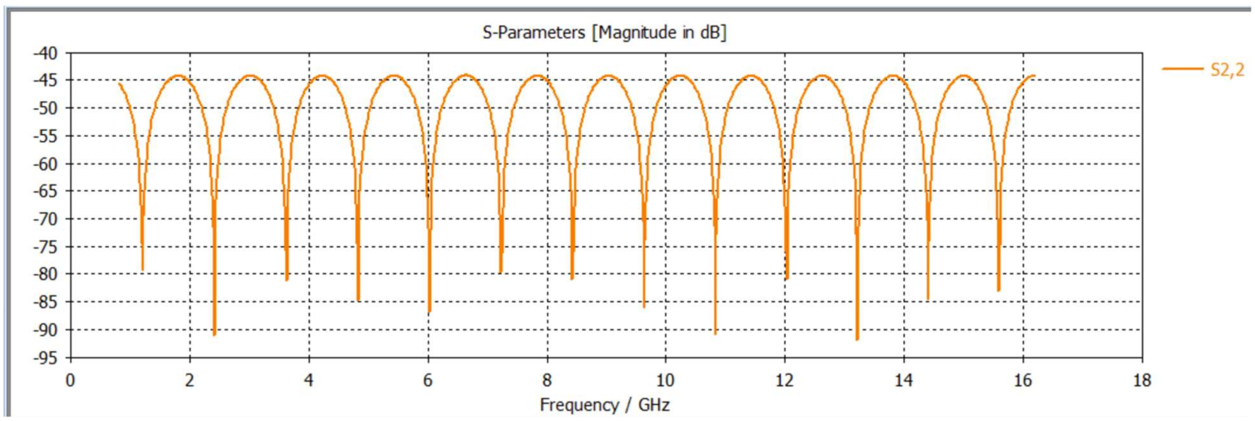
Screen 2: S12 magnitude



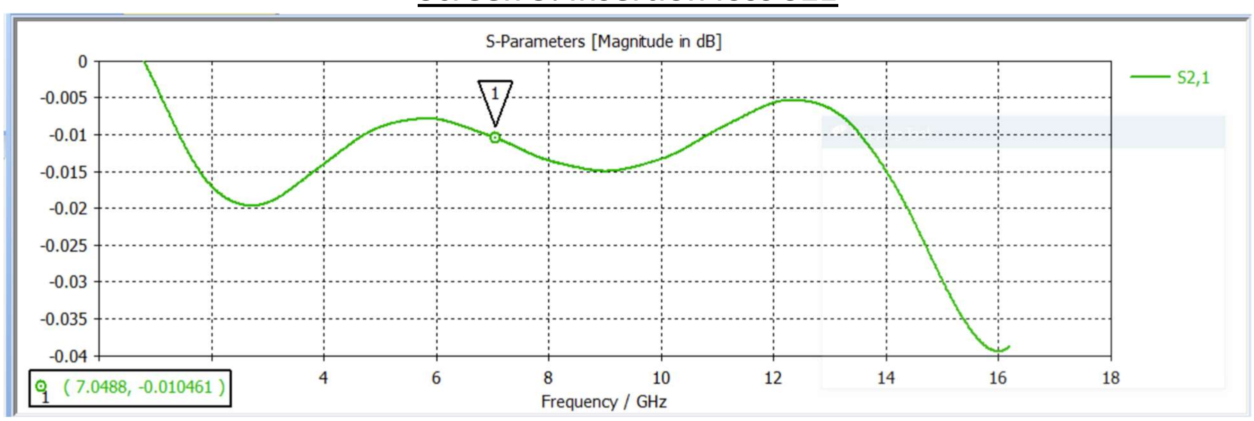
Screen 3: S11 magnitude



Screen 4: S22 magnitude

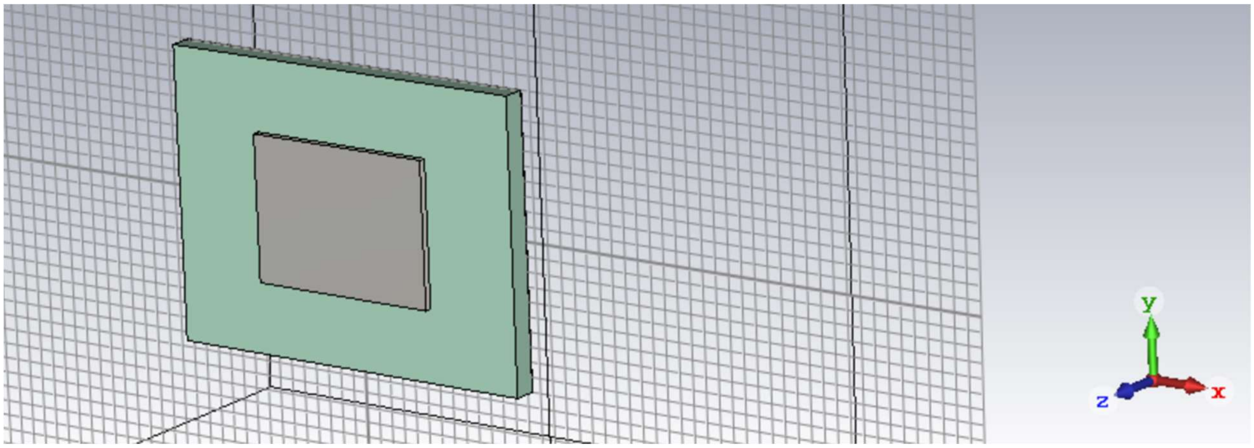


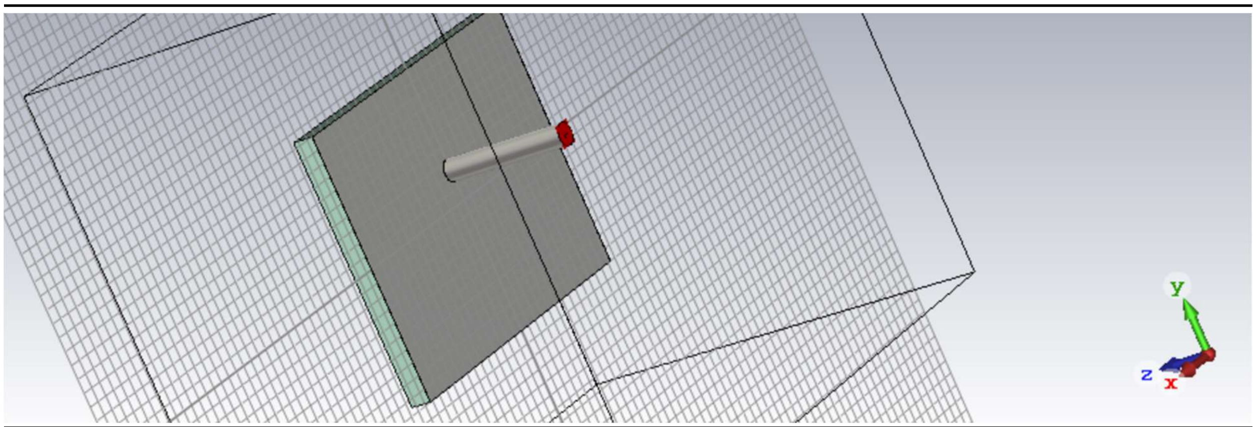
Screen 5: insertion loss S21



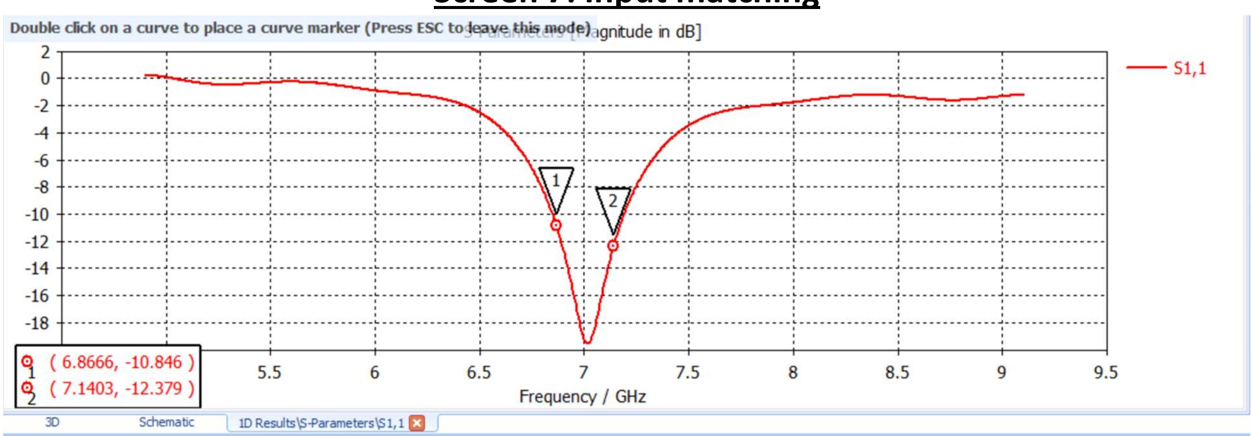
PART 2: PATCH ANTENNA COAX FEED

Screen 6: Patch antenna

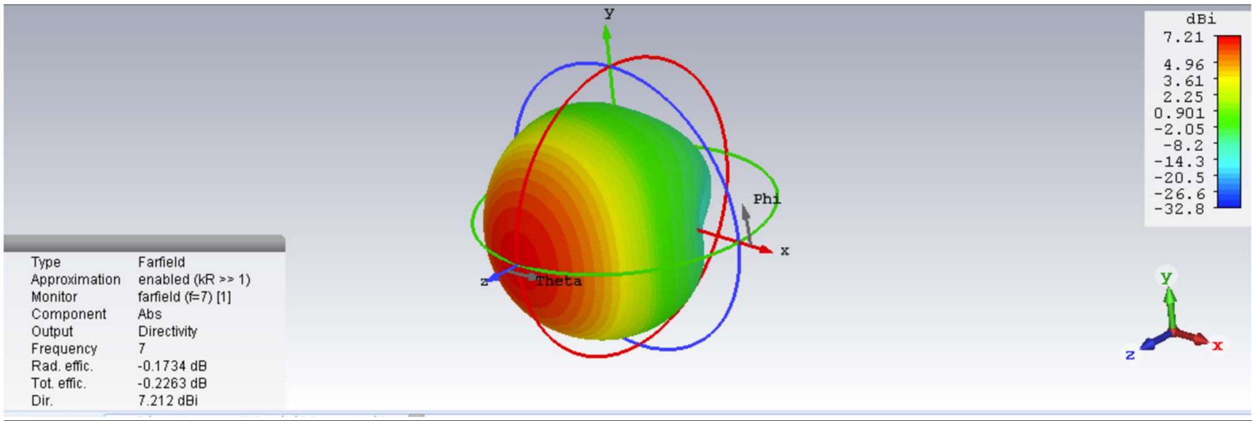




