CST Project 1 BOUSKILA LAURENE 949271043

Monday, May 11, 2020 4:11 PM

1) Coaxial Cable Design

$$Z = 30\,\Omega = \sqrt{\frac{\mu}{\varepsilon}}\,\frac{\ln(b/a)}{2\pi} = \sqrt{\frac{\mu_0}{\varepsilon_0}}\,\frac{1}{\sqrt{\varepsilon_{r_1}}}\,\frac{\ln(b/a)}{2\pi}$$

$\uparrow$ Teflon

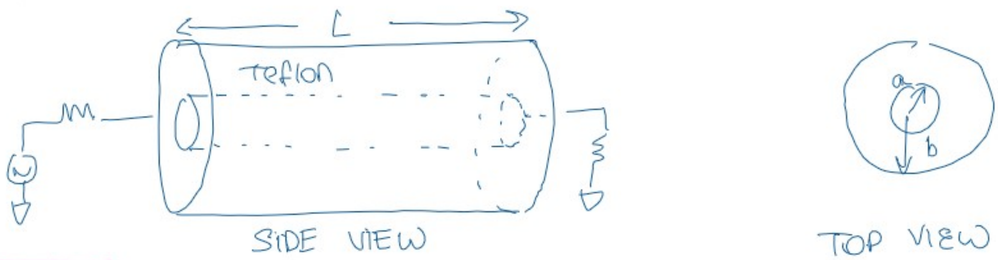
$$60\pi\sqrt{\frac{\varepsilon_0}{\mu_0}}\sqrt{\varepsilon_{r_1}} = \ln(b/a)$$

$$= 60\pi\,\frac{1}{120\pi}\sqrt{\varepsilon_{r_1}} \rightarrow b/a = e^{\frac{1}{2\sqrt{2,1}}} = 2{,}064$$

$a = 1\,mm \qquad b = 2{,}064\,mm$

Sanity Check: $120\pi\,\frac{1}{\sqrt{2,1}}\,\frac{\ln(2{,}06)}{2\pi} \approx 30$

2)



SCREEN 0

- $L = 10\lambda \qquad \lambda = c/f = \frac{3\cdot 10^8}{8{,}1\cdot 10^9} = 0{,}037037\ldots m$

  $L = 370\,mm$

  $\lambda \simeq 37\,mm$

frequency Band $0{,}1f \rightarrow 2f = 0{,}81G \longrightarrow 16{,}2\,GHz$

We chosed a and b to get matching with the characteristic impedance. So in THEORY we should not get losses. In practice the modelisation gets power absorbed by the coaxial cable → 3 types of losses

- mismatch losses
- ohmic "
- dialectric "

$S_{21} = 0dB \rightarrow$ no loss

$|S_{21}|_{dB} \leq 0 \rightarrow$ negative

$S_{21} \propto \frac{\text{received power}}{\text{Xmitted Power}}$

This changes also according to the length l of the transmission line. $l\uparrow \rightarrow$ losses $\uparrow$

$|S_{21}|_{dB} \leq 0$ ideally.

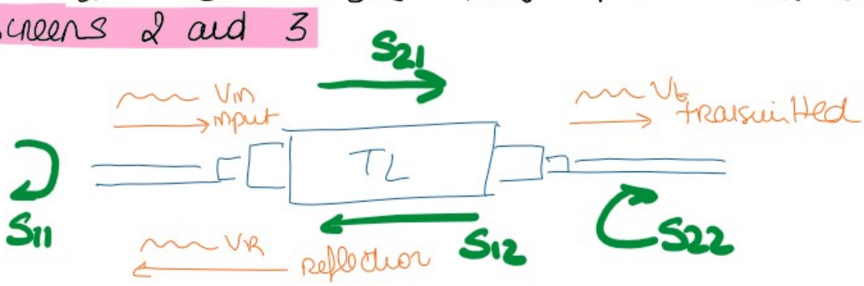
We Normalize S-parameters to $30\,\Omega$

(Simulation > SetupSolver > Normalized to fixed impedance > $30\,\Omega$)

We normalize S-parameters to 30 Ω
(Simulation > Setup Solver > Normalized to fixed impedance > 30 Ω)

Screen 1 → S_{21} around 0dB → no significant loss
Screen 2,3 → S_{11}, S_{22} before optimisation

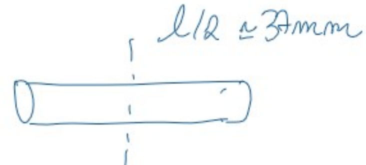
- We set a, b such that S_{11}, S_{22} will be below −25dB : and we can see that this is the case on screens 2 and 3



- Insertion loss = S_{21} @ $f = 8{,}1$ GHz
  ≃ 0,01dB from screen 1 which means almost no loss!
  This is expected because we tuned a, b for matching.

- S parameters : optimized cable = minimum insertion loss = matching.
  ↳ Screen 1,2,3,4

3) $l = 2\lambda \simeq 74{,}1$mm



The electric field @ the middle of the coaxial cable :
when you animate the simulation : we can see various properties of the $\vec{E}$ field.

Screen 5
- * direction alternatively go in and out
- * amplitude : higher every 90 angle

Note: the length of the coaxial cable doesn't influence the $\vec{E}$ field only a and b parameters do.

→ Surface current
(doesn't have the phase/time samples settings on my CST, I had a zoom sharing my screen session with Sumeet and he allowed me to take only screenshots)

Screen 6,7,8
- * Direction alternatively CW and CCW
- * amplitude : stronger on the same regions as $\vec{E}$

Note: We do see the TEM modes of propagation in the coaxial cable.

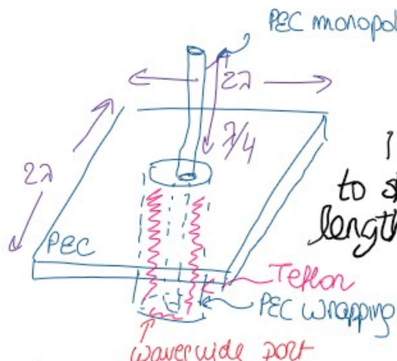
4) ground plane $2\lambda \times 2\lambda \cong 74 \times 74$ [mm] $f = 8{,}1$ GHz
monopole antenna design: SCREEN 9, 10, 11

we want S_{11} return loss scattering parameter better than -10dB
over 7,695 → 8,505 [GHz]

S_{11} = How much power is reflected from the antenna = Return loss
= Reflection coefficient.

In order to achieve matching, theoretically we should set the monopole antenna length to $\lambda/4$ = 9,25 mm (above the ground).

THEORETICAL DESIGN FOR MATCHING



Practically, we had to go a little bit below λ/4 length above the ground for the monopole antenna (17mm - 9,25) above the ground
The 0,95, 0,98 is the coefficient which is usually used to shorten the length of the monopole as compared to the length of a theoretical λ/4 monopole. This is due to the capacitance created by the ends of the finite diameter of a practical monopole.

But finally we reach S_{11} below -10dB for f_0 = 8,1 GHz → S_{11} ≃ - dB
↳ more negative (in dB)
↳ more attenuation
↳ lower losses
↳ optimized model.

SCREEN 12

- 3D far field RD : xz-plane = "elevation" → Screen 13
  xy " = "Azimuth" → Screen 14

This is what we expect from theory because it's in the shape of a sinc function of θ which correspond to a "donut" in the xyz 3D plane. The fact that the ground is not infinite plane makes the RP radiates in a "skewed" direction
Direction of peak gain: xy plane. (But because of our boundaries settings: ground plane is considered ∞te and we don't have this effect)
peak gain: 3,202 SCREEN 15 $\eta = G/D$ = 98,31 %.
peak directivity 3,257 SCREEN 16

There's a very small difference between gain and directivity which leads to a very high efficiency.
This is because there are 3 types of losses
mismatch, ohmic, dielectric losses
But we designed our monopole antenna so that it's matched

mismatch, ohmic, dialectric losses
But we designed our monopole antenna so that it's matched to f_0 and to get minimal losses because
$\lambda/4$ -> monopole antenna $L \ll \lambda$
only the coaxial cable (not the antenna itself) experiences very few losses - almost No losses overall -> very high η

- Surface currents Screen 17, 18

* in the monopole antenna : the Surface current is higher when closer to the port (in the coaxial cable) and progressively decreases -
It alternates between upward and downward direction.
* in the ground plane: alternatively inward/outwards
the magnitude of the surface current is very low

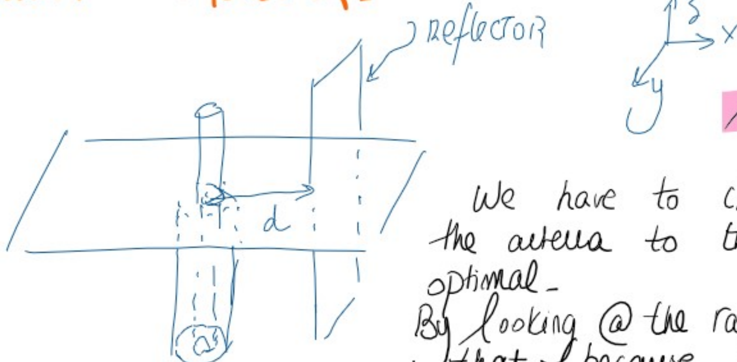
This is what we expect from theory since the port is a source, so the surface current should be higher around it -
And the ground plane is theoretically a PEC
That's the reason why there's no impressed currents but only induced current -
This surface current is radiating the EM wave -> $\vec{E}$ field predominant

monopole v/s dipole

The ground plane (PEC) enable us to use imaging principle -> equivalent to dipole antenna ~ mirror

$Z_{monopole} = 0{,}5 * Z_{dipole} = 36{,}5\,\Omega$
$D_{monopole} = 2D_{dipole}$

5) Addition of a reflector -



Screen 19

We have to chose a distance d (from the antenna to the reflector) to be optimal -
By looking @ the radiation pattern, we notice that (because the reflector will be normal to the x-axis) we'll get a gain maximized in one single direction -> x direction -> max ~~peak~~ gain
-> that's why $d = 0{,}6\lambda$

→ that's why $d = 0{,}6\lambda$

gain = 11,34 Screen 20 D = 11,99 Screen 21 → $\eta = 94{,}58\%$

The reflector reflects the em waves by acting as a matching element. It's length and distance from the antenna induce a potential difference which produces a wave offset polarity.
We can change the reflector induction by increasing its length. So we might change the monopole length in order to get better than −10 dB for $0{,}95f \rightarrow 1{,}05f$

As can be seen on screen 22 we did not have to change the length of the monopole antenna because the above range is already better than −10dB

As before, the monopole antenna length is close to a $\lambda/4$ (slightly less for the same reasons as previous section)

↳ We also see the matching @ $f = 8{,}1\,GHz$!

- Far field Pattern: Screen 23
  The radiation pattern gets reflected on the x-axis as expected from theory since the reflector is placed normal to the x axis and reflects the radiations accordingly.
  ↳ no radiations goes beyond the reflector.

Note: that without the reflector, we got lower gain and directivity with the same excitation as expected.
and the RP was "full" as before
Screen 24,25,26

6) ARRAY

3 elements along the x-axis d = spacing = $0{,}7\lambda \simeq 25{,}9\,mm$

- Normalized Array factor:

$N-1$ $j(k\hat{r} - \bar{r}_n)$

• Normalized Array factor:

$$AF = \sum_{m=1}^{N-1} e^{j(k\hat{r} - \bar{r}_m)} \qquad \hat{r} = \sin\theta\cos\phi\,\hat{x} + \sin\theta\sin\phi\,\hat{y} + \cos\theta\,\hat{z}$$

constant excitation assumed $\bar{r}_m$ = position vector of the array element $= md\hat{x}$

$$AF = \sum_{m=0}^{N-1} e^{jkmd\sin\theta\cos\varphi} \qquad \begin{aligned} m &= -1, 0, 1 \text{ (3 elements)} \\ d &= 0{,}7\lambda \end{aligned}$$

$$= \sum_{m=0}^{2} e^{jkmd\sin\theta\cos\varphi} = \frac{1 - e^{j3kd\sin\theta\cos\varphi}}{1 - e^{jkd\sin\theta\cos\varphi}}$$

$$= \boxed{\frac{\sin\left(\frac{3kd}{2}\sin\theta\cos\varphi\right)}{\sin\left(\frac{kd}{2}\sin\theta\cos\varphi\right)}} = AF$$

$\Delta\varphi$

$$AF = \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin(\psi/2)} \qquad N = 3,\ \psi = kd\sin\theta\cos\phi - \Delta\phi$$

• Per element $\rightarrow \dfrac{\sin(N\psi/2)}{N\sin(\psi/2)}$

• when dealing with matlab we're looking at the xy plane
↳ $\theta = 90°$ $\quad \psi = kd\cos\theta$

$$k = \frac{2\pi f}{c} \qquad \psi = kd\cos\varphi \qquad AF = \frac{\sin(3\psi/2)}{\sin(\psi/2)}$$

and we need to plot $AF(\varphi)$ Screen 27
↳ Sinc shaped as expected with lower amplitude for the middle element

• Directivity of the array $\quad D = \dfrac{2\pi}{P_{rad}} \quad P_{rad} = \displaystyle\int_{\theta=0}^{\pi/2}\int_{\varphi=0}^{2\pi} U(\theta,\varphi)\sin\theta\, d\varphi\, d\theta$

$U(\theta,\varphi) = (AF)^2$ using matlab Numerical Solver -

$$D = 2\pi / 1{,}5838 = 3{,}967$$

• Steer Beam @ $\varphi = 30°$ $\quad kd\sin\theta\cos(30°) - \Delta\varphi = 0$

$$\Delta\varphi = kd\sin\theta\cos(30°) = 2\pi\, 0{,}7 \sin\theta\cos(30°) = 3{,}809 \text{ Rad}$$

$\Delta\varphi = kd \sin\theta \cos(30°) = 2\pi\, 0{,}7 \sin\theta \cos(30°) = 3{,}809$ Rad
$\cong 171{,}9°$

Normalized AF → Screen 28

- Array design CST: Screen 29

3D Radiation pattern: Screen 30
RP xy plane Screen 31

We can observe that the 3D RP gets a sinc shape as expected from theory
The middle elements gets higher radiations whereas the side ones are smaller and of same size.