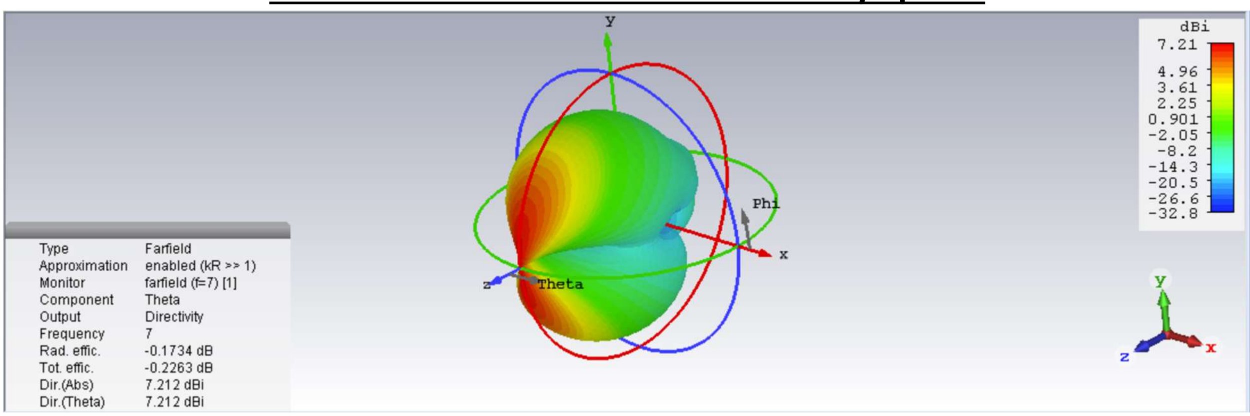
Screen 7: Input matching

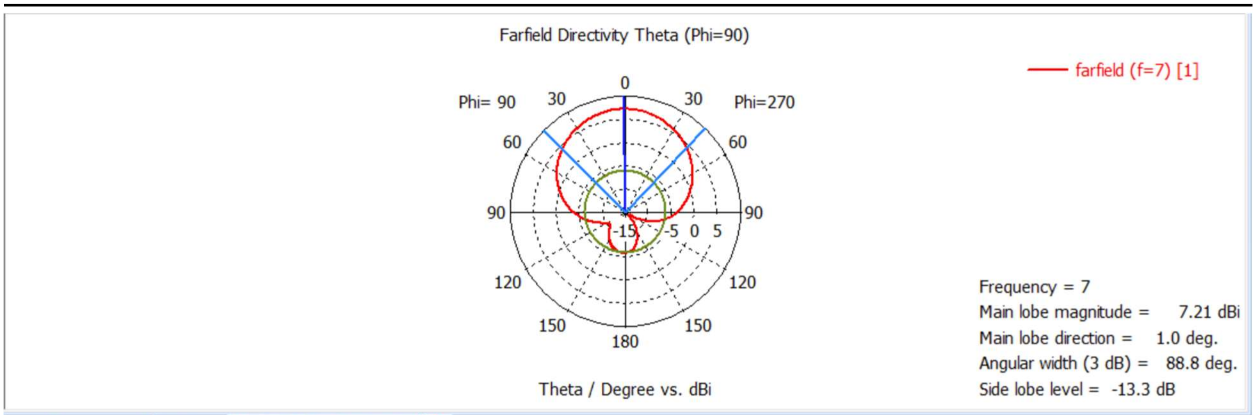


Screen 8: 3D field Radiation Pattern of the Patch antenna at f=7GHz

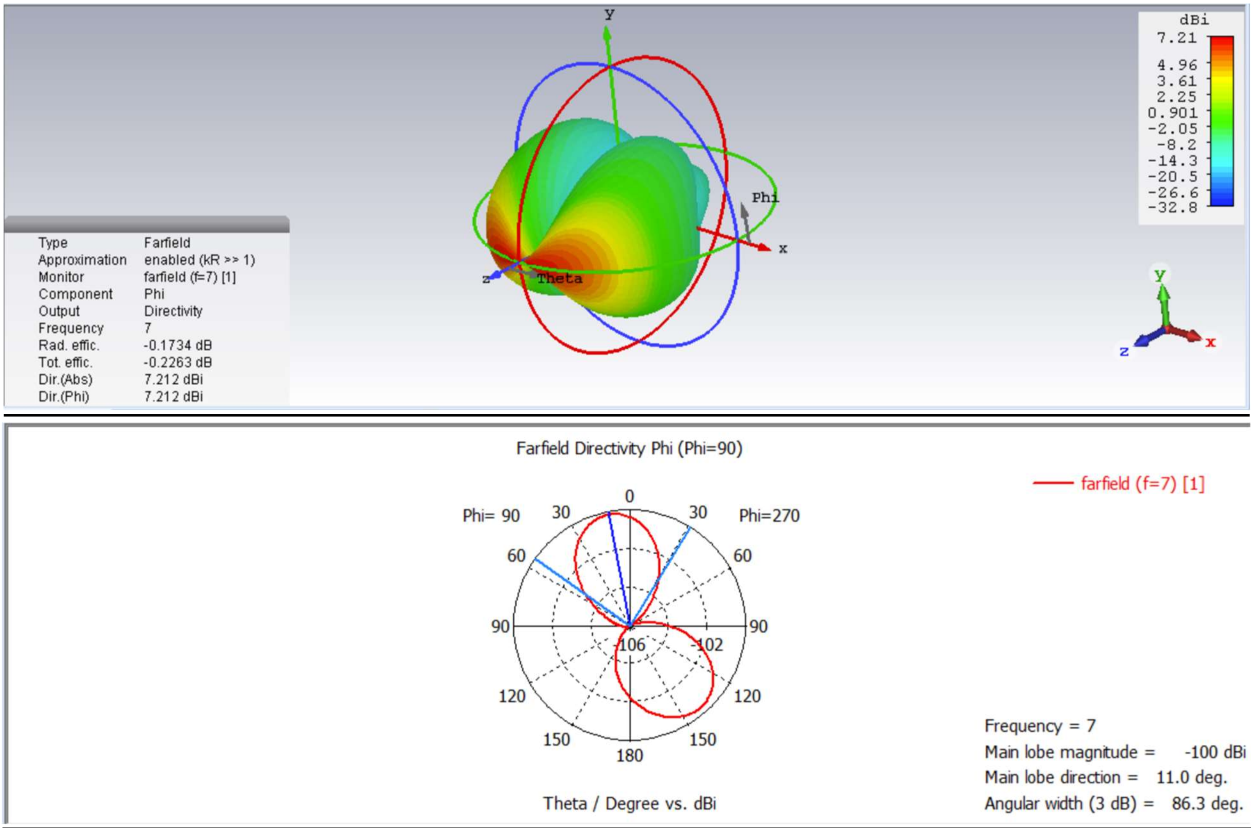


Screen 9: Elevation Radiation Pattern yz-plane

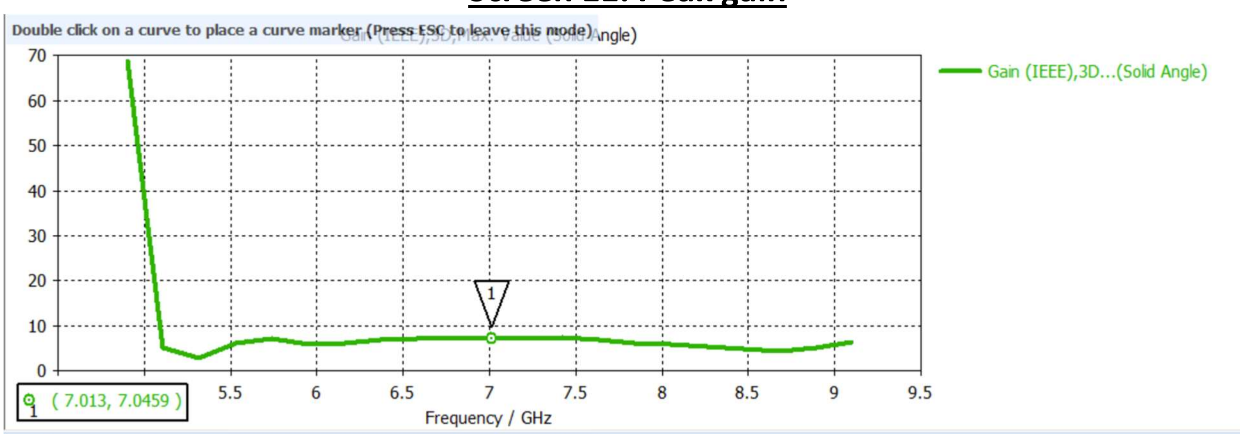




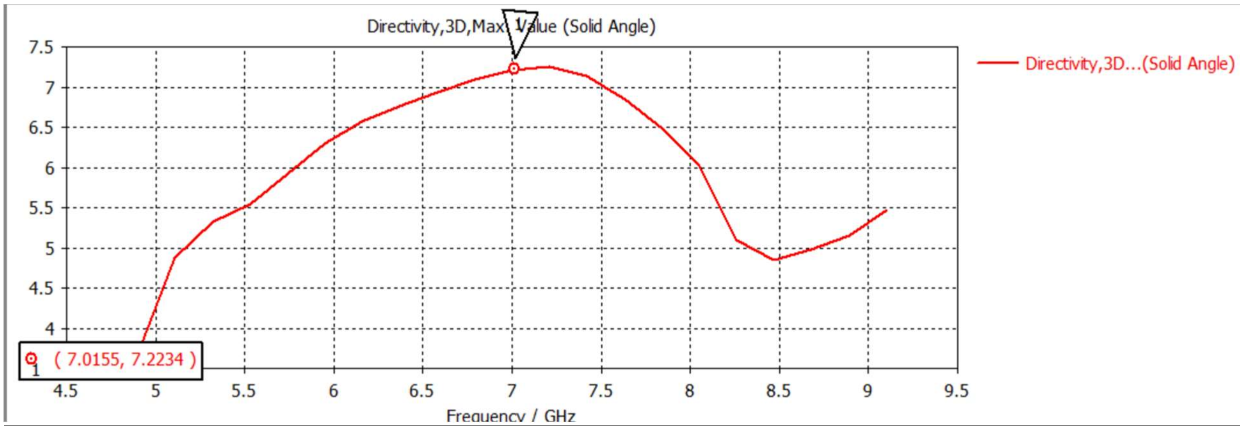
Screen 10: Azimuth Radiation Pattern xz-plane



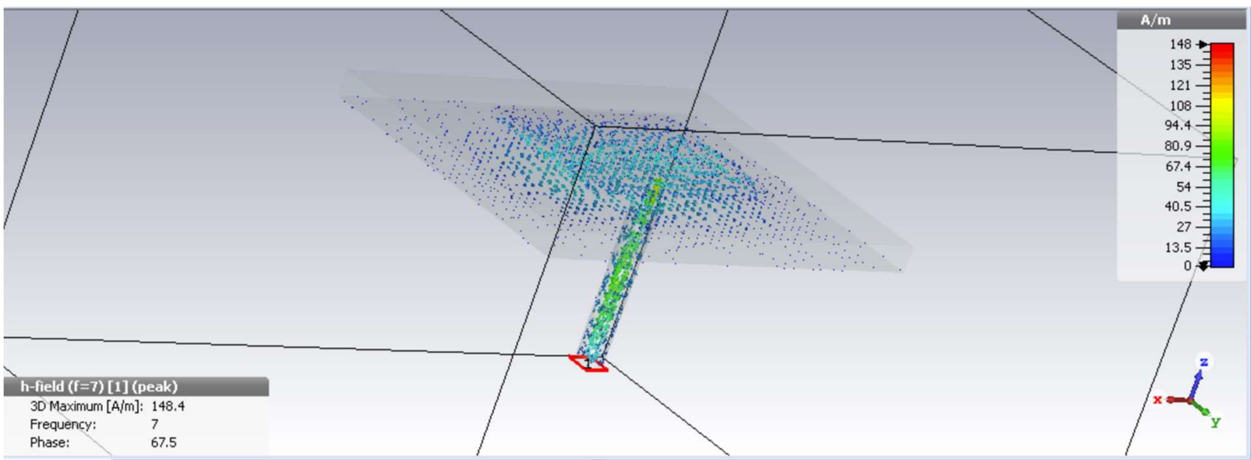
Screen 11: Peak gain



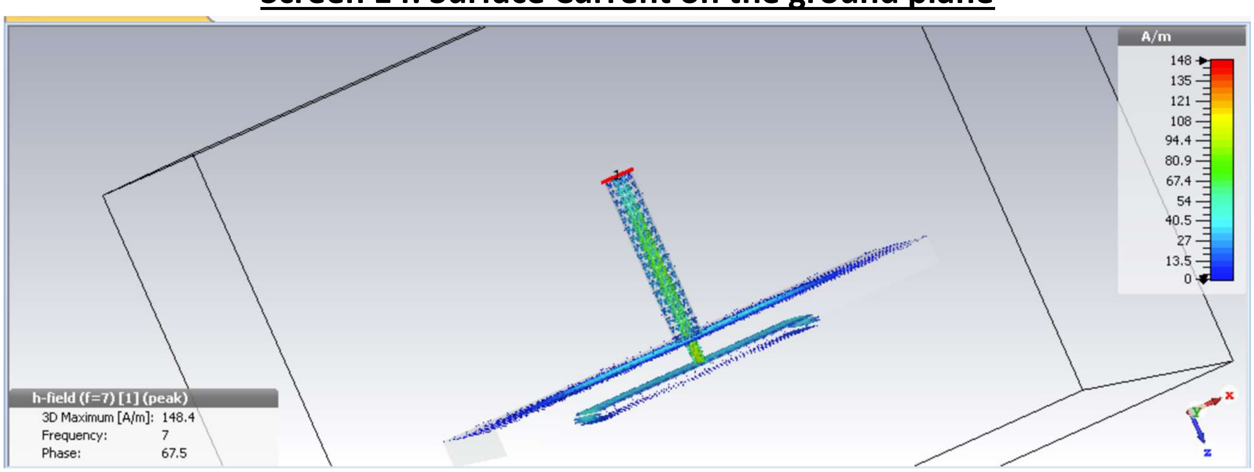
Screen 12: Directivity



Screen 13: Surface Current on Patch antenna

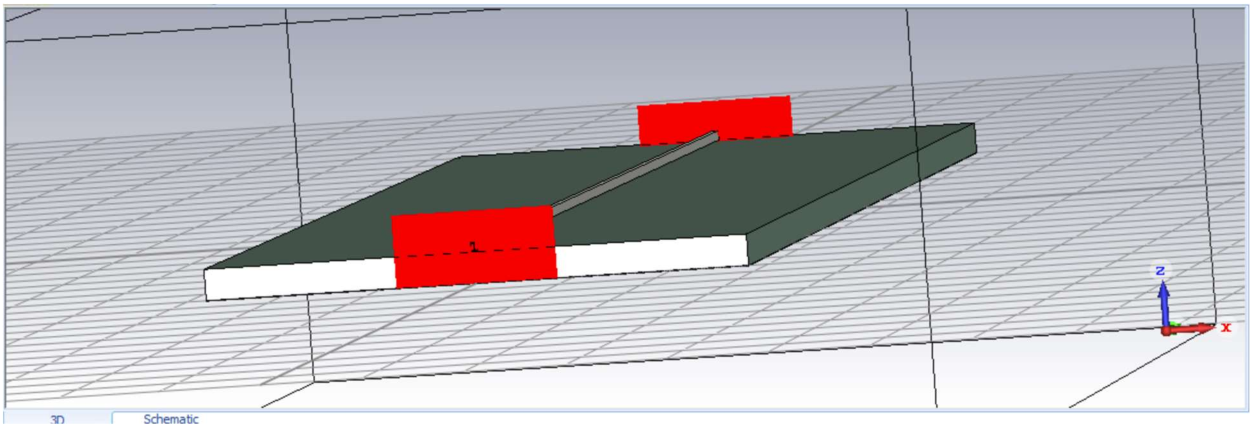


Screen 14: Surface Current on the ground plane

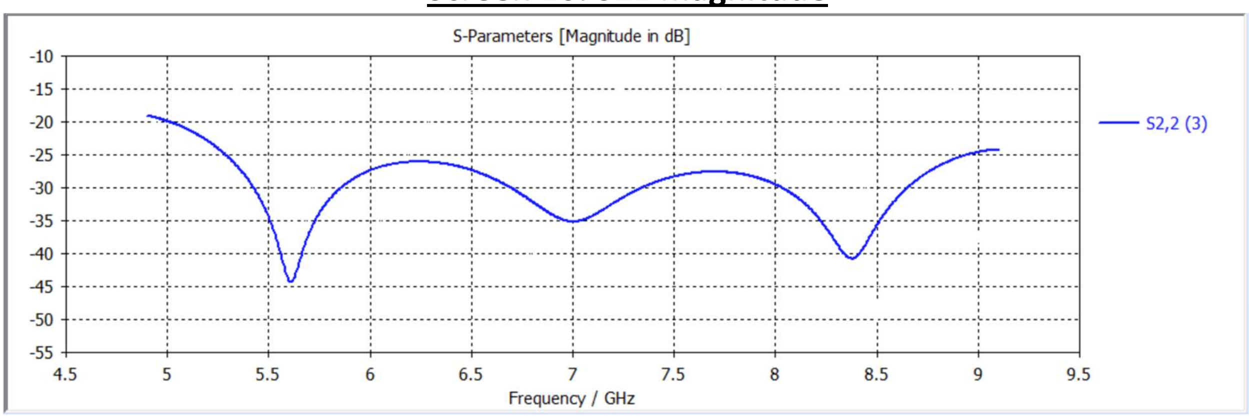


PART 3: MICROSTRIP ANTENNA

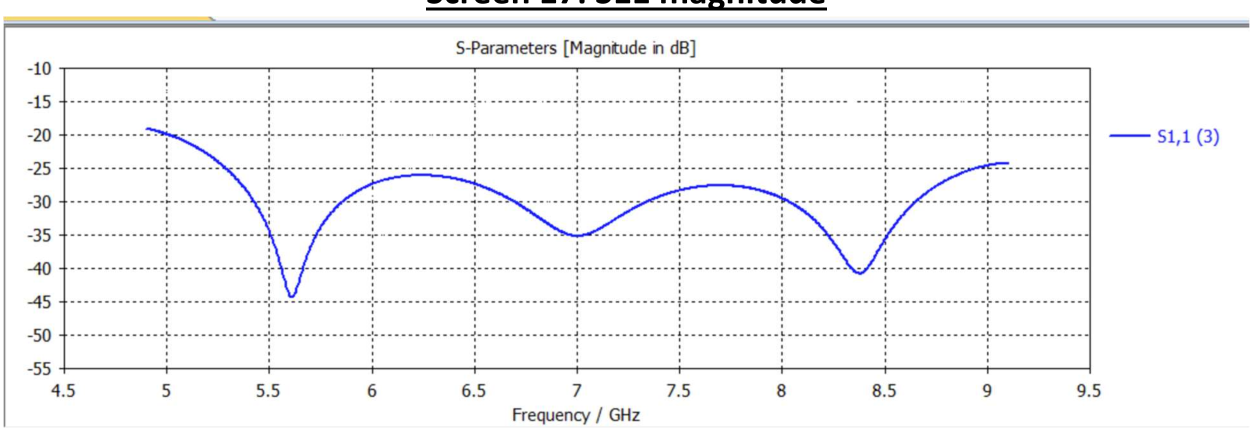
Screen 15: Microstrip antenna



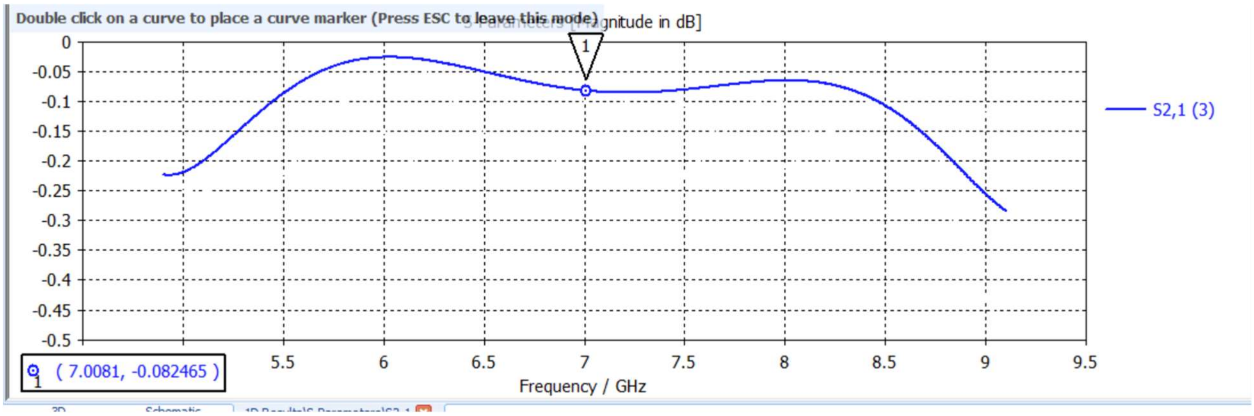
Screen 16: S22 magnitude



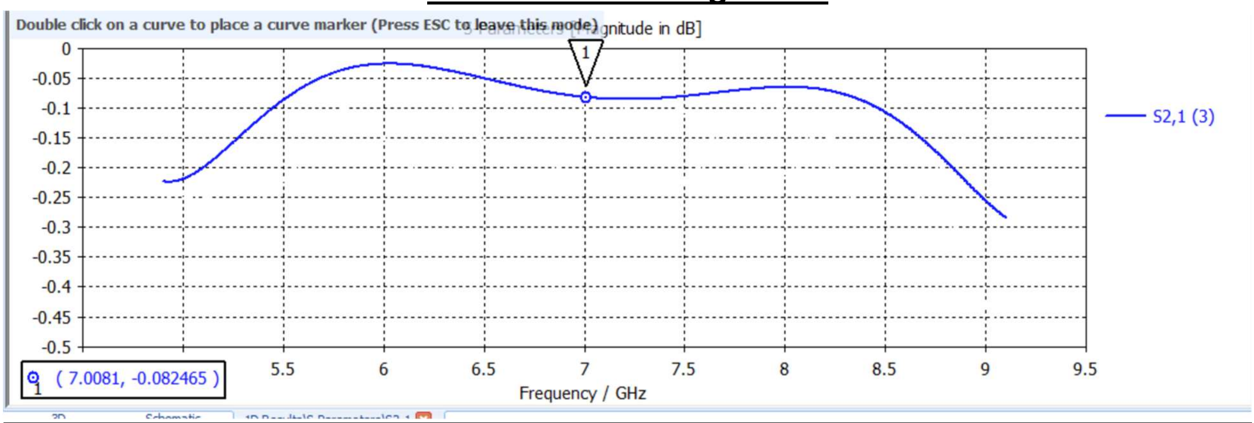
Screen 17: S11 magnitude



Screen 18: insertion loss S21 at f=7GHz

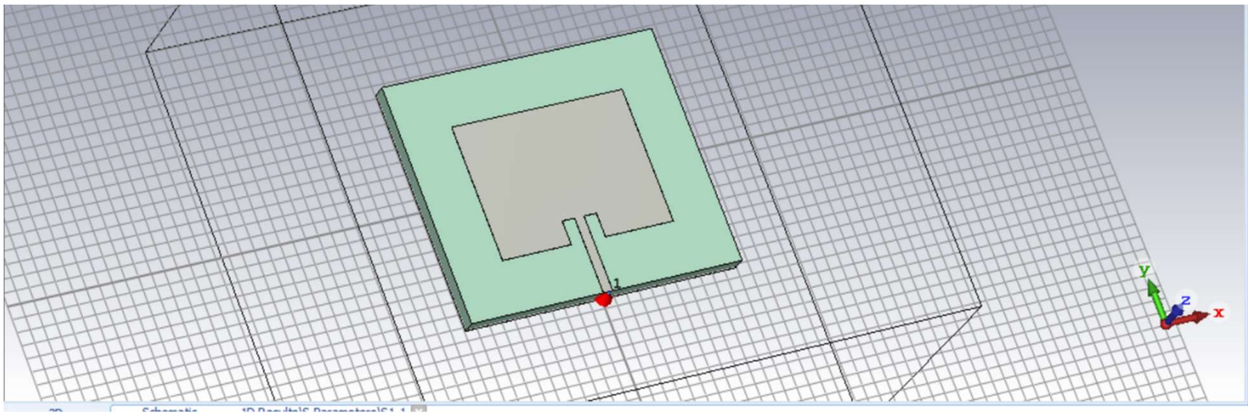


Screen 19: S12 magnitude

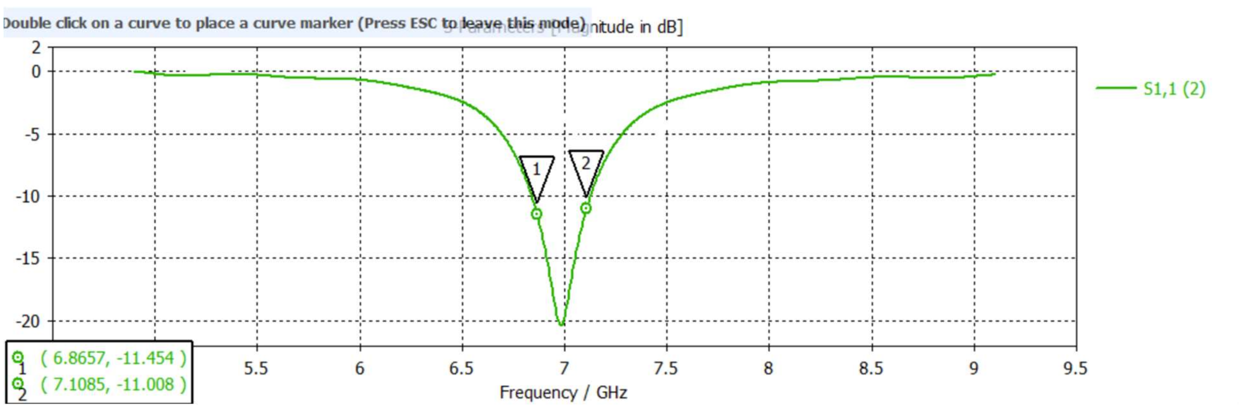


PART 4 : PATCH ANTENNA MICROSTRIP FEED