- Peak Directivity: Screen 32, 32 bis

gain = 7,7742 Screen 33, 34

D = 8,033 η = 96,78 %

By plotting the gain as a function of phi (Screen 34) we observe that we get the same shape as what we computed with Matlab → so our simulations match with theory.

- Input matching: middle element Screen 35

Again, by looking at the S parameters, we can see that we get proper matching at f = 8,1 GHz as expected: where it decreases drastically to ≃ −13 dB!

Phase: left element − −171,9°
middle " 0° Screen 38

Phase : left element - $-171,9°$
middle " $0°$
Right " $+171,9°$

Screen 38

3D RP → Screen 36, 36bis
XY RP → Screen 37, 37BIS

INPUT matching : Screen 39

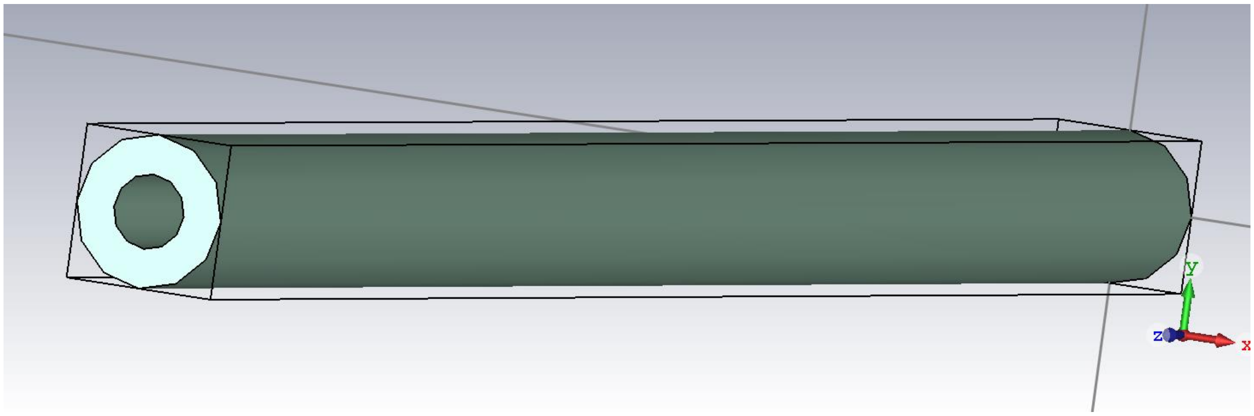
Again we can observe proper matching By looking at S_{11} at $f = 8,1GHz$

gain Screen 40, 41

Directivity Screen 42, 43

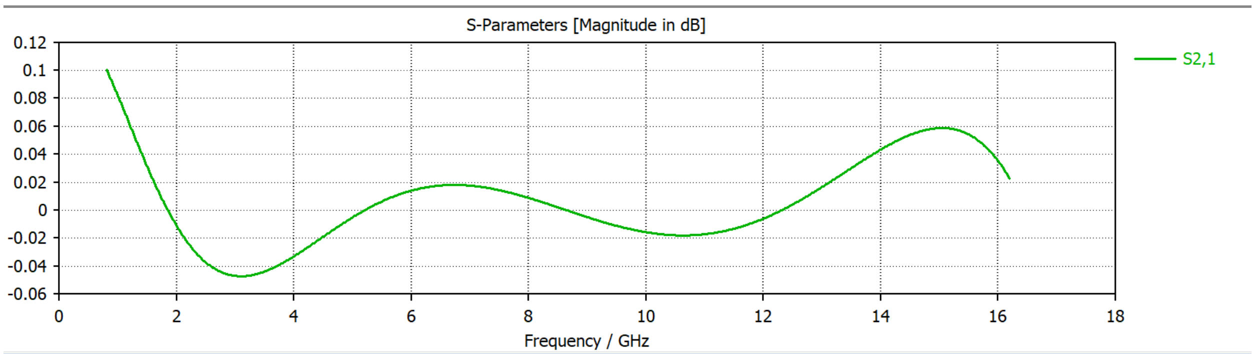
$D = 10,05$ $G = 9,735$ $\eta = 96,87\%$

Screen 0: coaxial cable



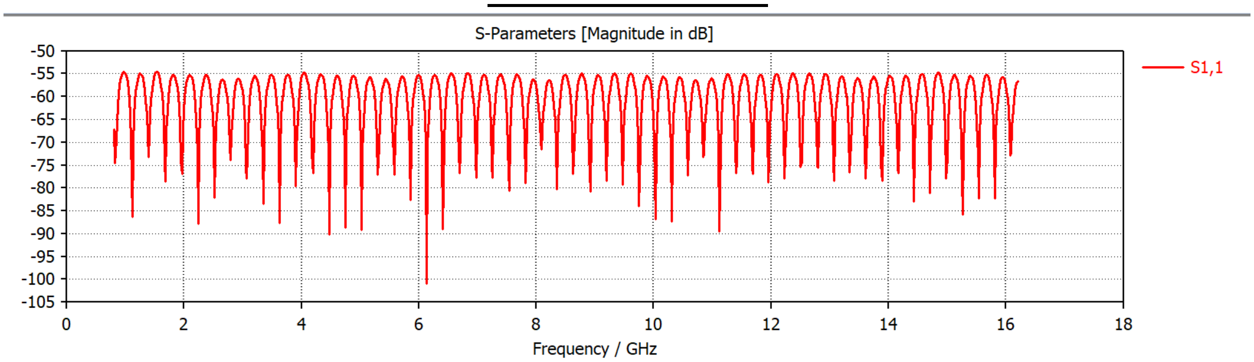
Screen 1: S21 = insertion loss coefficent

Note: we see that it is around 0dB which means that the loss are negligible



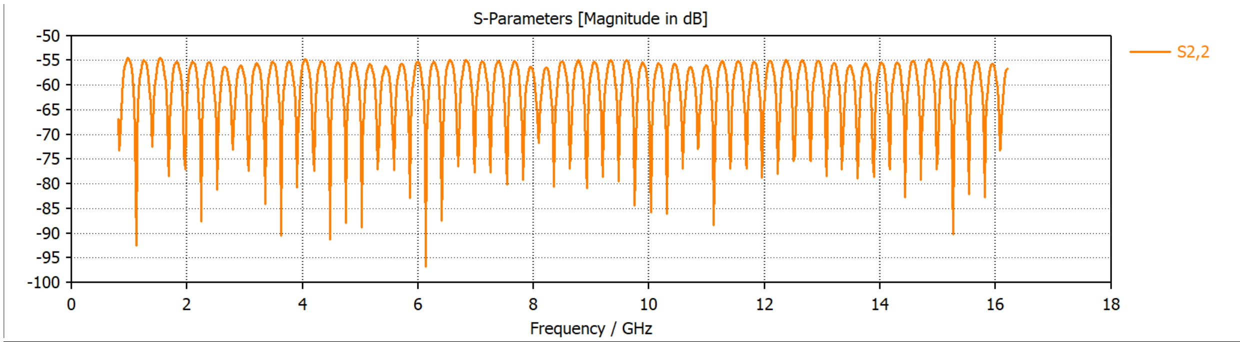
Screen 2: S11 reflection coefficient parameter at port 1

Note:below -25db



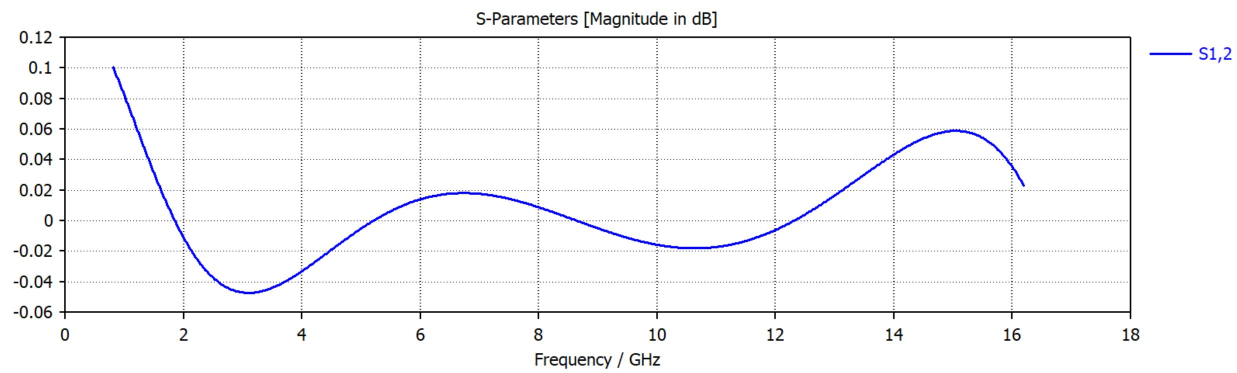
Screen 3: S11 reflection coefficient parameter at port 2