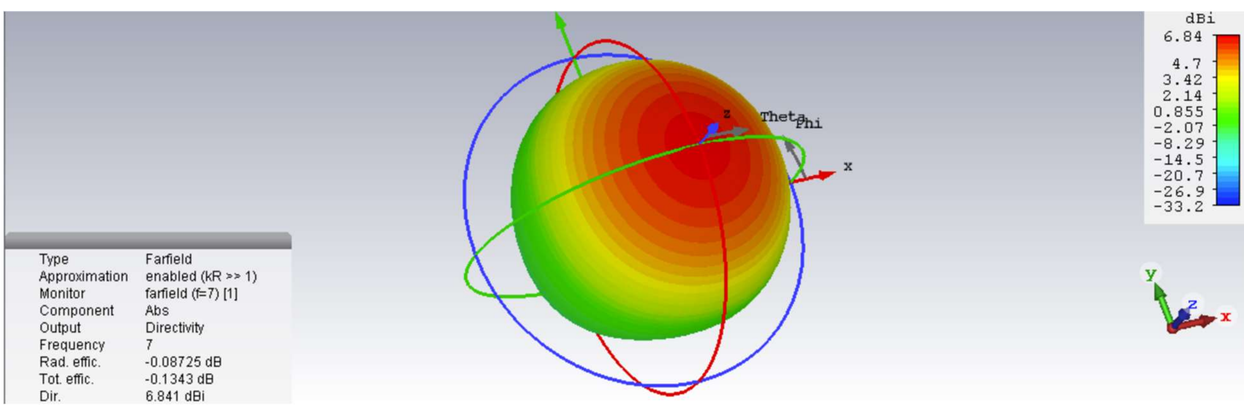
Screen 20: Patch Antenna



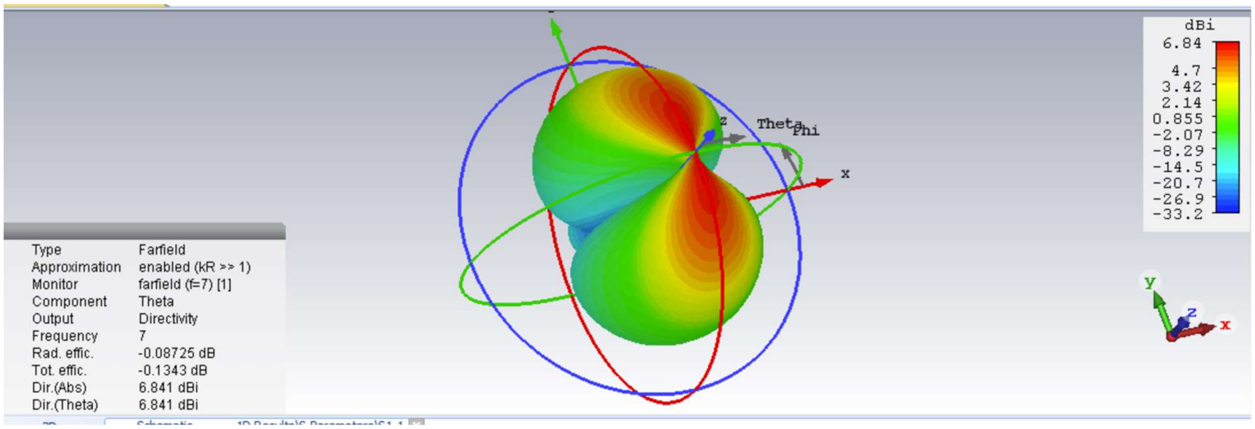
Screen 21: S11 magnitude

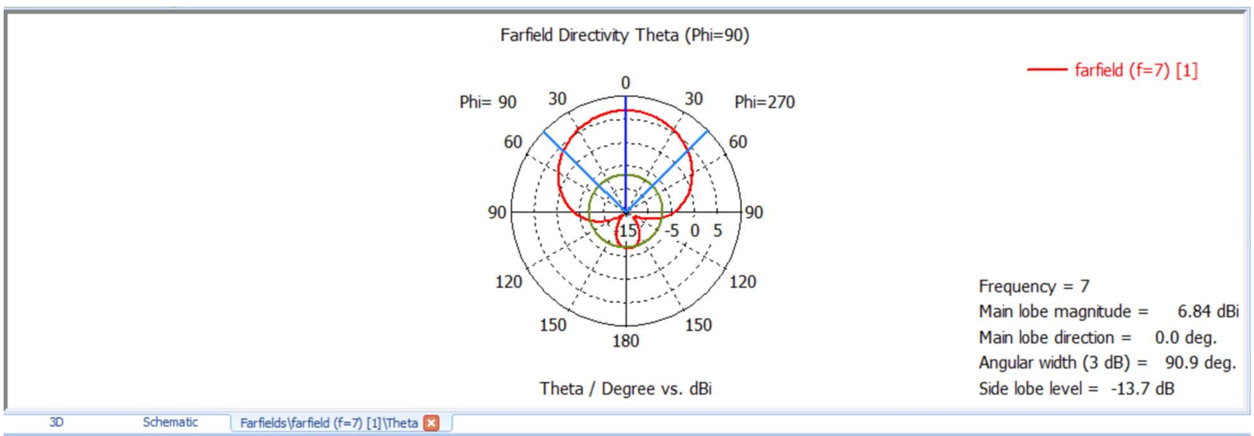


Screen 22: 3D far field radiation pattern

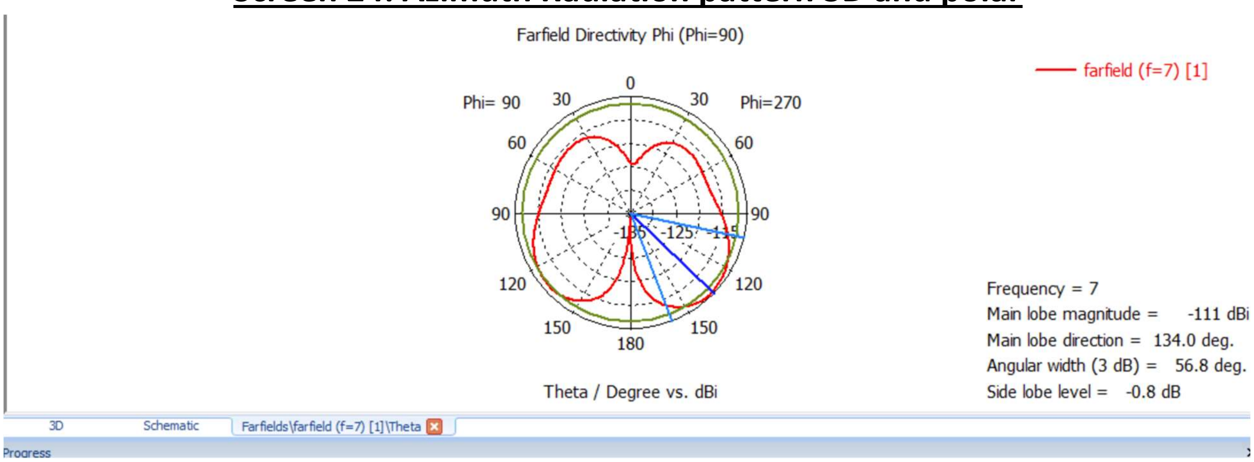


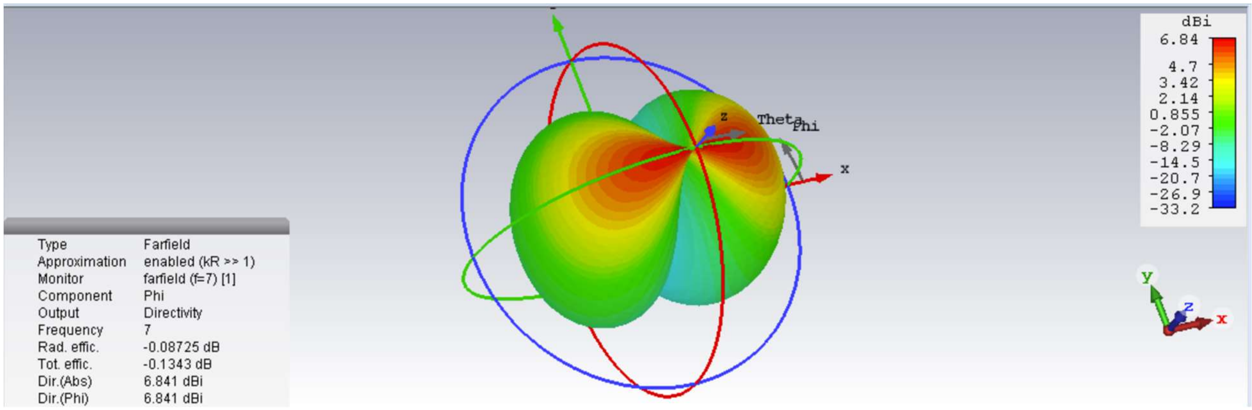
Screen 23: Elevation Radiation pattern, 3D and polar





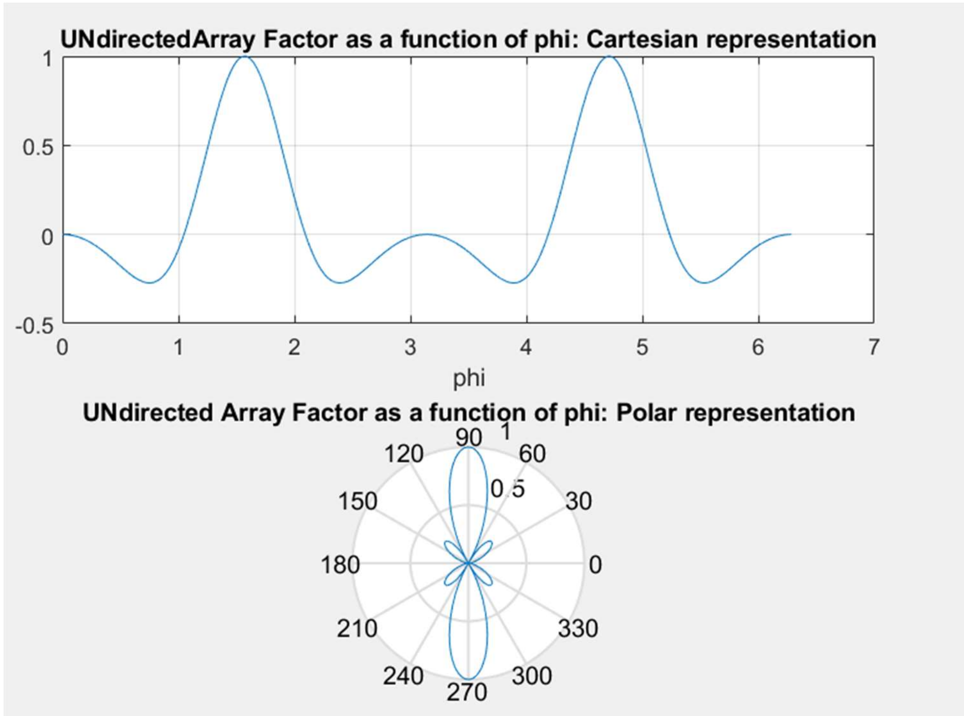
Screen 24: Azimuth Radiation pattern 3D and polar



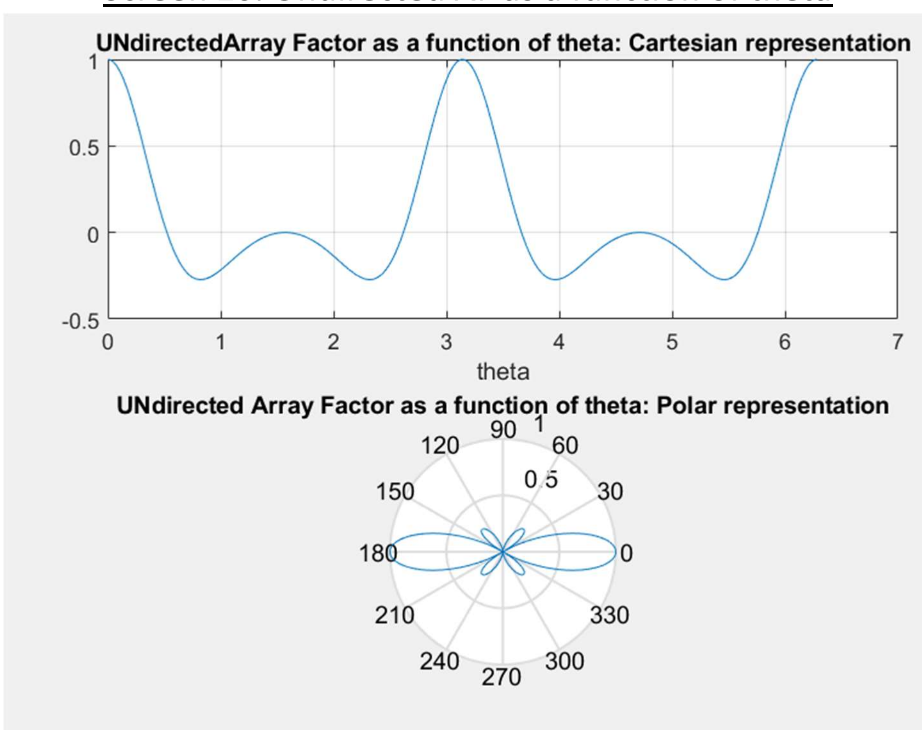

dBi
6.84
4.7
3.42
2.14
0.855
-2.07
-8.29
-14.5
-20.7
-26.9
-33.2
Theta
Phi
z
x
y
Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=7) [1]
Component Phi
Output Directivity
Frequency 7
Rad. effic. -0.08725 dB
Tot. effic. -0.1343 dB
Dir.(Abs) 6.841 dBi
Dir.(Phi) 6.841 dBi

PART 5: ARRAY OF PATCH ANTENNA 4x1

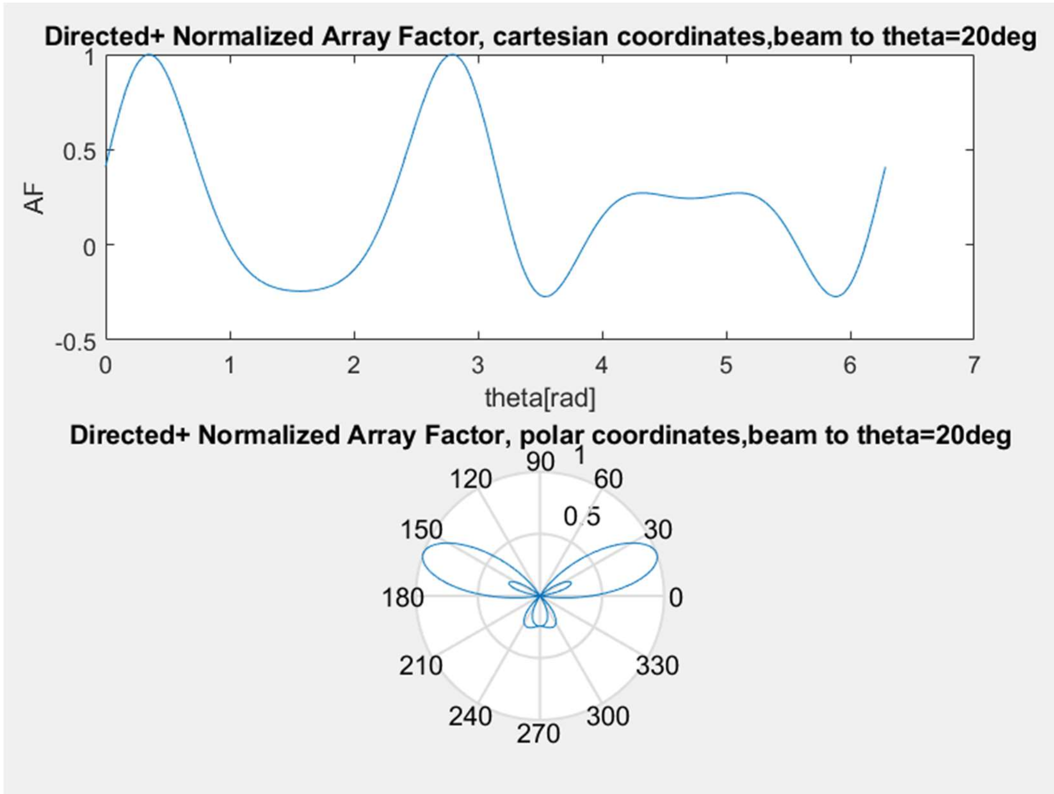
Screen 25: Undirected AF /// phi



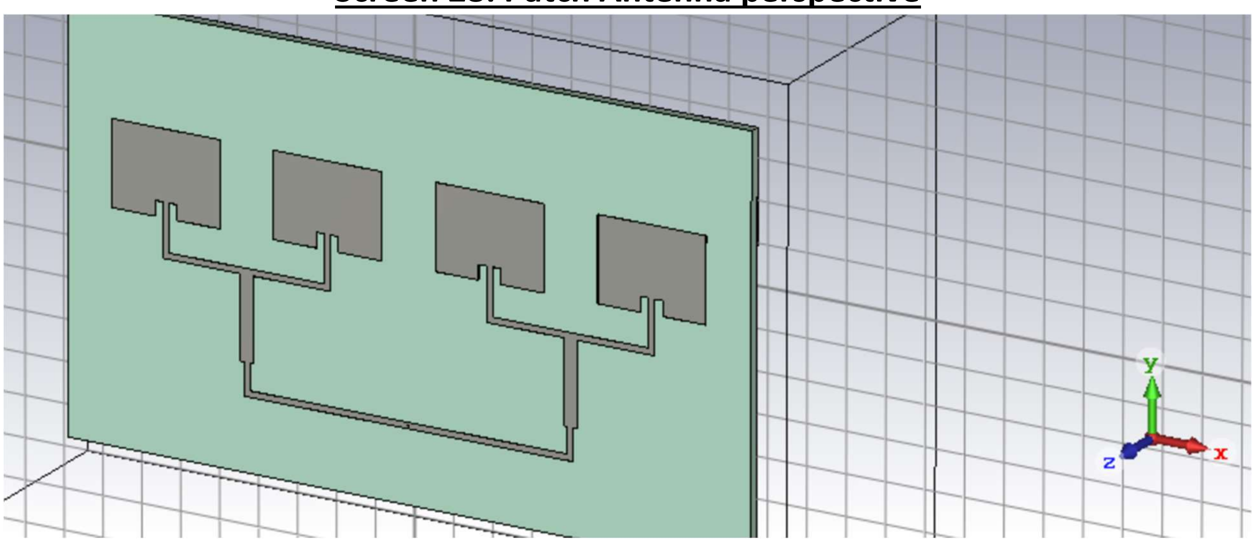
Screen 26: Undirected AF as a function of theta



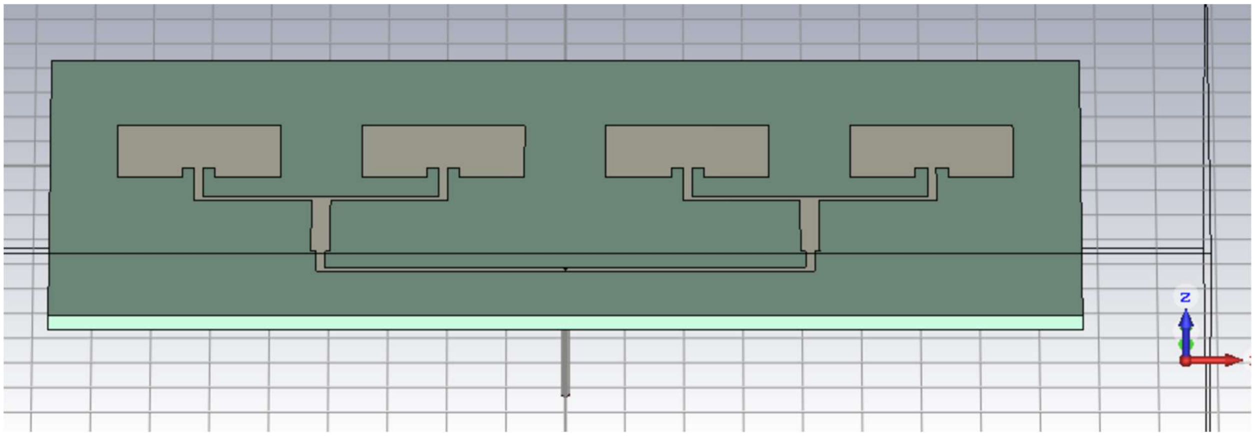
Screen 27: Directd and normalized AF (theta=20deg)



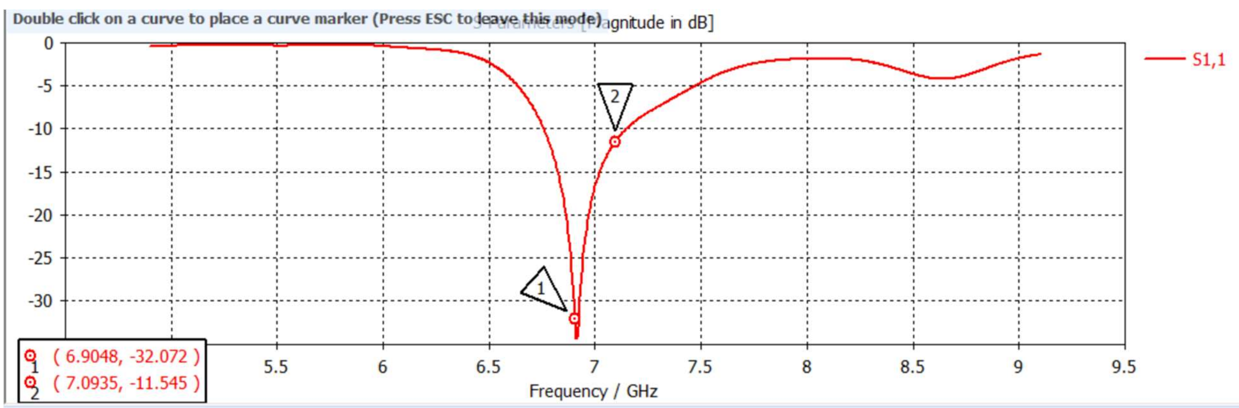
Screen 28: Patch Antenna perspective



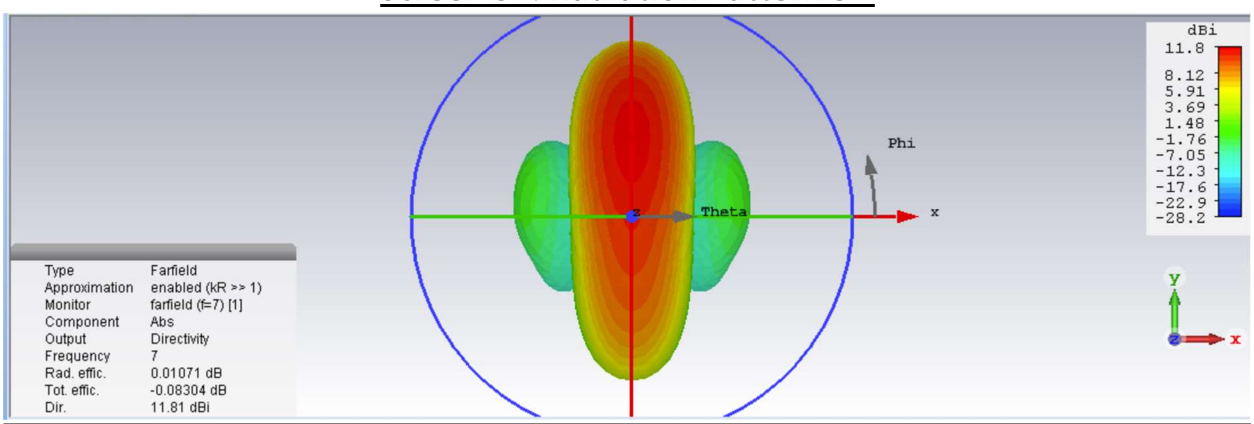
Screen 29: Patch Antenna perspective



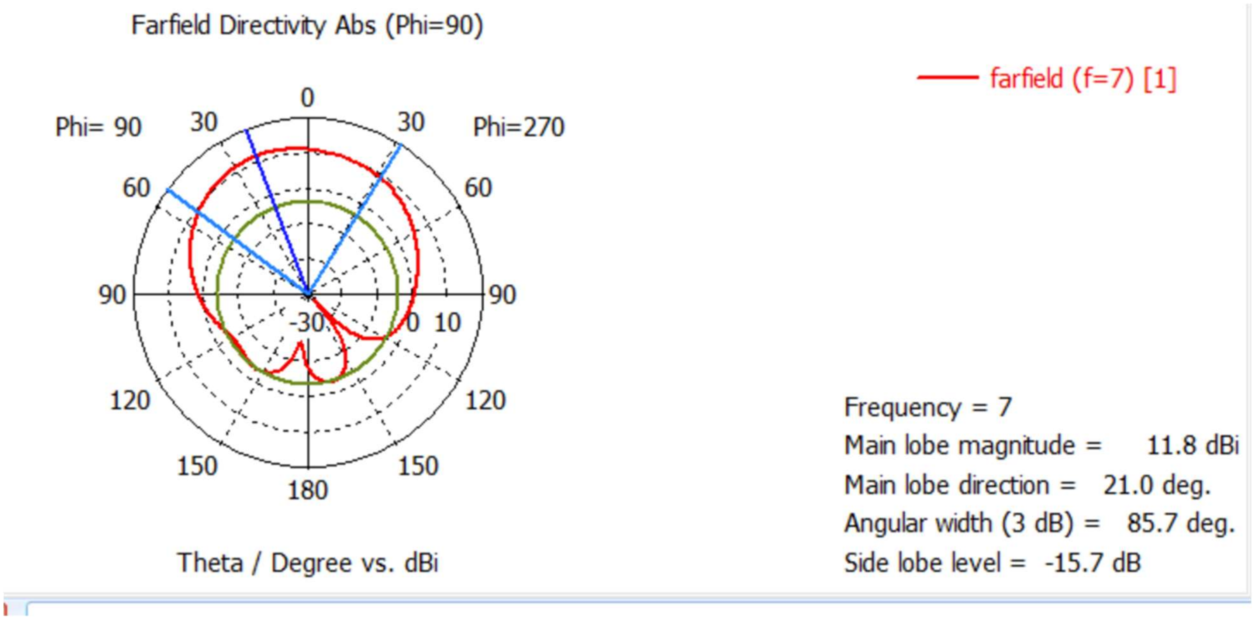
Screen 30: S11 magnitude matched at f=7GHz