Note:below -25db

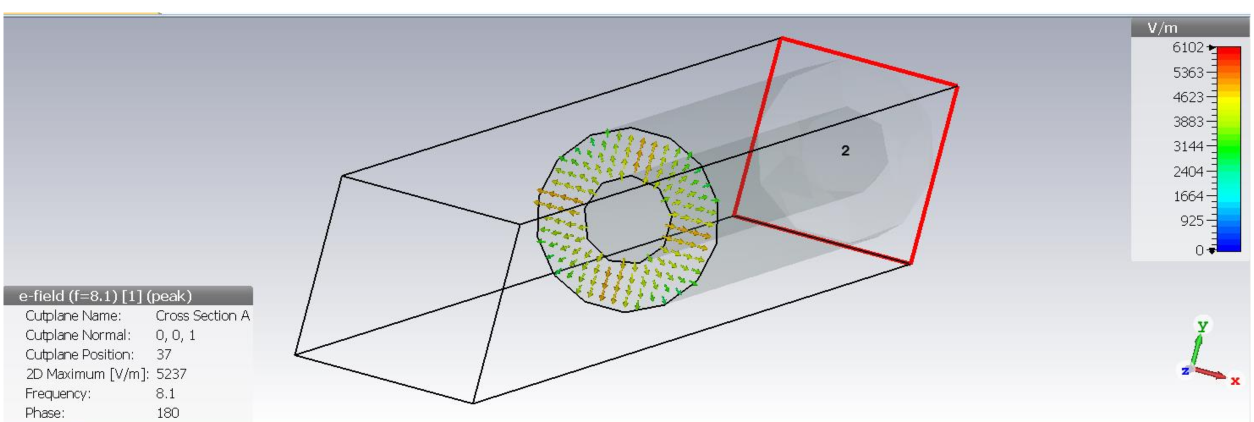


Screen 4: S12 parameter

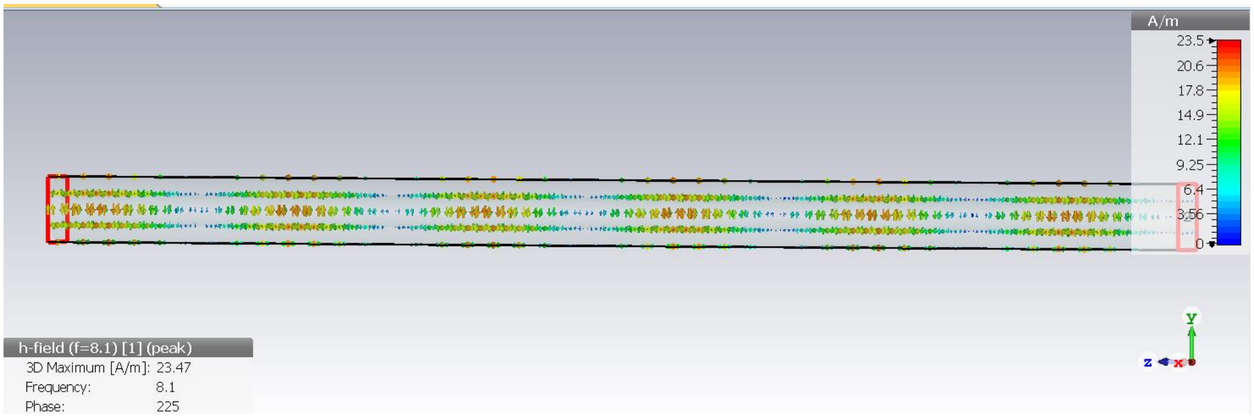
Note: around 0 dB



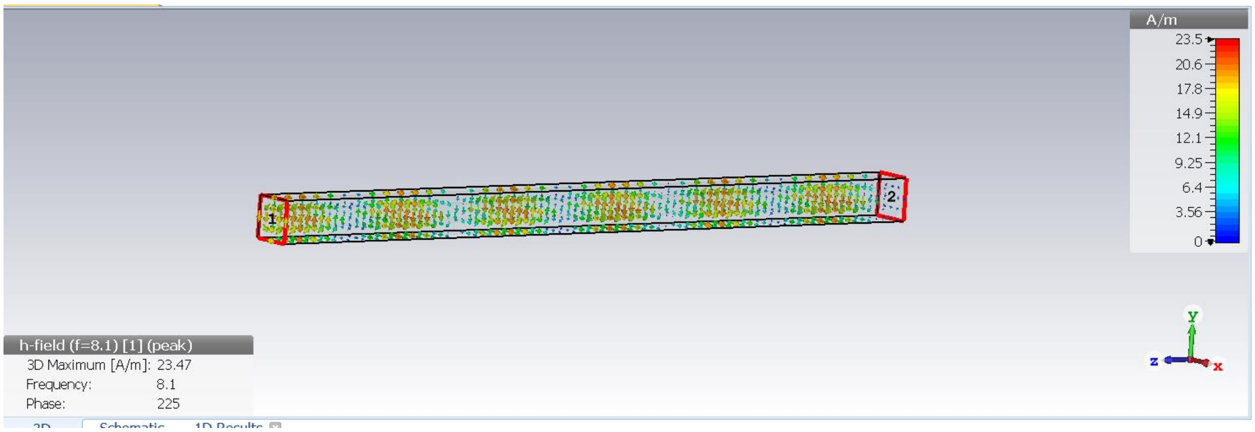
Screen 5: Slice section of the coaxial cable, Electric field view



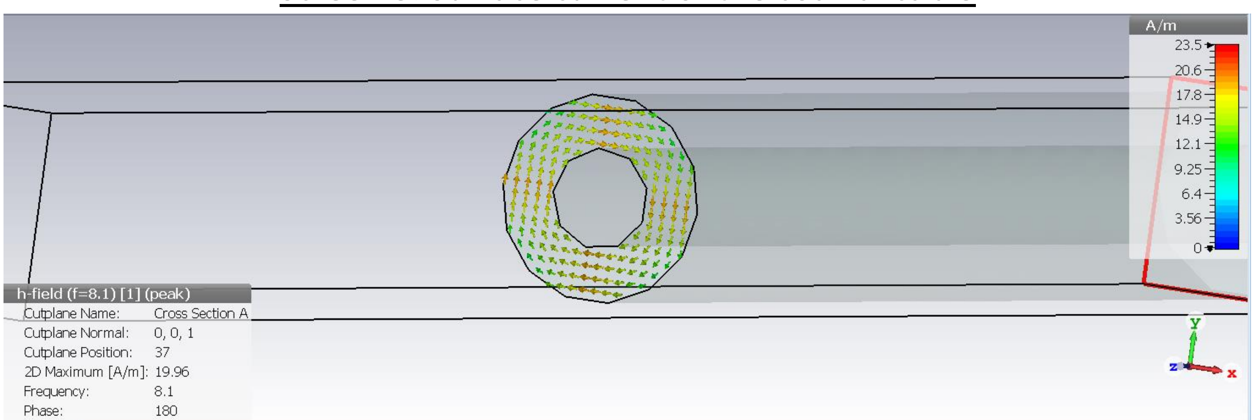
Screen 6: Surface current of the coaxial cable



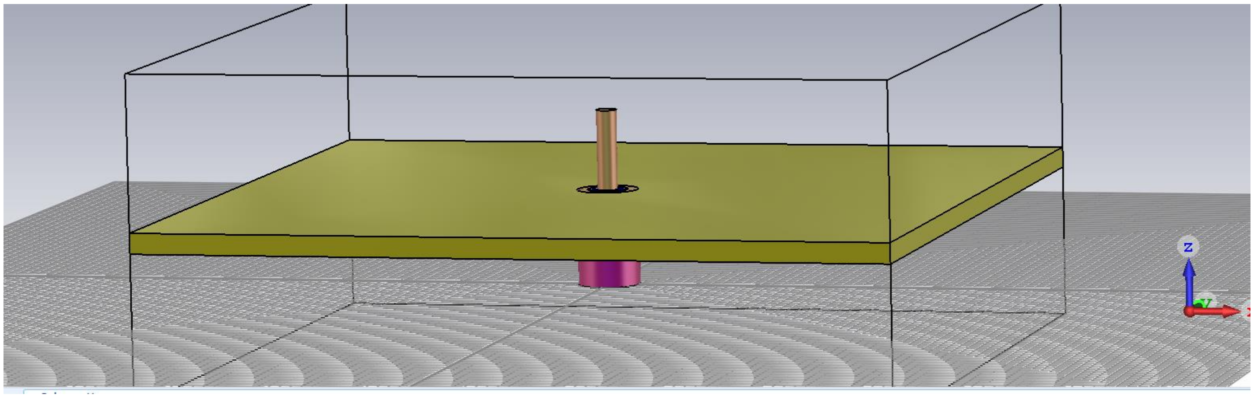
Screen 7: Surface current of the coaxial cable



Screen 8: Surface current of the coaxial cable

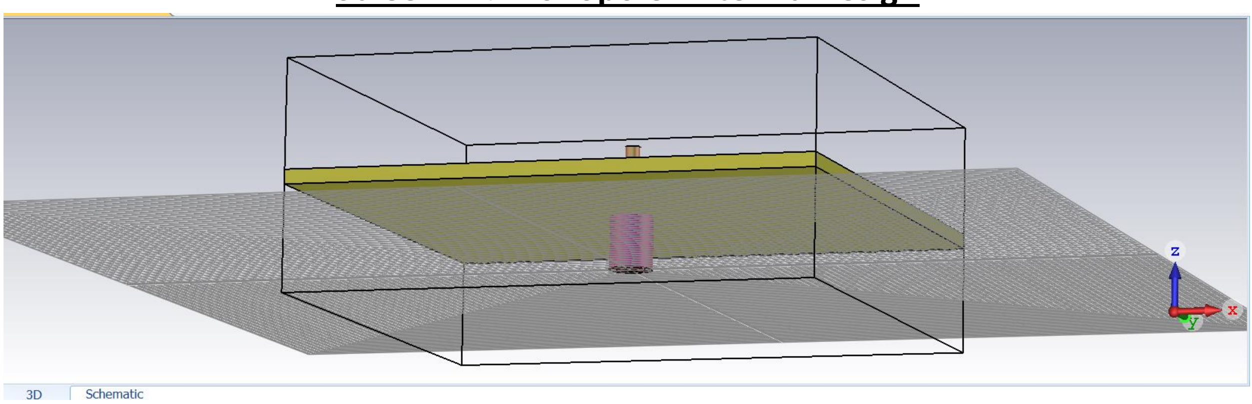


Screen 9: Monopole Antenna Design



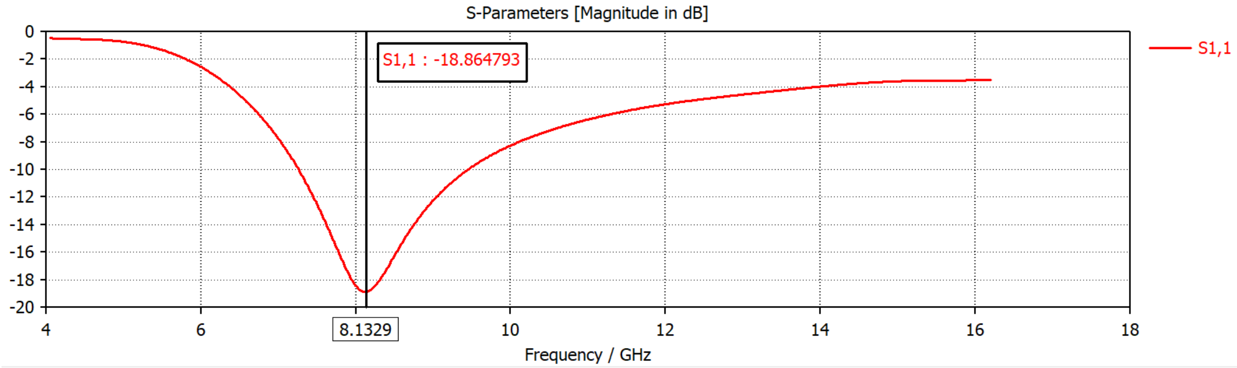
Screen 10: Monopole Antenna Design

Screen 11: Monopole Antenna Design

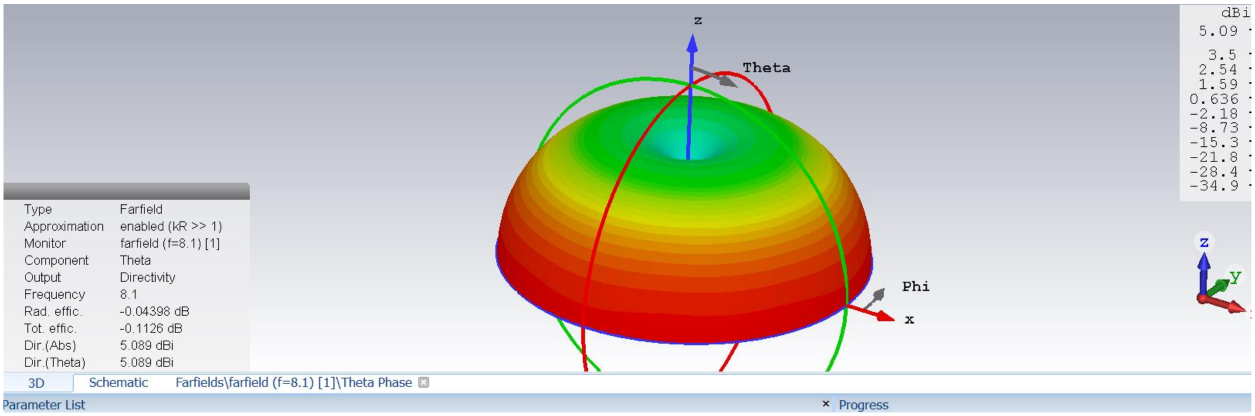


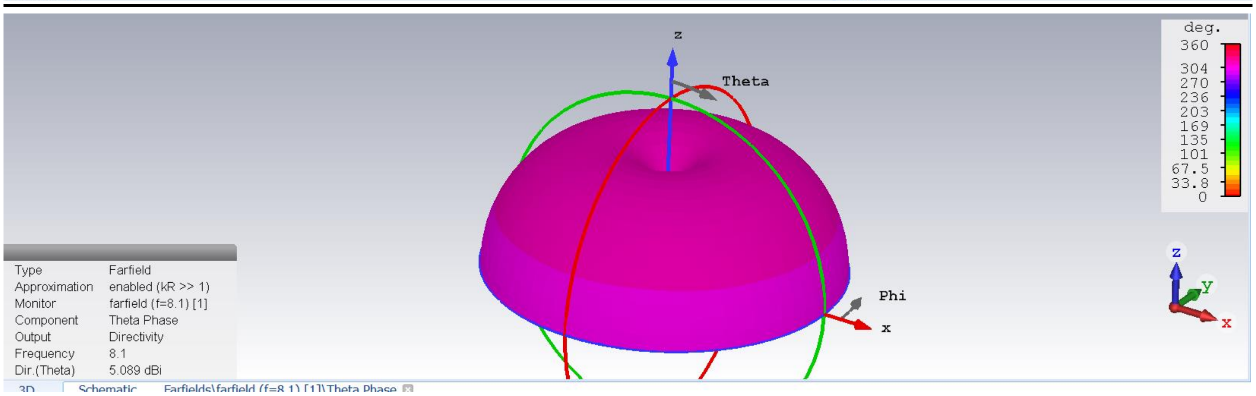
Screen 12: Monopole Antenna Design

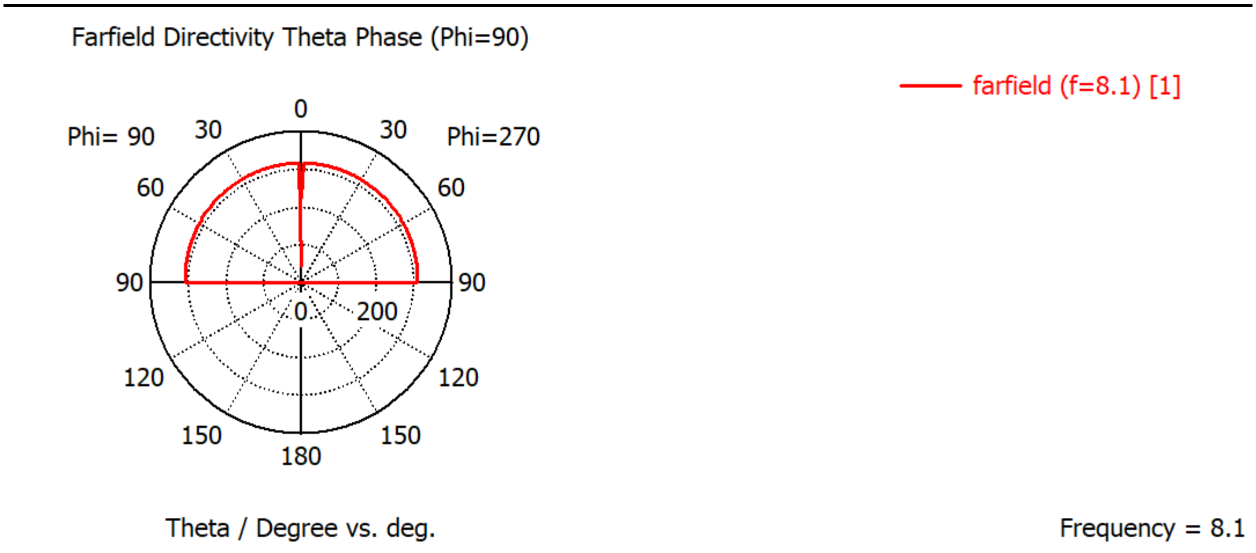
Note: We observe that the our design is successful since we designed for f=8.1GHz and the relfection coefficient at this point is -18dB, attenuates drastically the losses at matching frequency