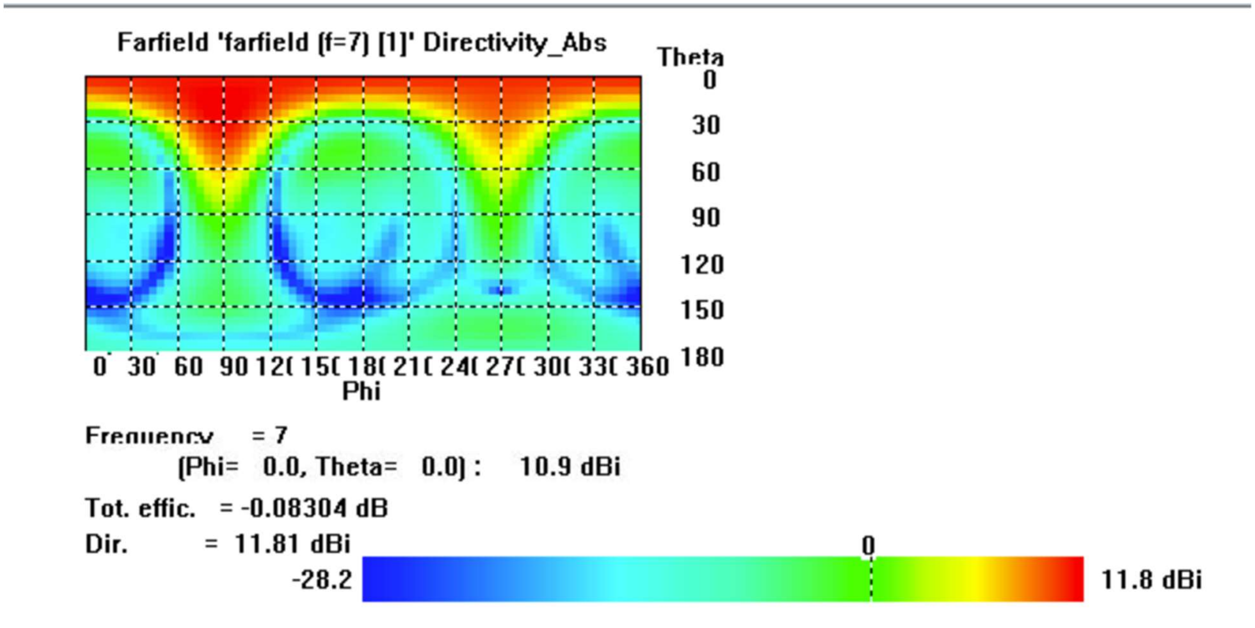
Screen 31: Radiation Pattern 3D



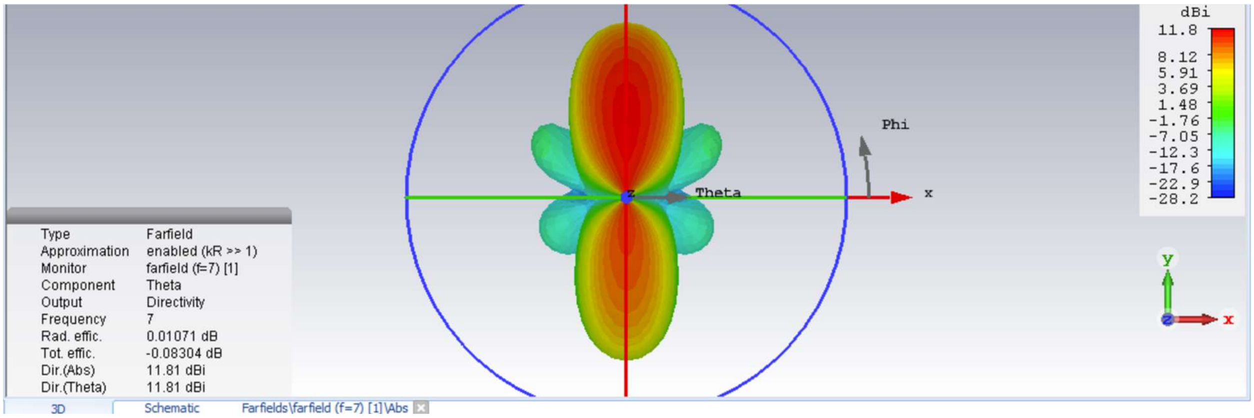
Screen 32: Radiation Pattern polar



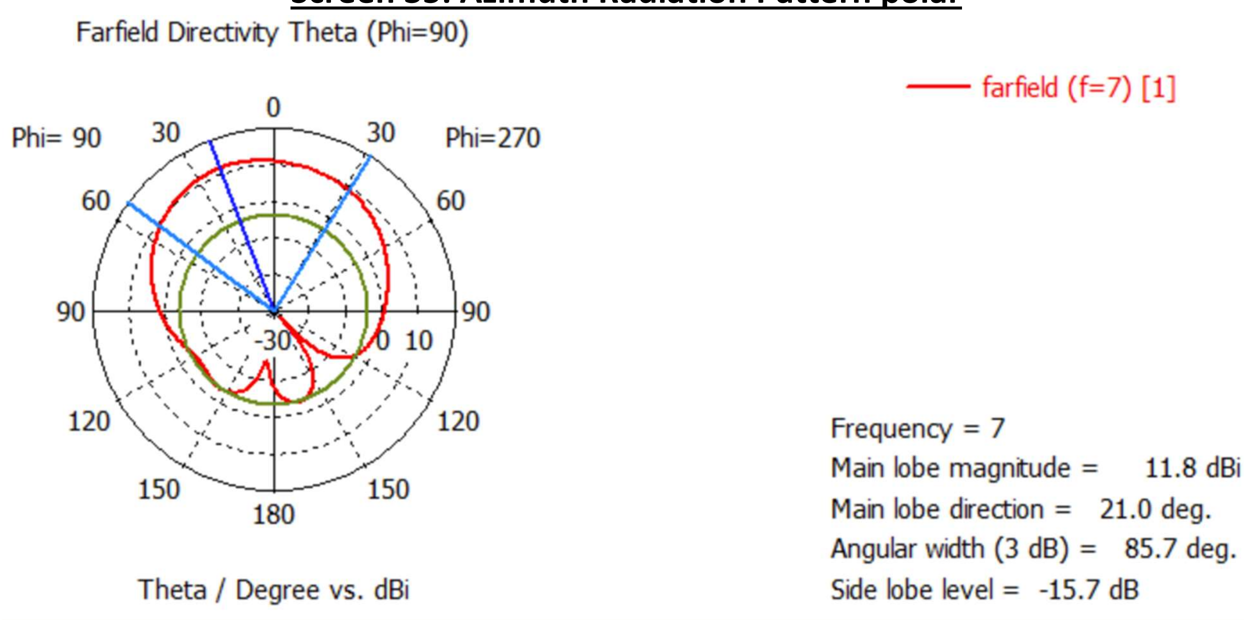
Screen 33: Radiation Pattern 2D



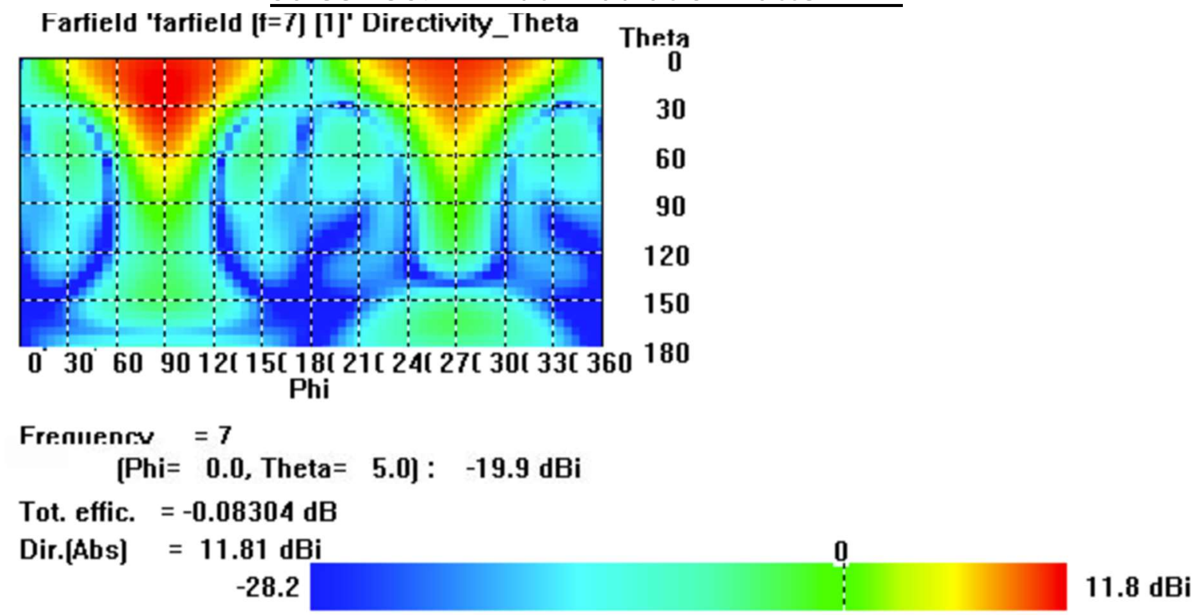
Screen 34: Azimuth Radiation Pattern 3D



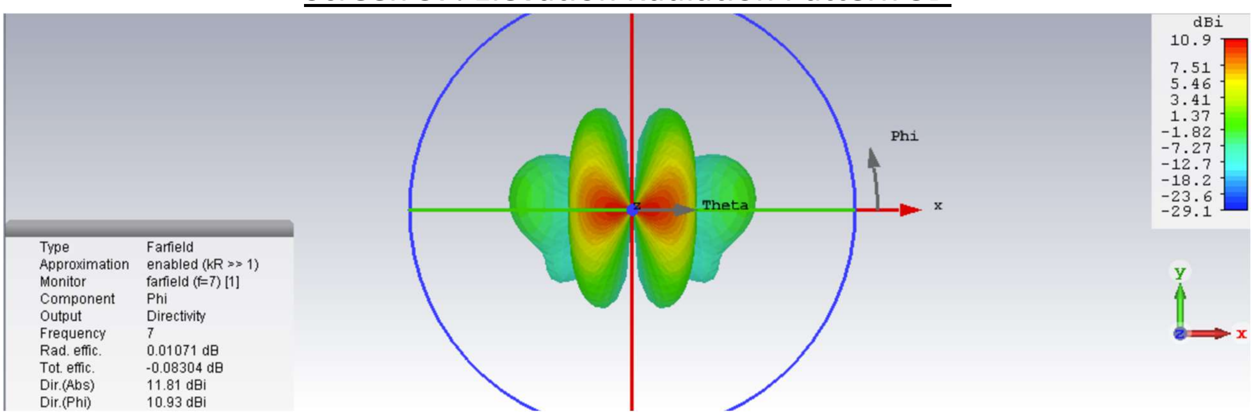
Screen 35: Azimuth Radiation Pattern polar