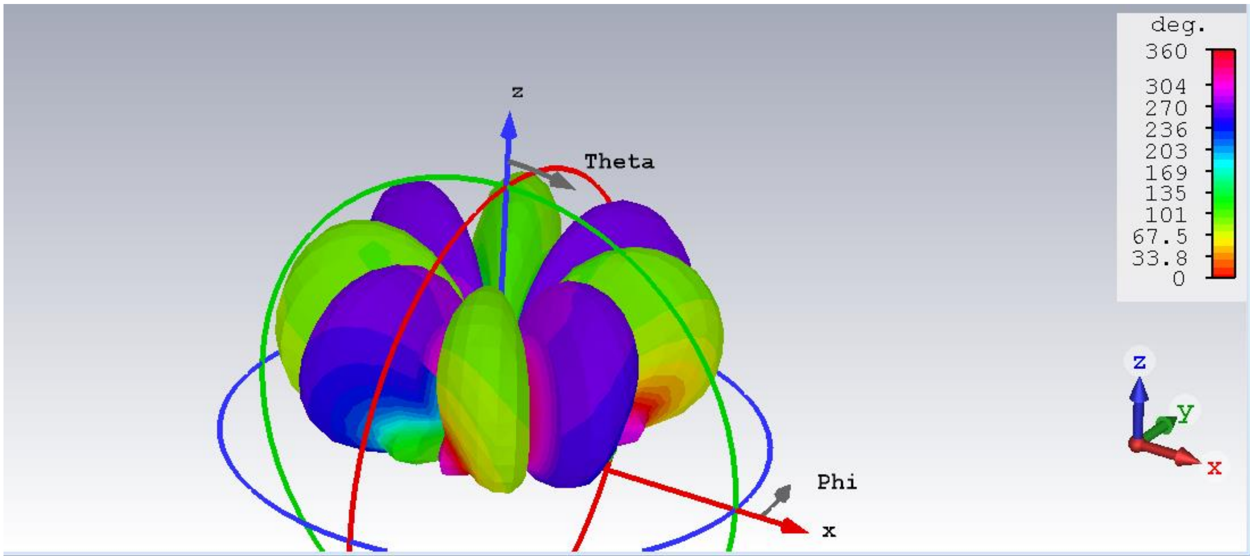
Screen 13: Elevation far field radiation pattern, x-z plane

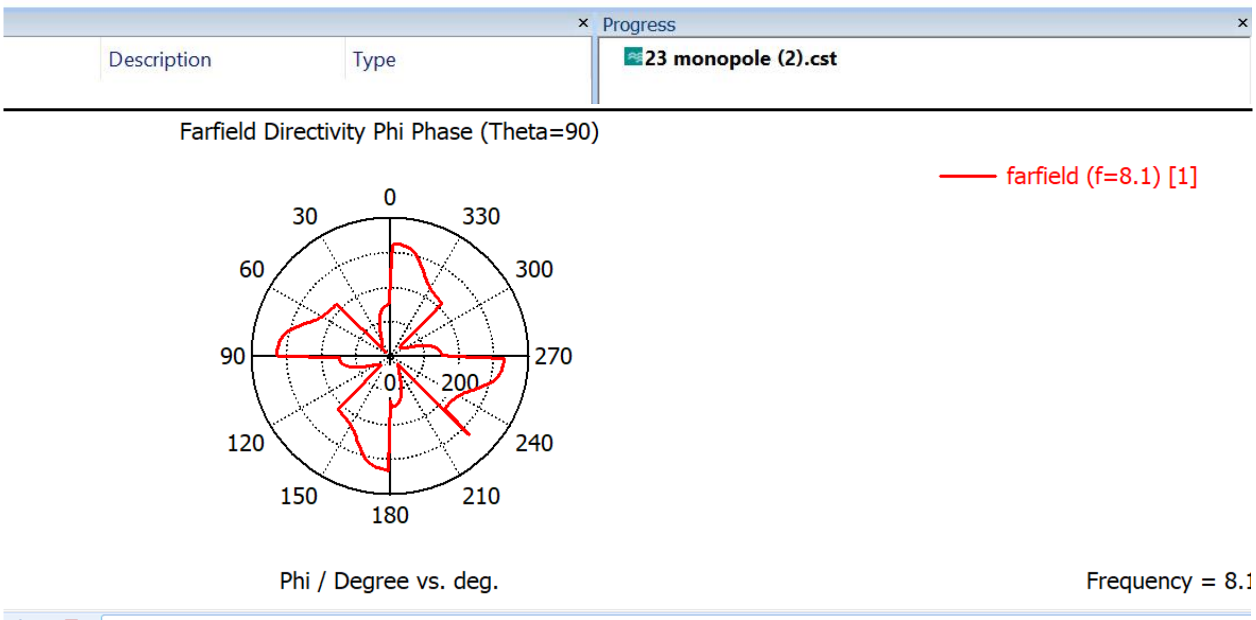


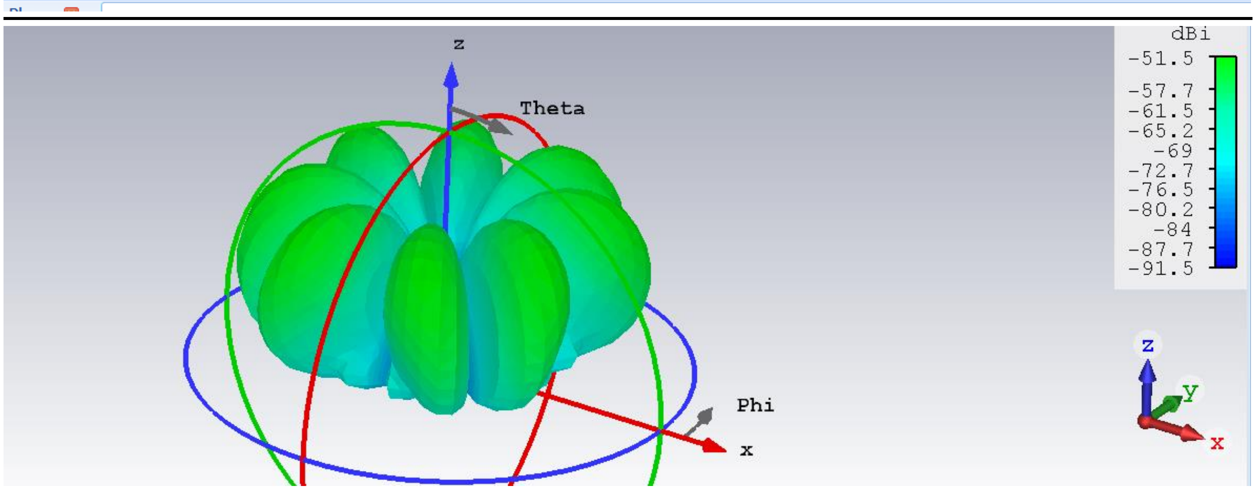




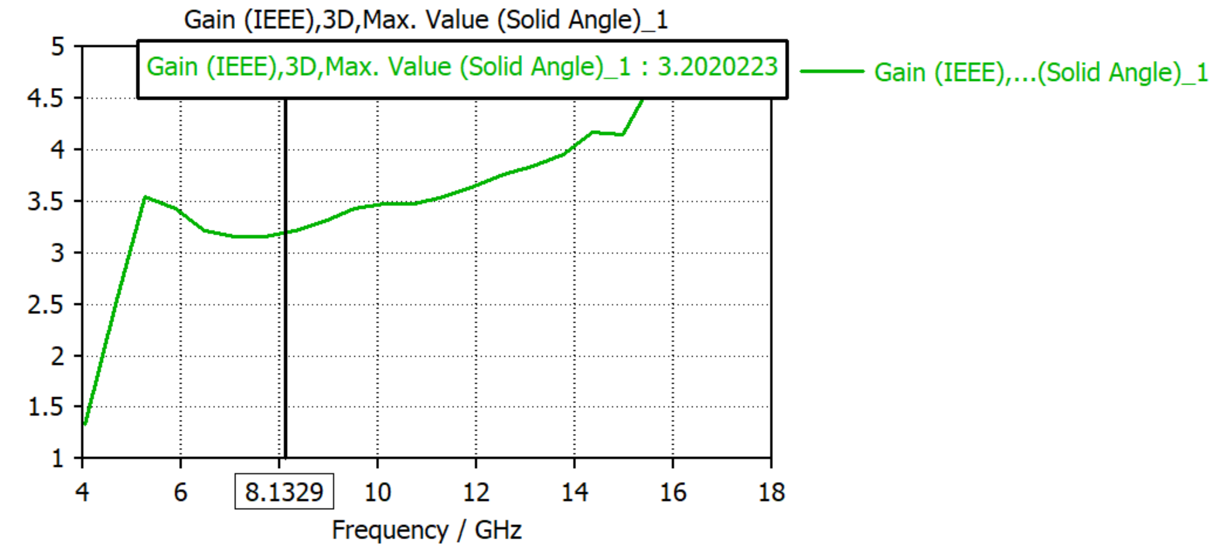
Screen 14: Ezimuthal far field radiation pattern, x-y plane


deg.
360
304
270
236
203
169
135
101
67.5
33.8
0
z
Theta
Phi
x
z
y
x

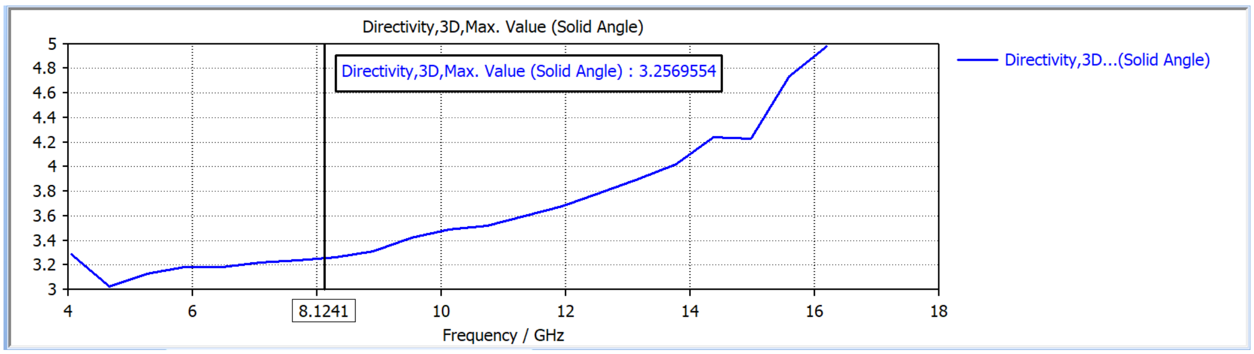

Description
Type
Progress
23 monopole (2).cst
Farfield Directivity Phi Phase (Theta=90)
farfield (f=8.1) [1]
0
30
330
60
300
90
270
120
240
150
210
180
0
200
Phi / Degree vs. deg.
Frequency = 8.1


dBi
-51.5
-57.7
-61.5
-65.2
-69
-72.7
-76.5
-80.2
-84
-87.7
-91.5
z
Theta
Phi
x
z
y
x

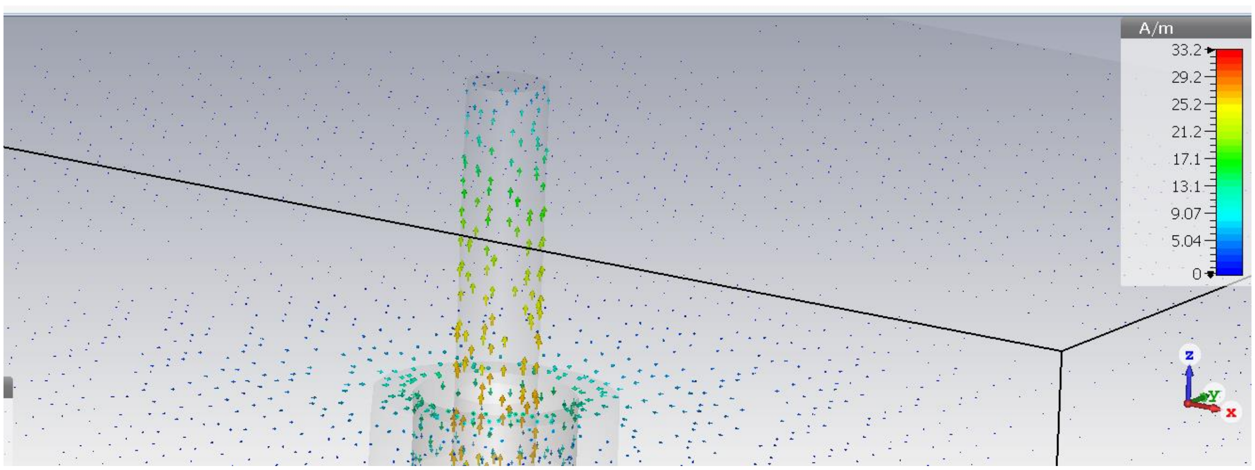
Screen 15: Peak gain



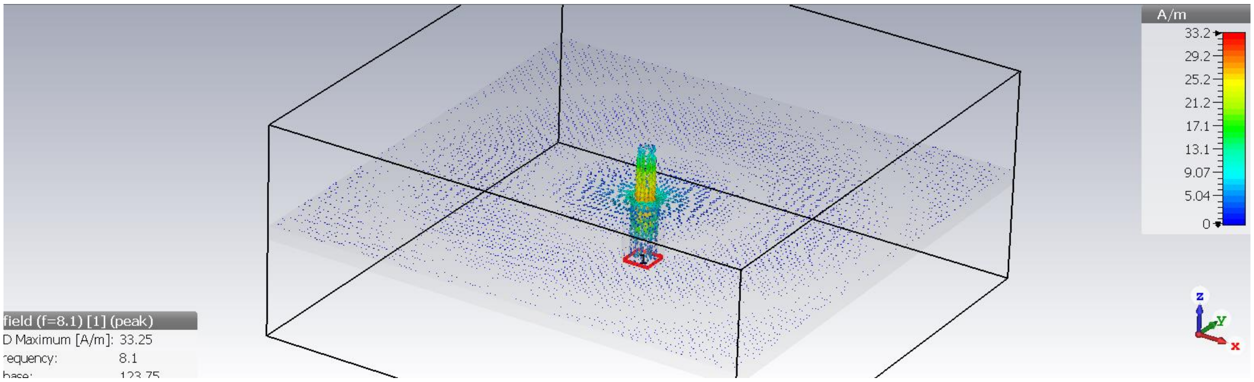
Screen 16: Peak Directivity



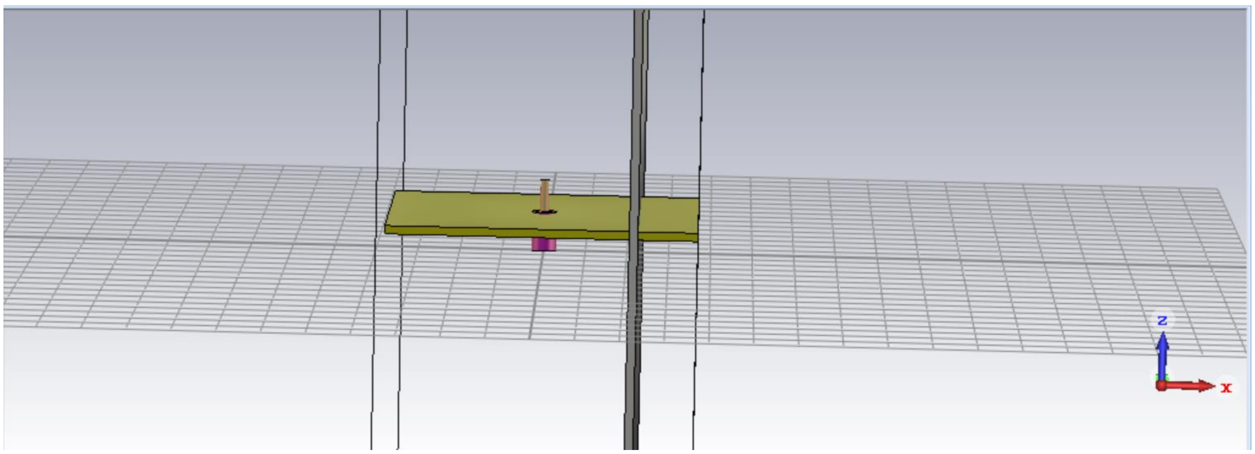
Screen 17: Surface current



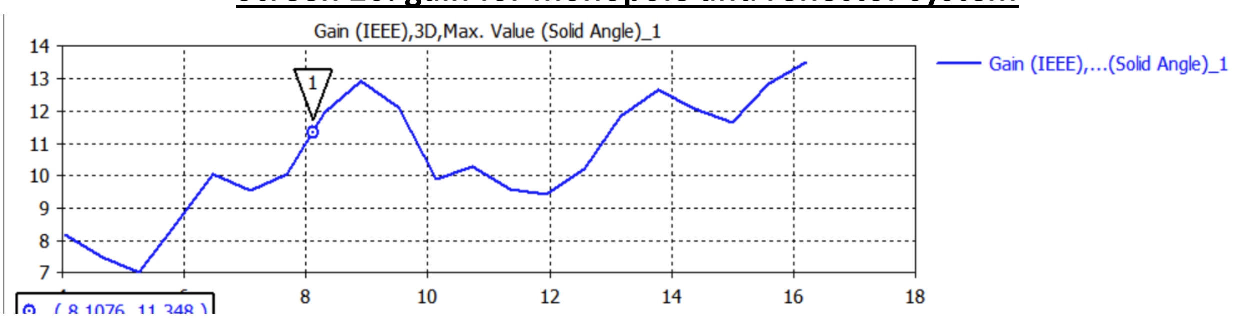
Screen 18: Surface current



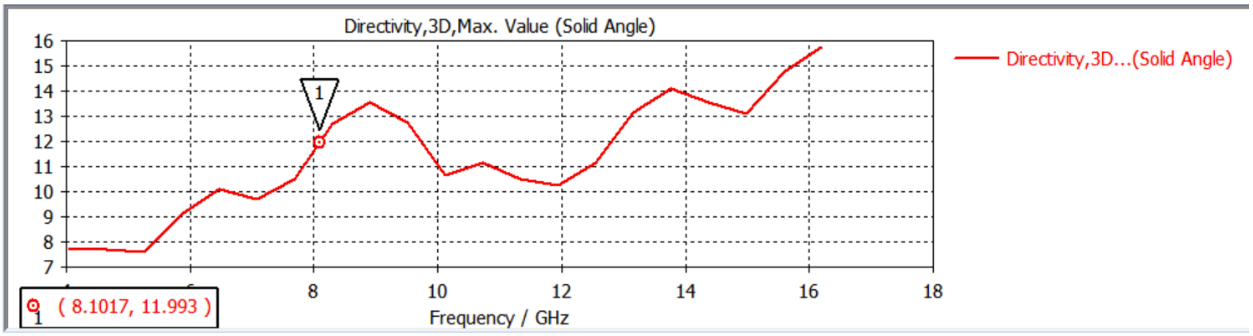
Screen 19:Monpole antenna and reflector



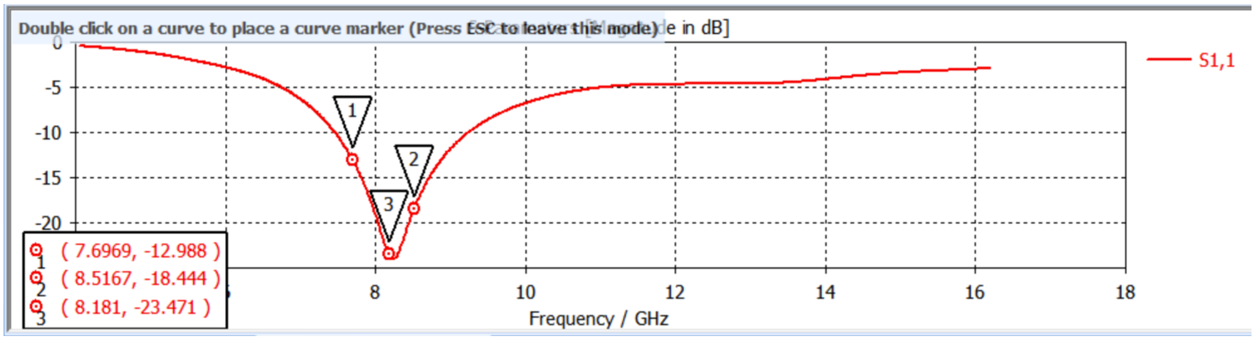
Screen 20: gain for monopole and reflector system



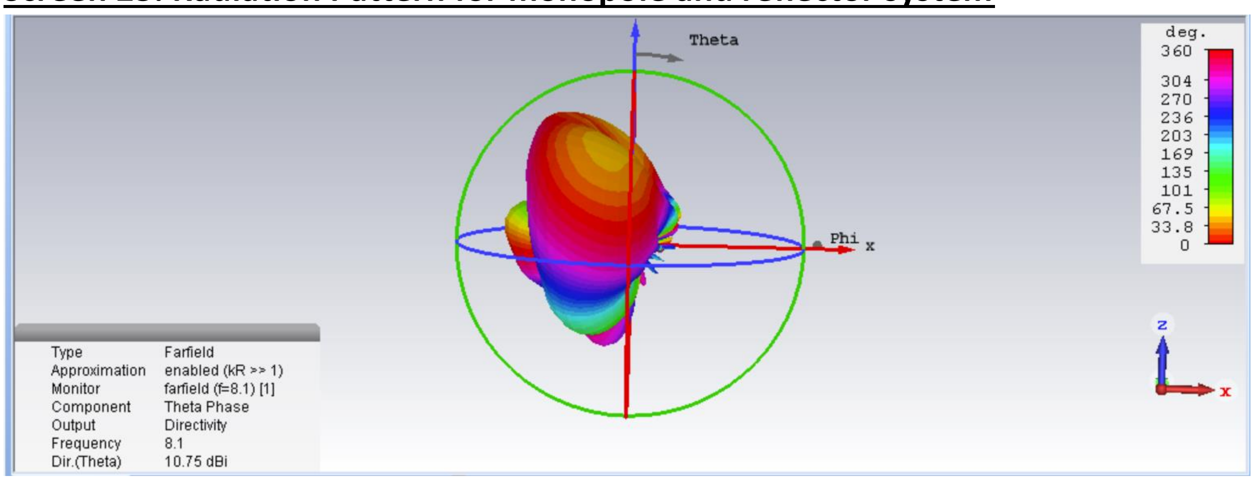
Screen 21: directivity for monopole and reflector system



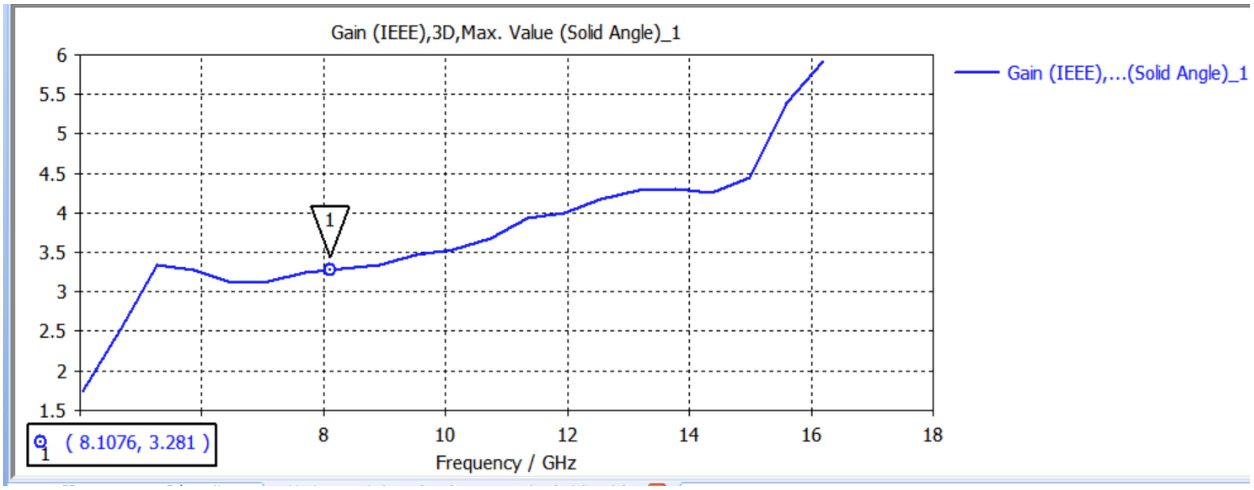
Screen 22: Reflection coefficient for monopole and reflector system