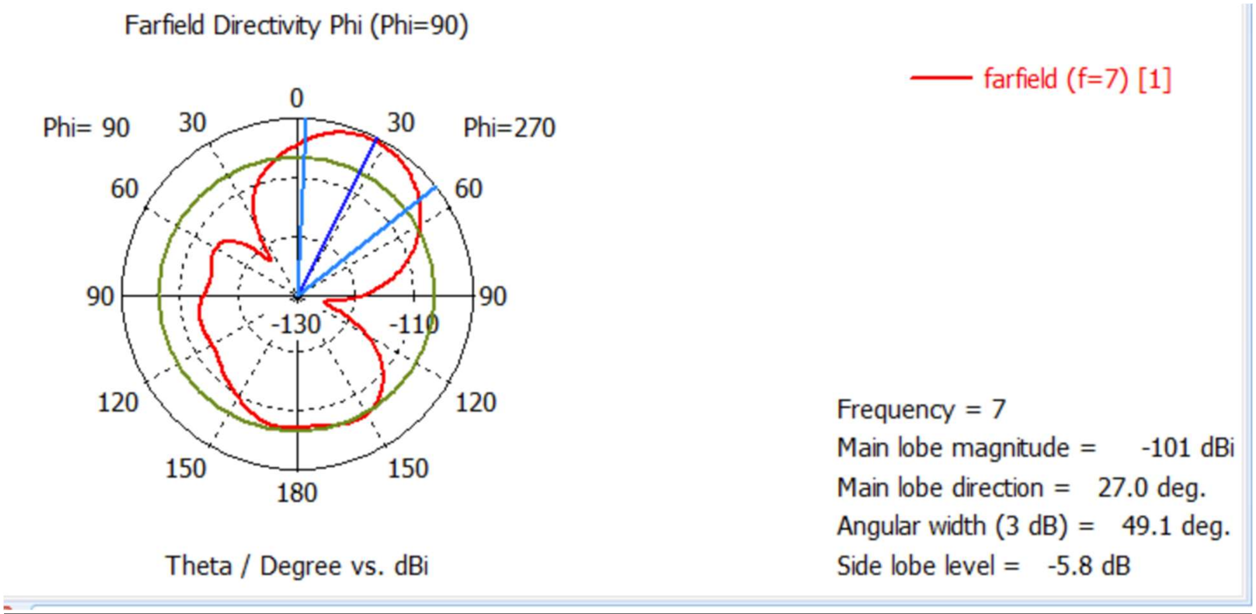
Screen 36: Azimuth Radiation Pattern 2D



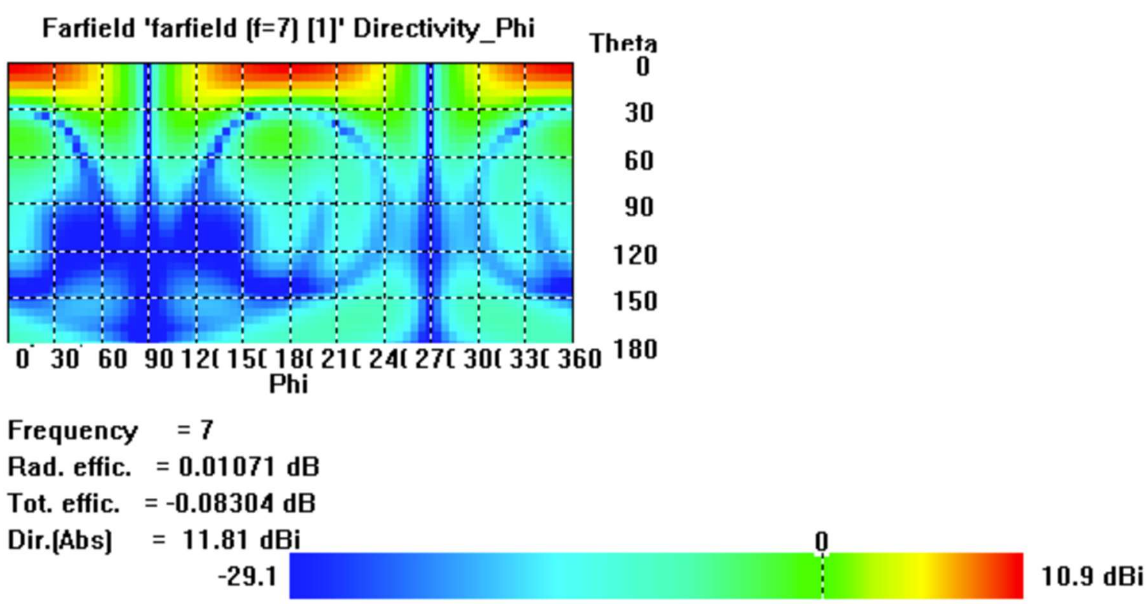
Screen 37: Elevation Radiation Pattern 3D



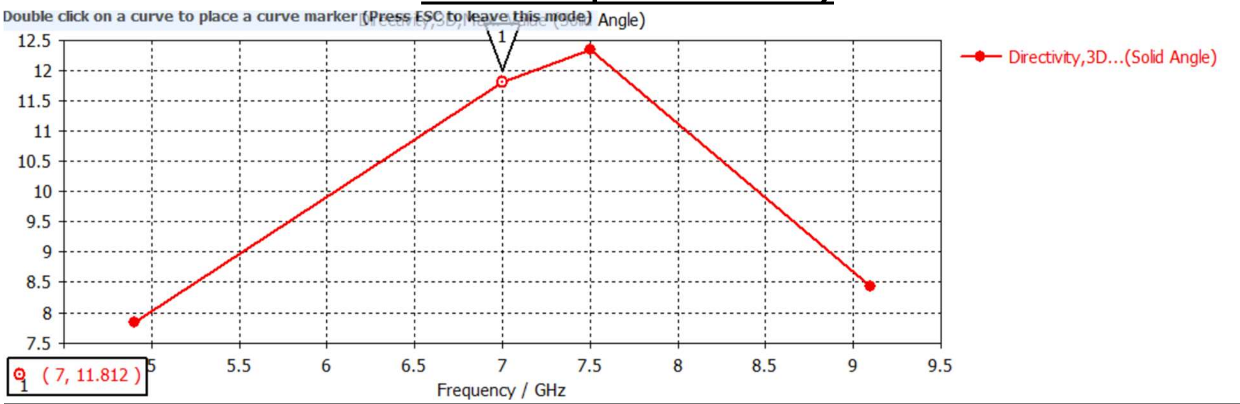
Screen 38: Elevation Radiation Pattern polar



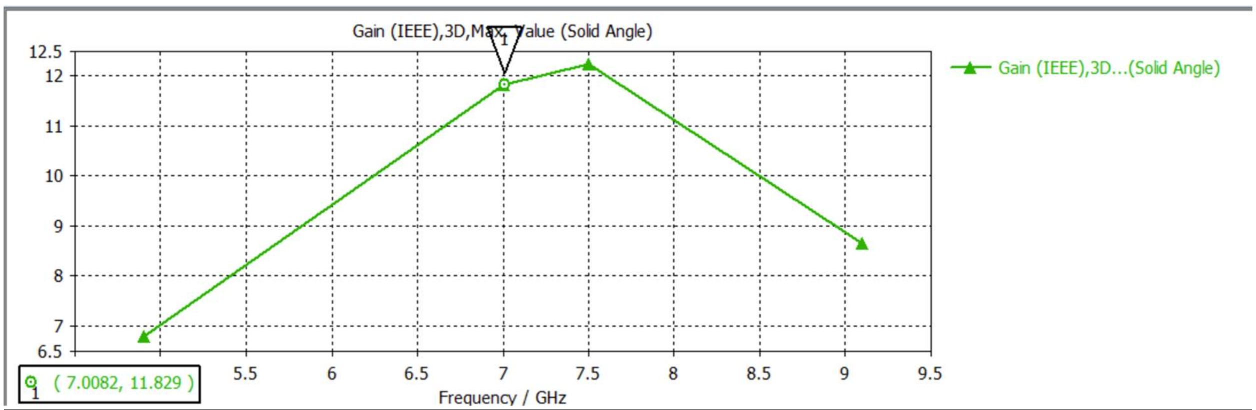
Screen 39: Elevation Radiation Pattern 2D