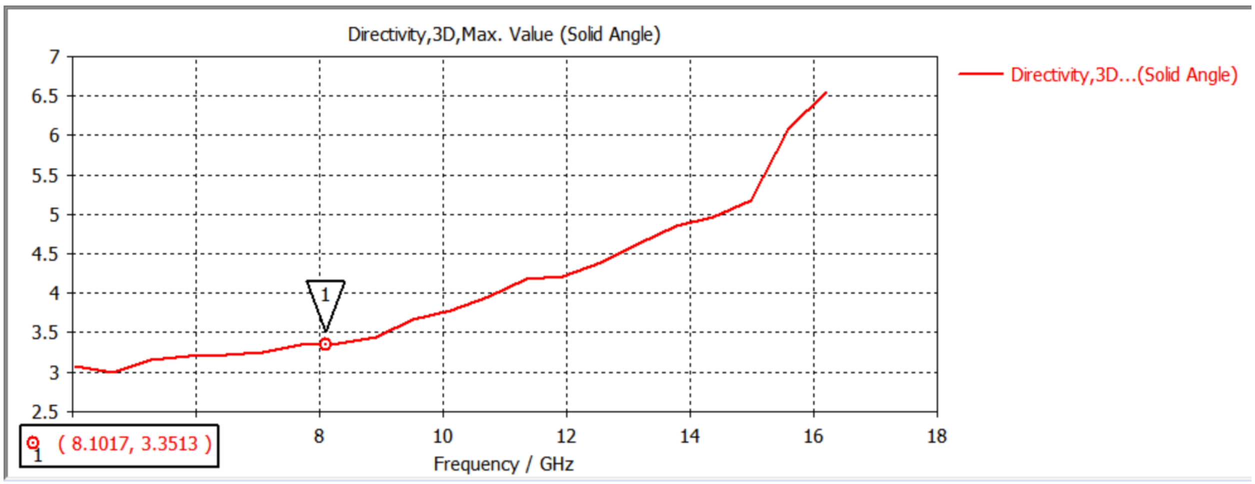
Screen 23: Radiation Pattern for monopole and reflector system



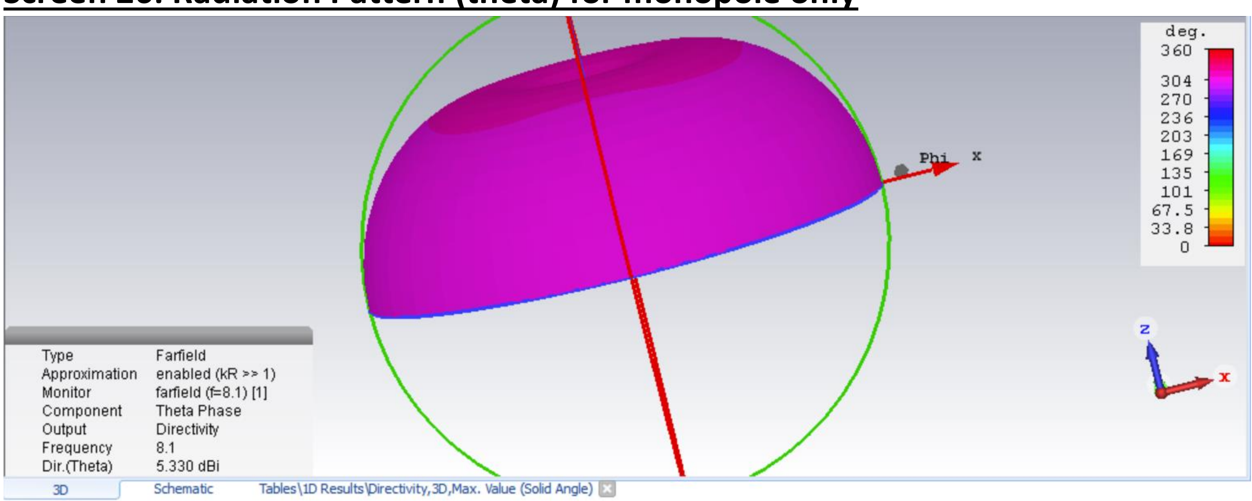
Screen 24: Gain for monopole only



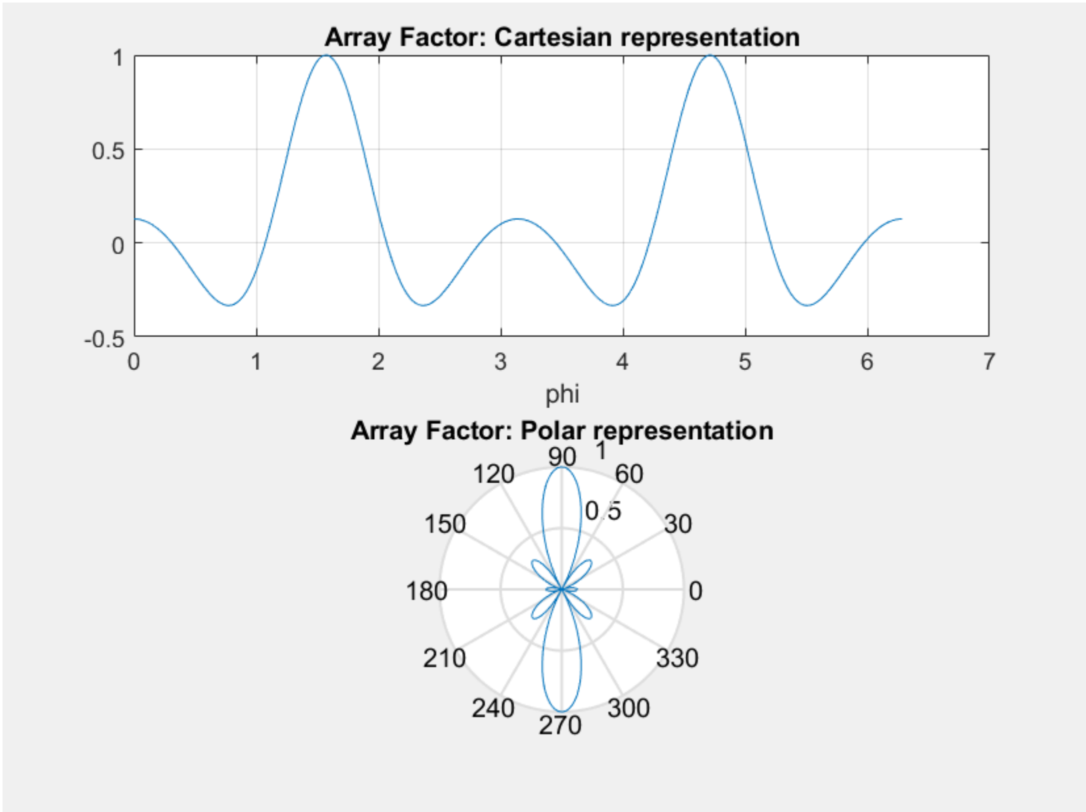
Screen 25: Directivity for monopole only



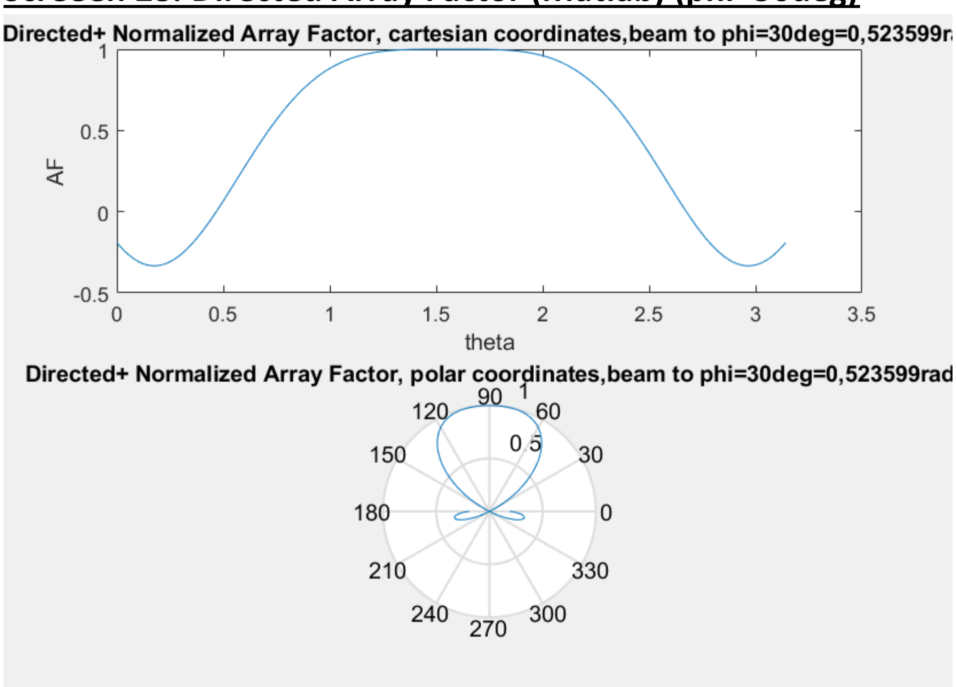
Screen 26: Radiation Pattern (theta) for monopole only



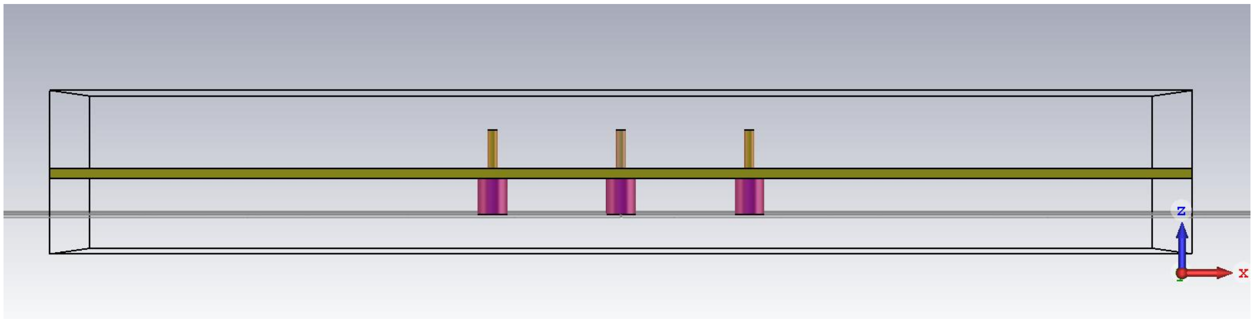
Screen 27: Undirected Array Factor plots (Matlab)



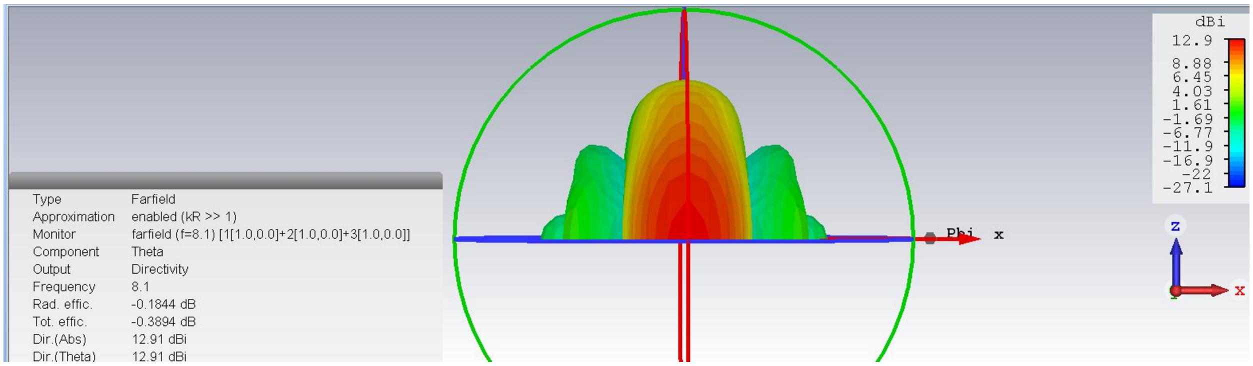
Screeen 28: Directed Array Factor (Matlab) (phi=30deg)



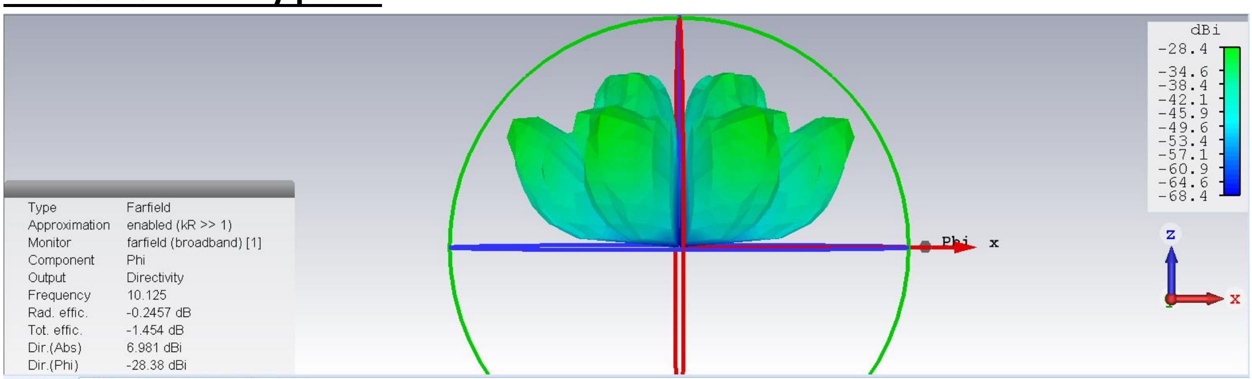
Screeen 29: Array Design model



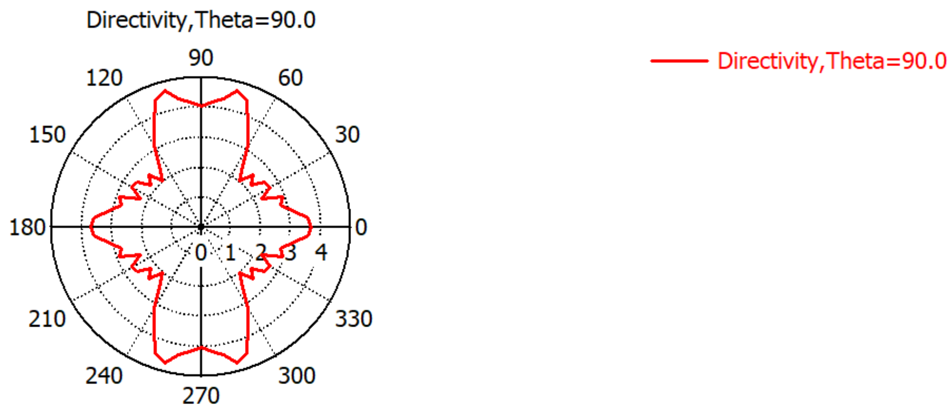
Screeen 30: 3D RP



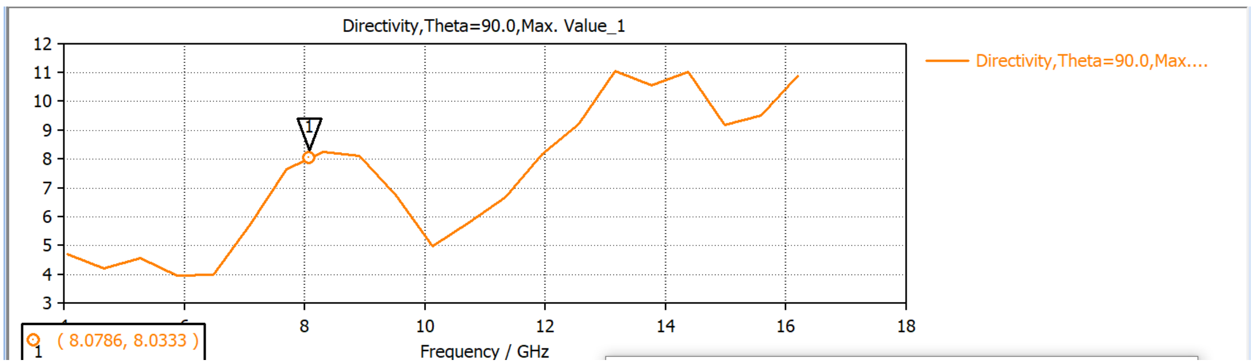
Screeen 31: RP- xy plane



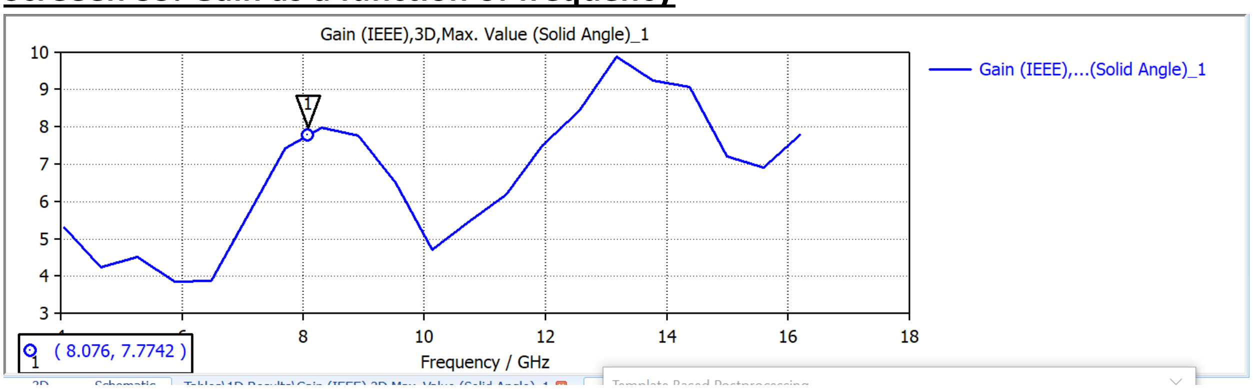
Screeen 32:Directivity :Polar coordinates



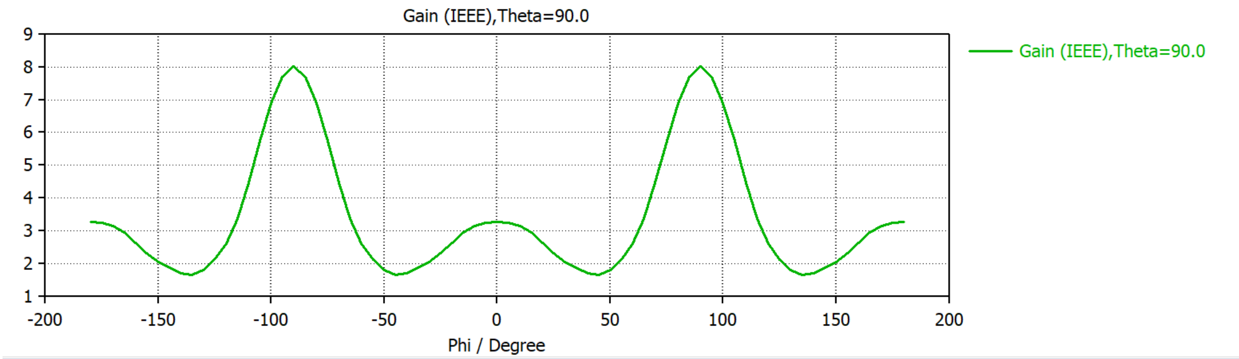
Screeen 32bis:Directivity :Cartesian coordinates



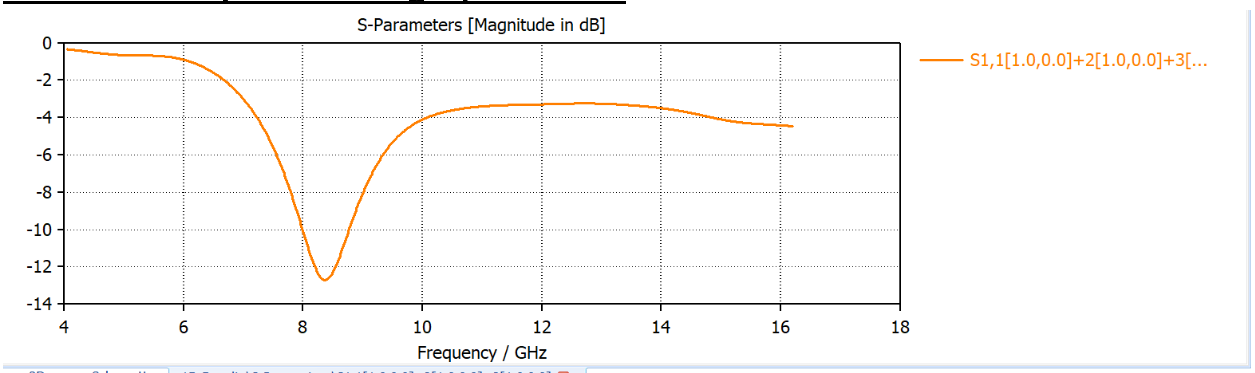
Screeen 33: Gain as a function of frequency



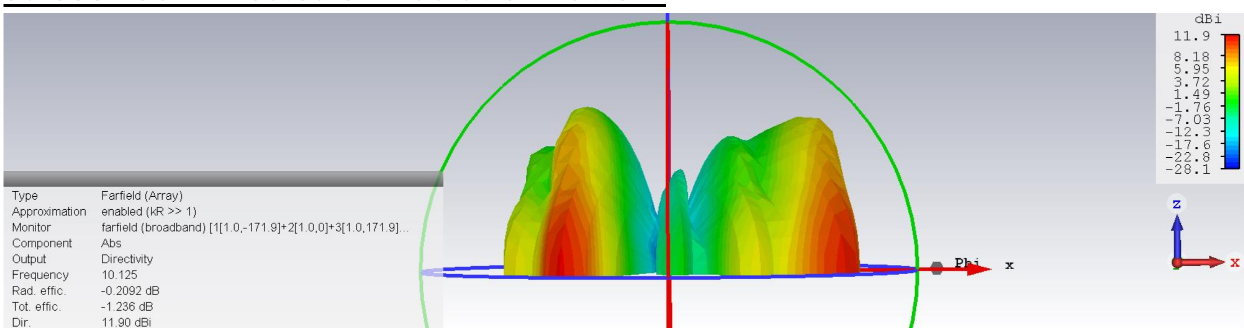
Screeen 34: Gain as a function of phi



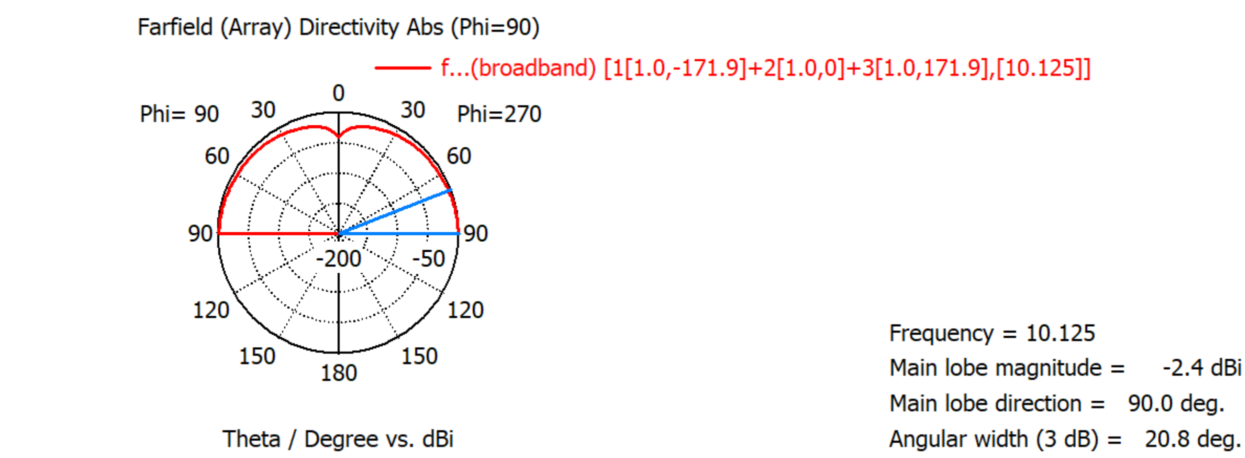
Screeen 35: Input matching S parameter



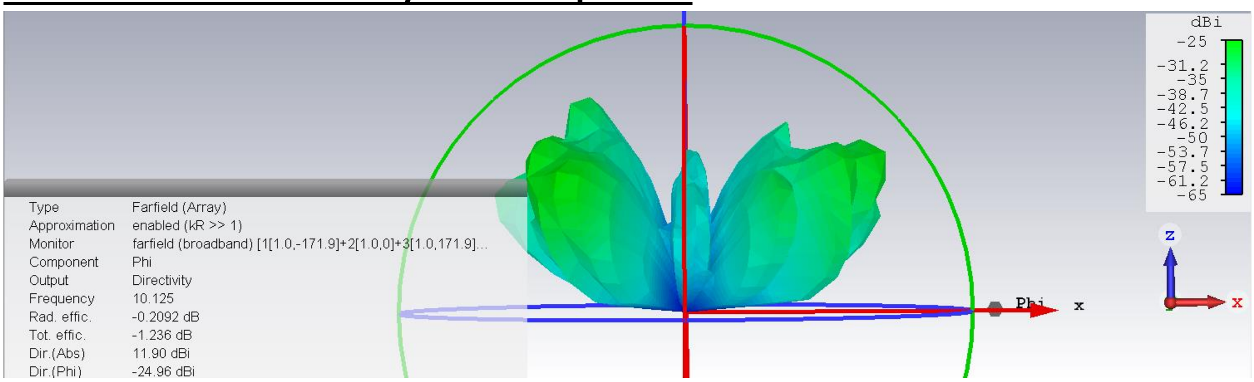
Screeen 36: Directed 3D Radiation Pattern