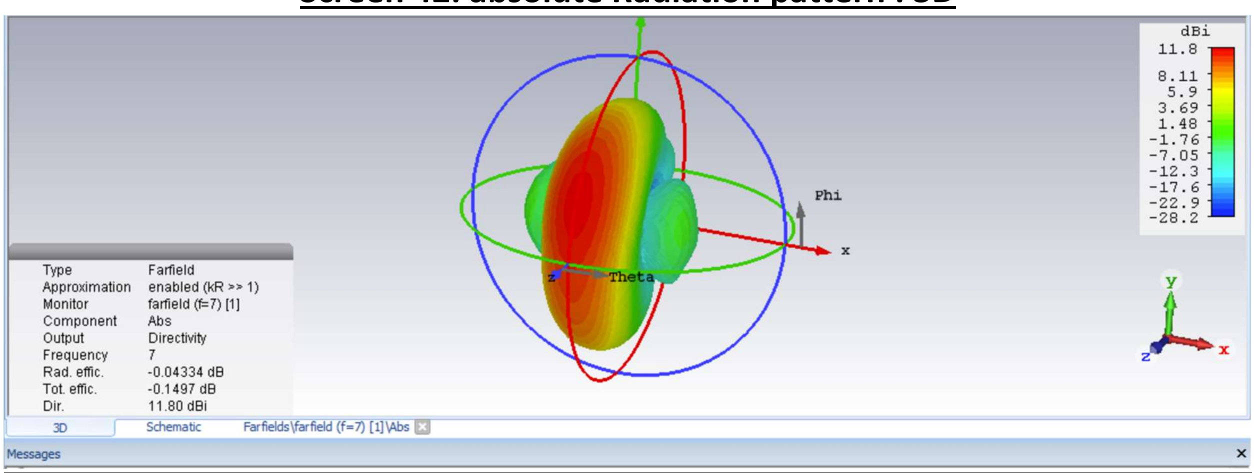
Screen 40: peak Directivity



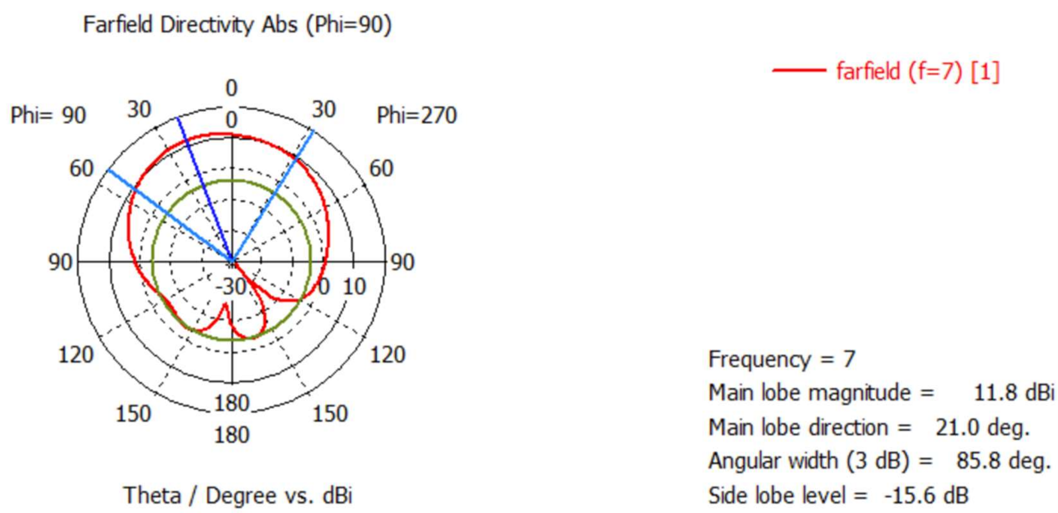
Screen 41: Gain



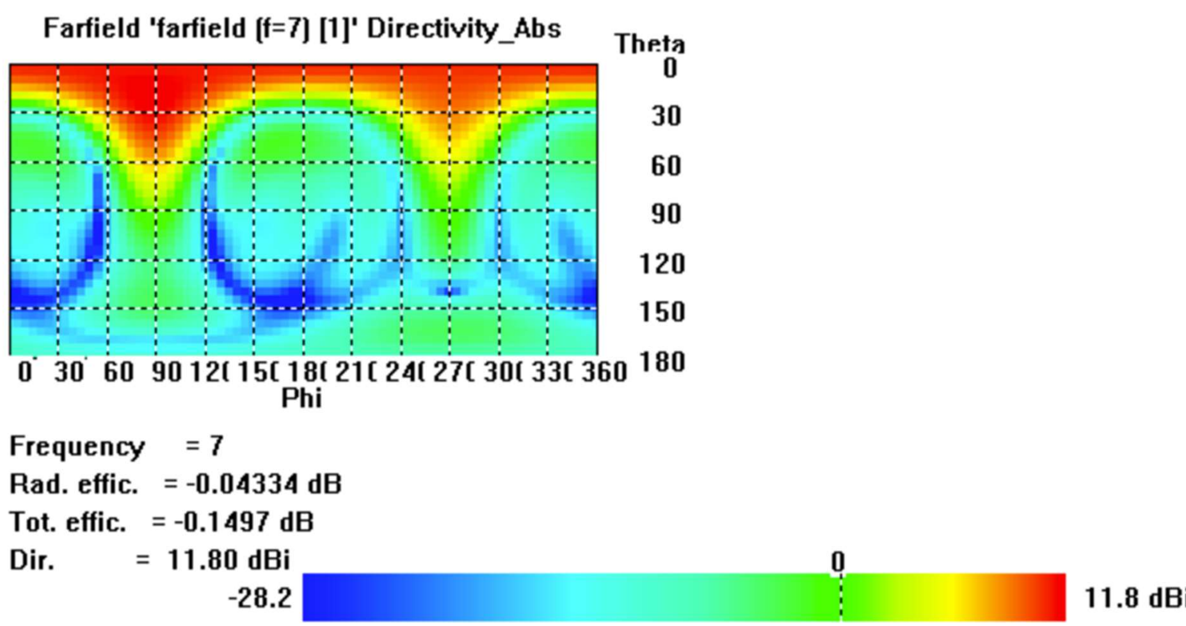
Screen 42: absolute Radiation pattern : 3D



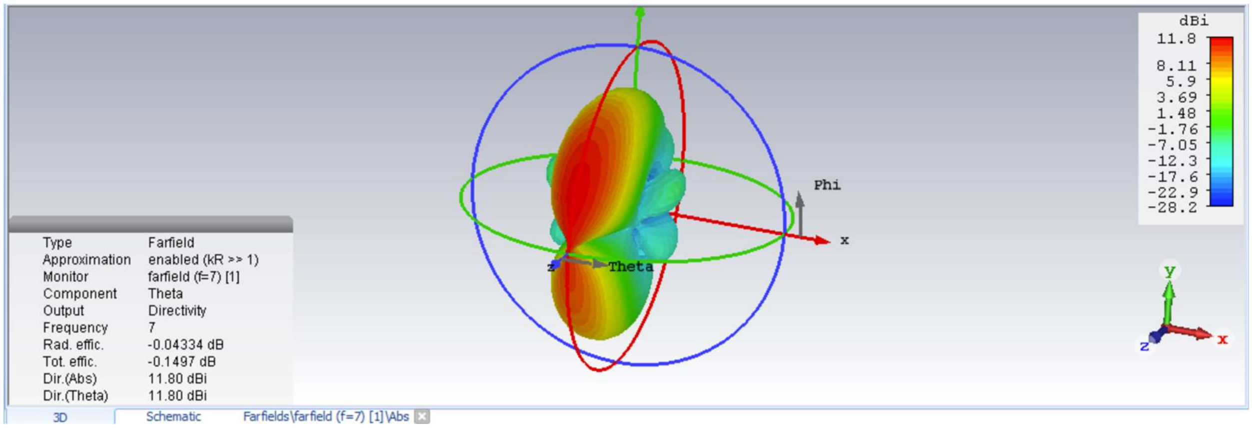
Screen 43: absolute Radiation pattern : polar



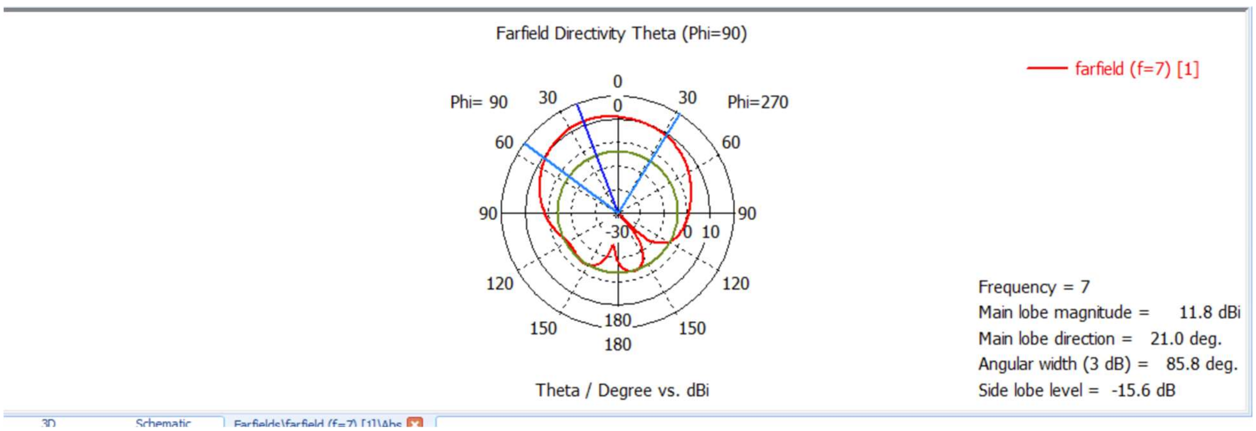
Screen 44: absolute Radiation pattern : 2D



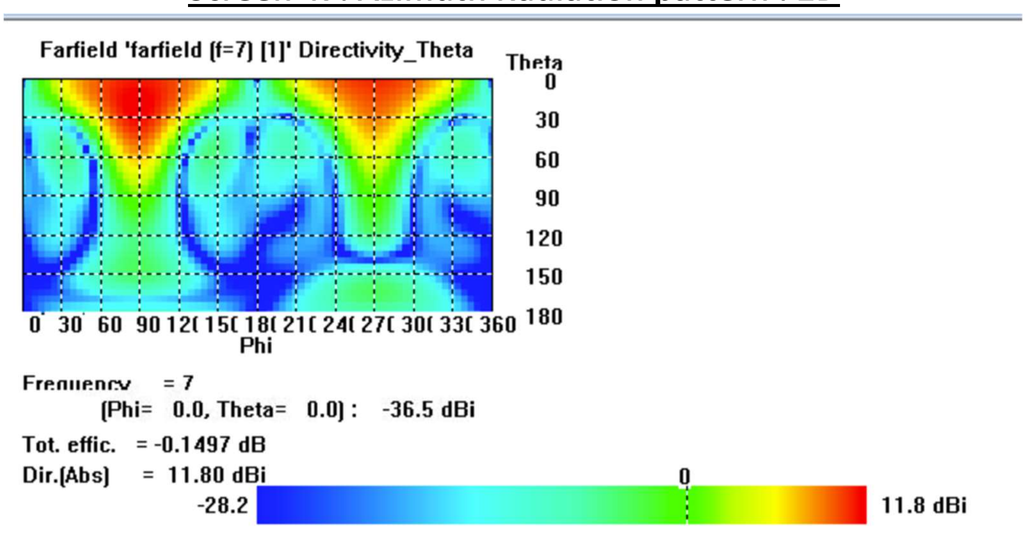
Screen 45: Azimuth Radiation pattern : 3D



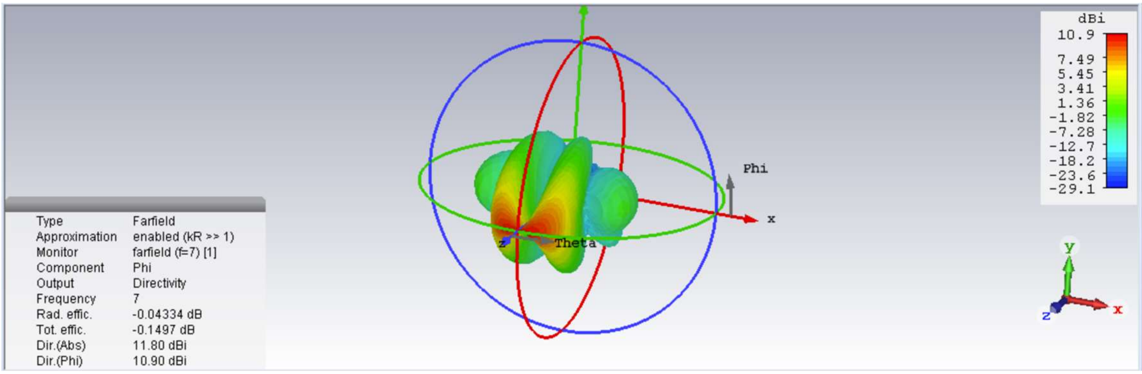
Screen 46: Azimuth Radiation pattern : polar



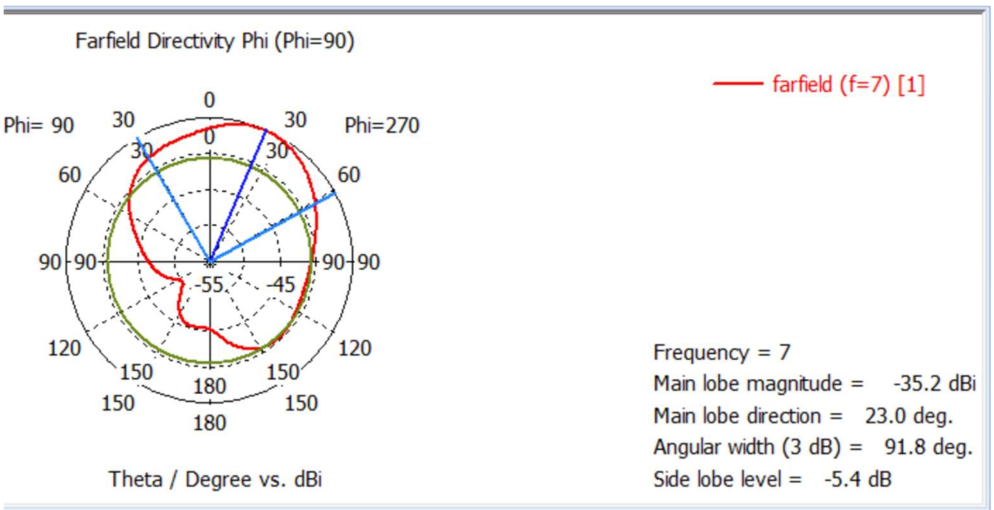
Screen 47: Azimuth Radiation pattern : 2D



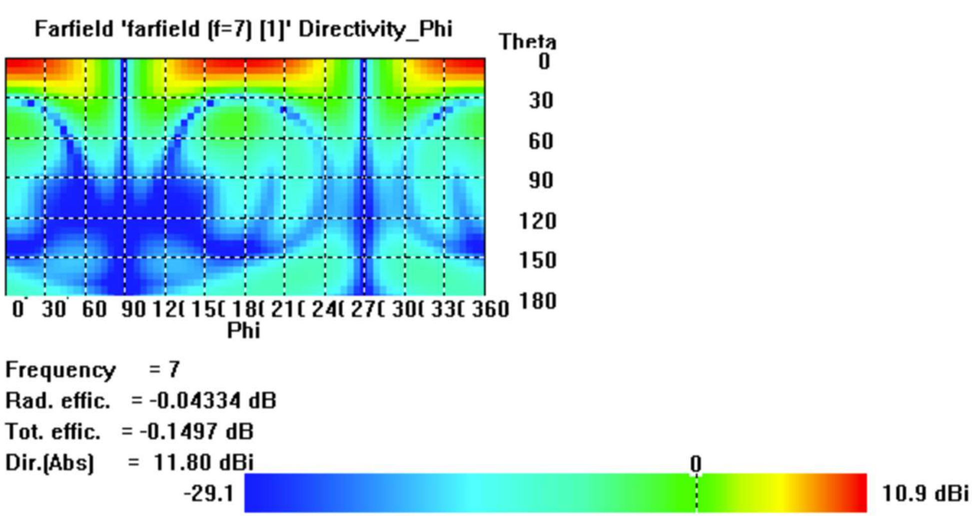
Screen 48: Elevation Radiation pattern : 3D



Screen 49: Elevation Radiation pattern : polar



Screen 50: Elevation Radiation pattern : 2D



Screen 51: Input matching S11