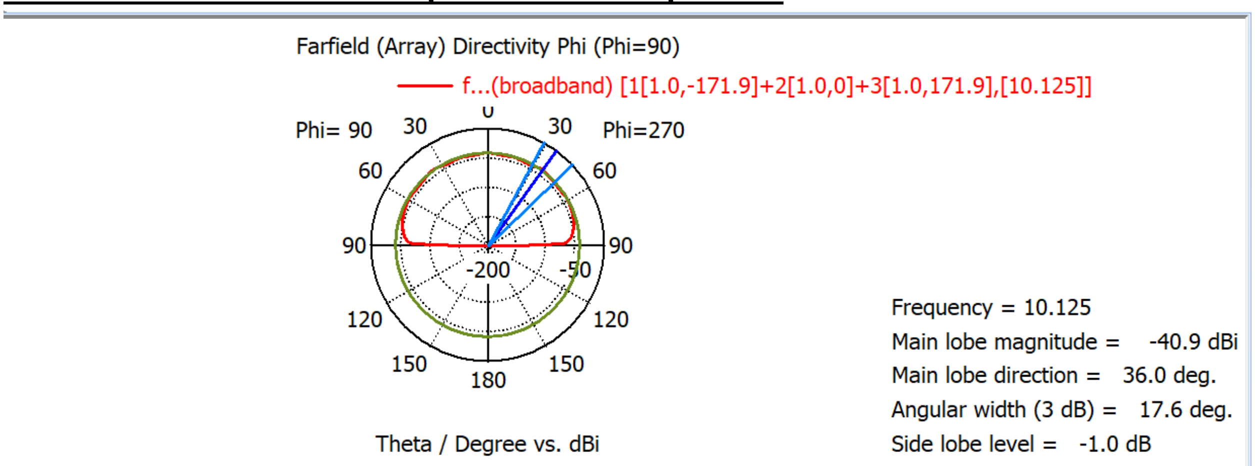
Screeen 36bis: Directed Polar Radiation Pattern



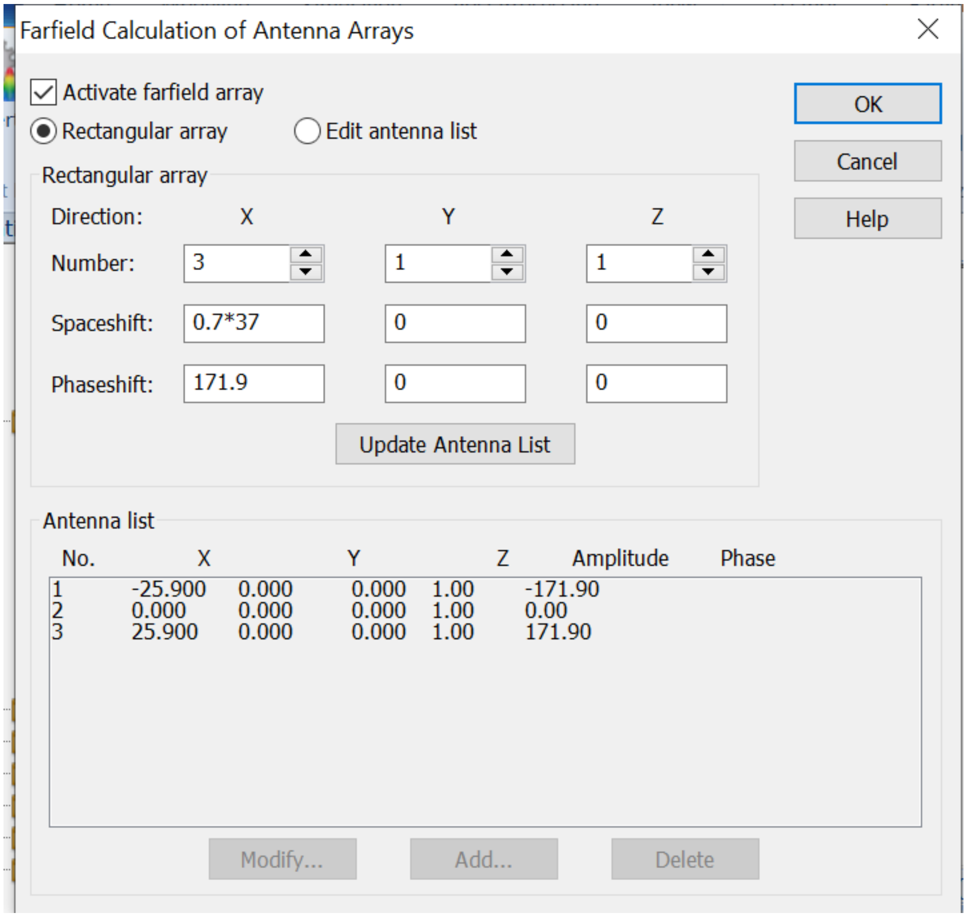
Screeen 37: Directed 3D xy radiation pattern



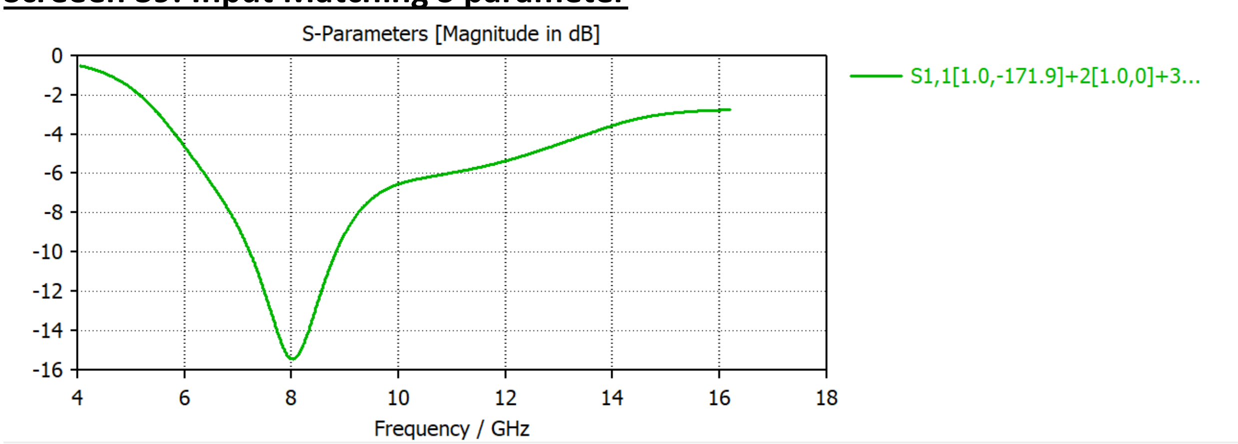
Screeen 37bis: Directed 3D polar radiation pattern



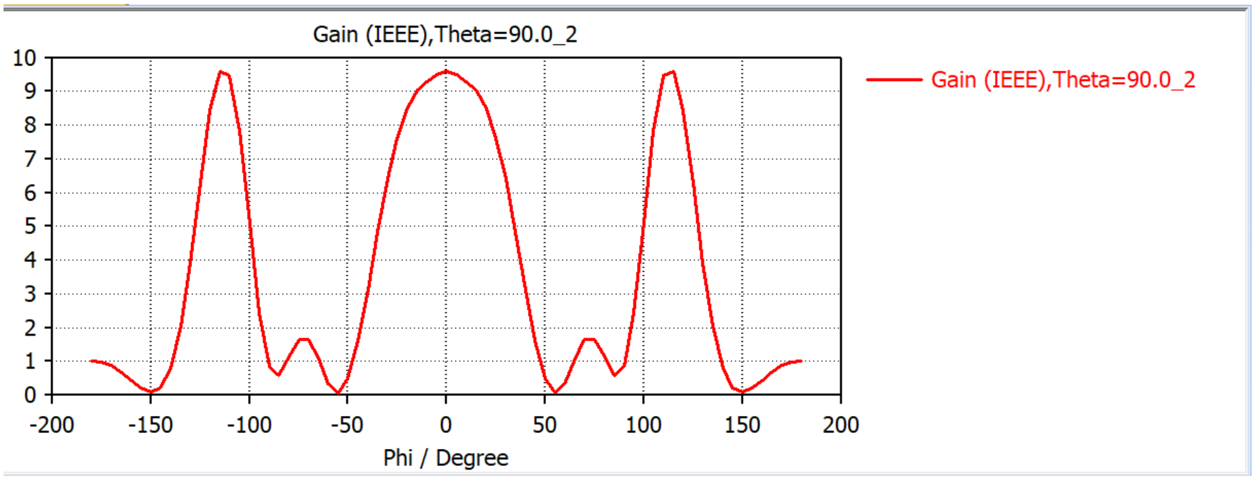
Screen 38: Array tool Parameters



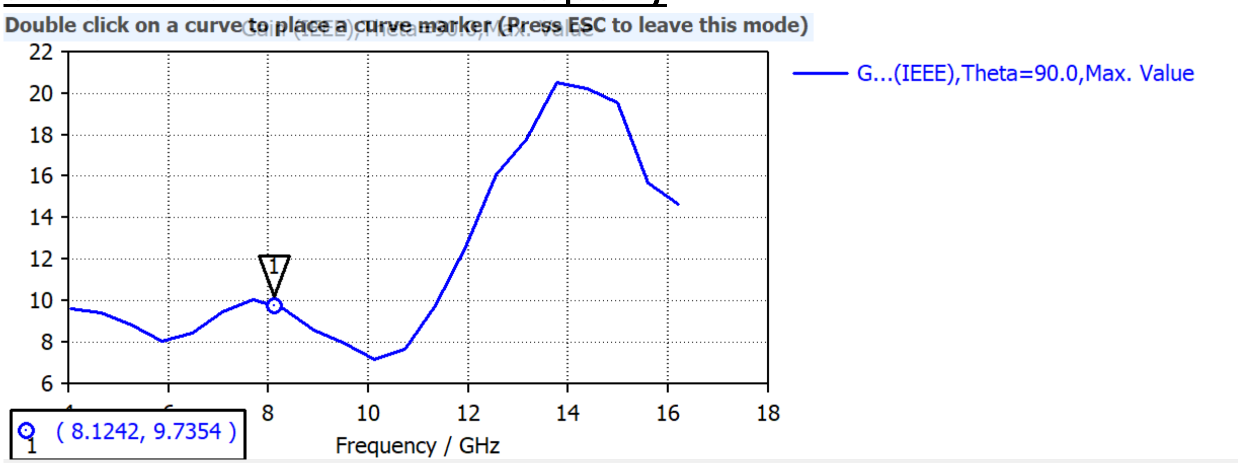
Screeen 39: Input Matching S parameter



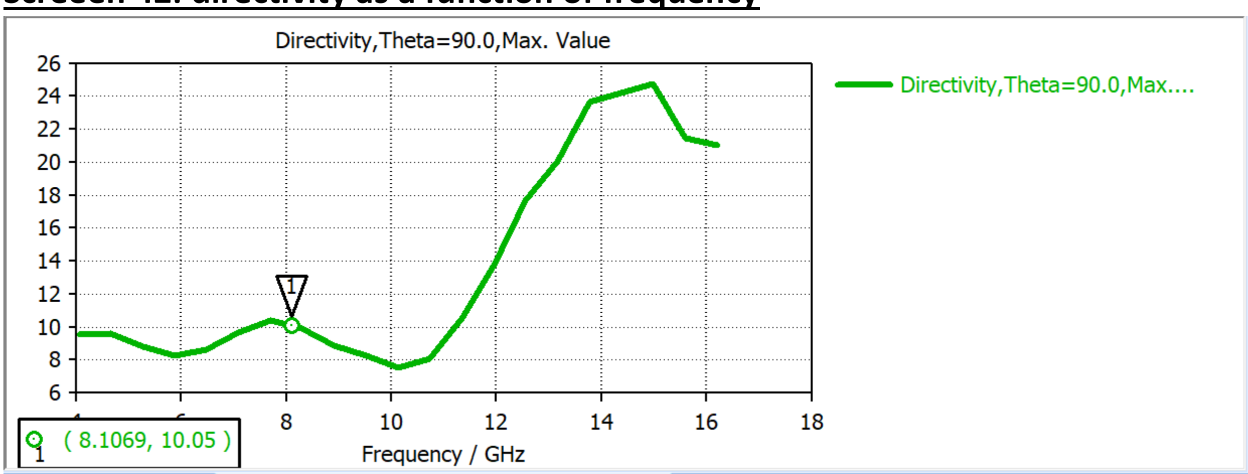
Screeen 40:Gain as a function of phi



Screeen 41:Gain as a function of frequency



Screeen 42: directivity as a function of frequency



Screeen 43: directivity at f=8.1GHz