Project ELC3050

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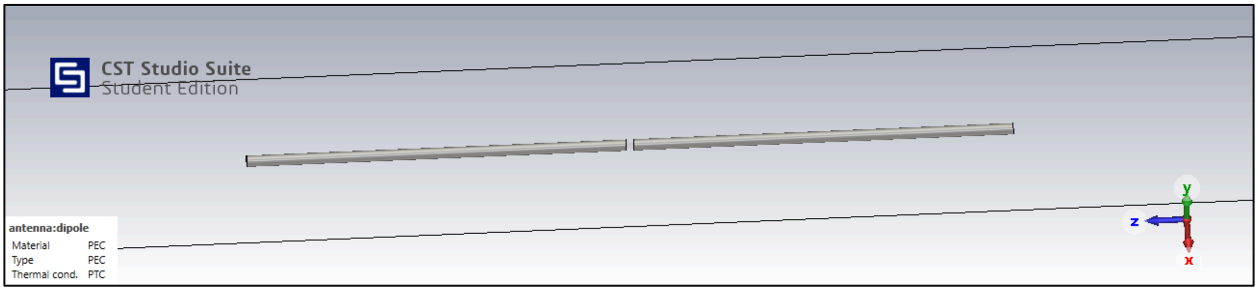
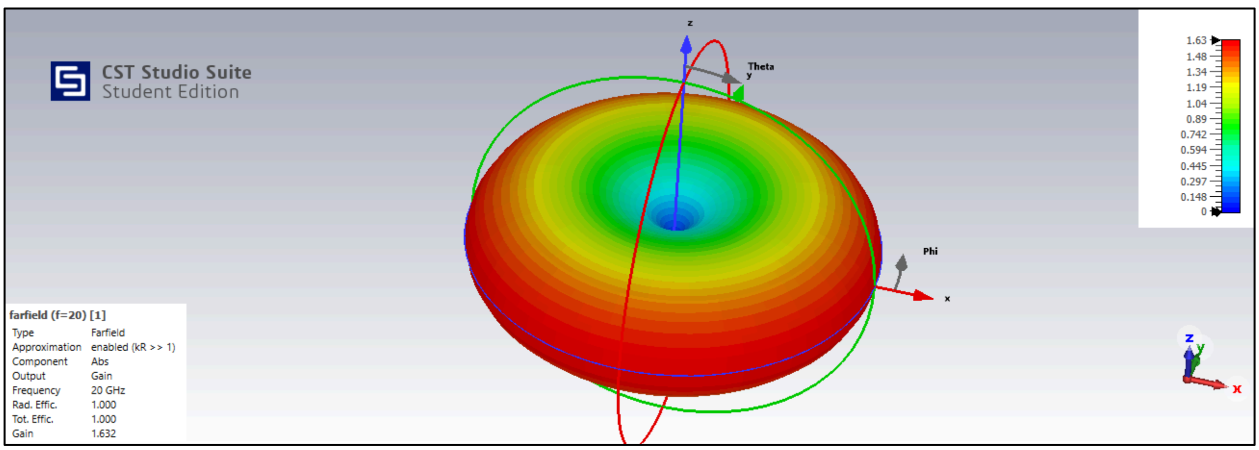
a) The schematic of the dipole antenna:



The used parameters in design:

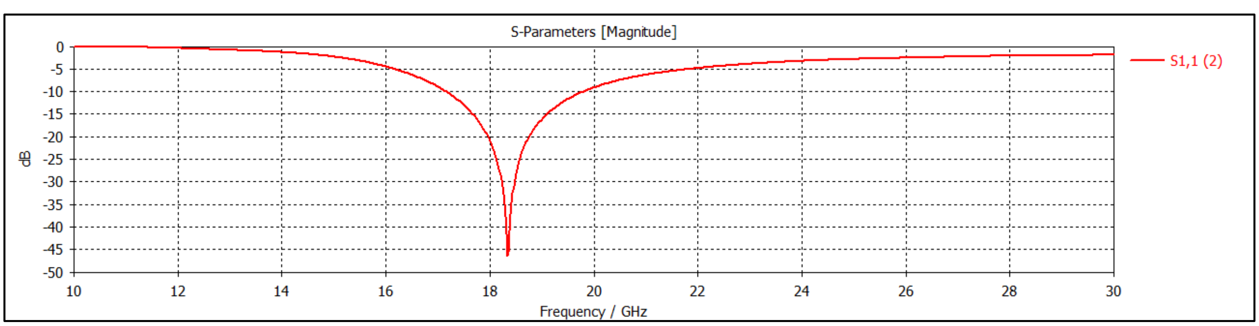
Name	Expression	Value	Description
Zo	= 73	73	port impedence
r	= 0.003369*lambda	0.050535	radius of the dipole
length	= (adjustment_factor*lambda)/2	6.86625	length of the antenna
lambda	= 15	15	wavelength
d	= length/100	0.0686625	distance between the two rods
adjustment_factor	= 18.31/20	0.9155	
<new parameter>			

Radiation pattern (3D-plot):

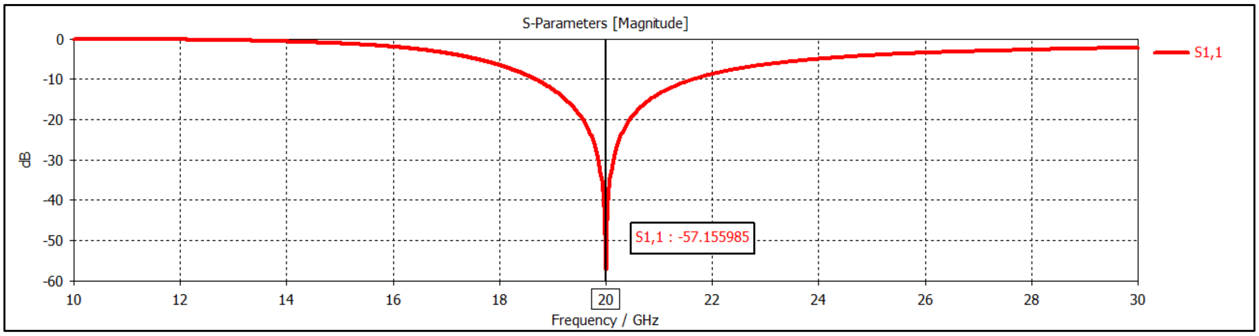


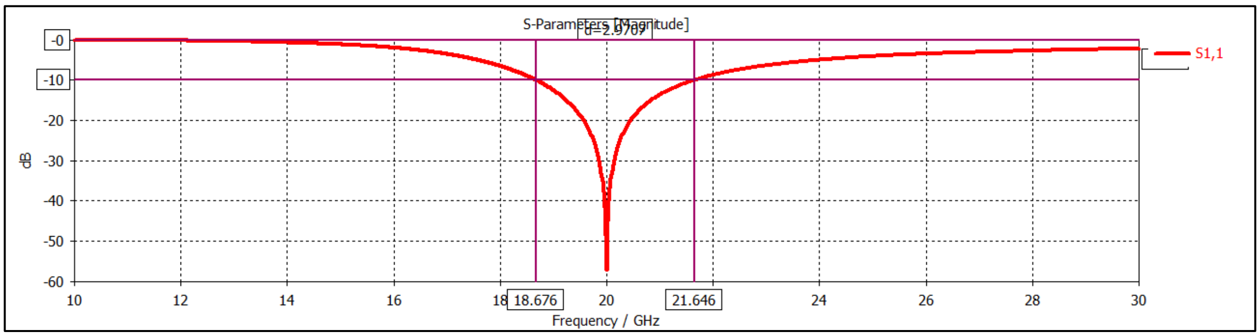
b) The reflection coefficient in dB:

i- Before adjustment:



ii- After adjustment:



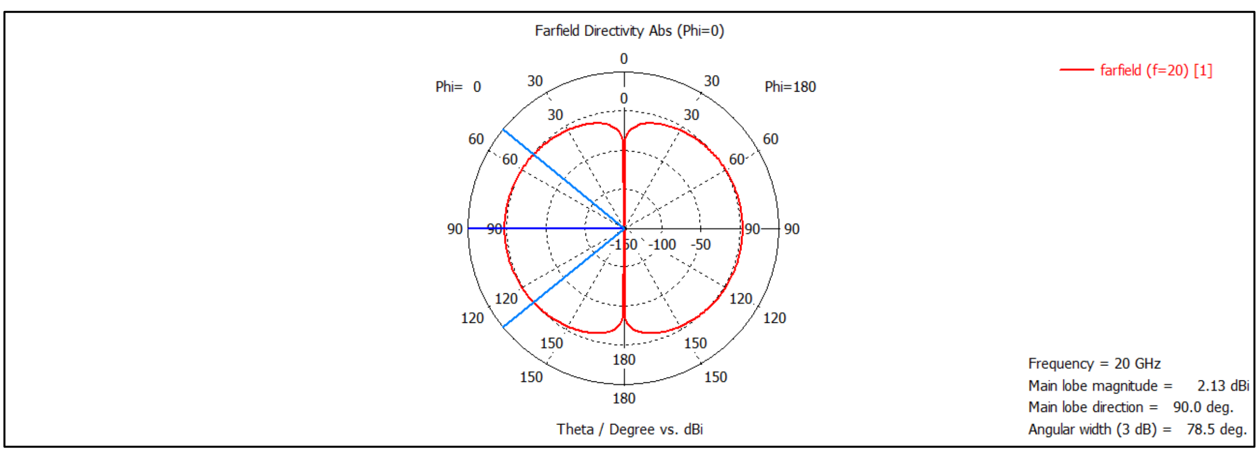


$$\textbf{\textit{Fractional Bandwidth}} = \frac{f_2 - f_1}{f_c} = \frac{21.646 - 18.676}{20} * 100\% = \mathbf{14.85\%}$$

c) ***Radiation Pattern Plotting:***

i- E-plane:

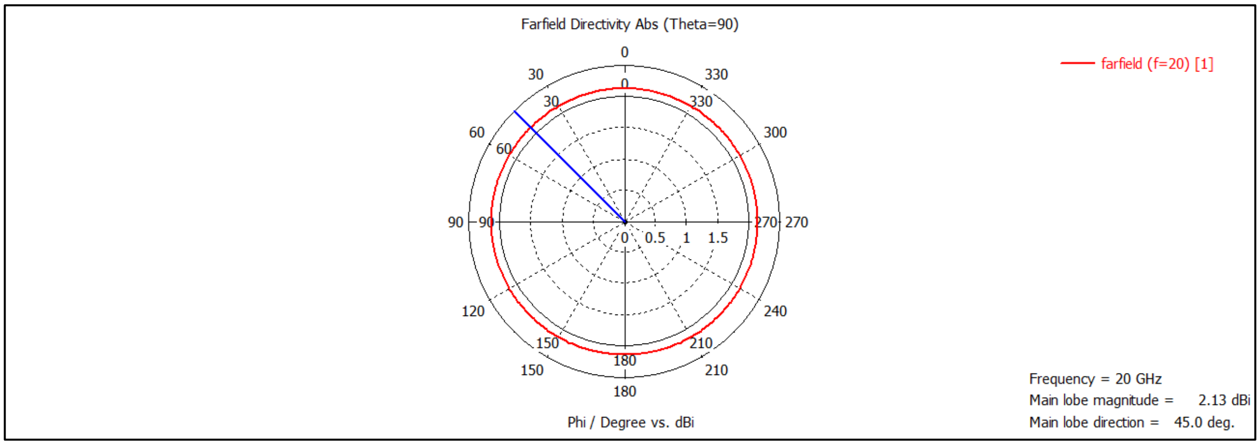
$@\ \emptyset = 0°\ (xz\ plane)$



E-plane

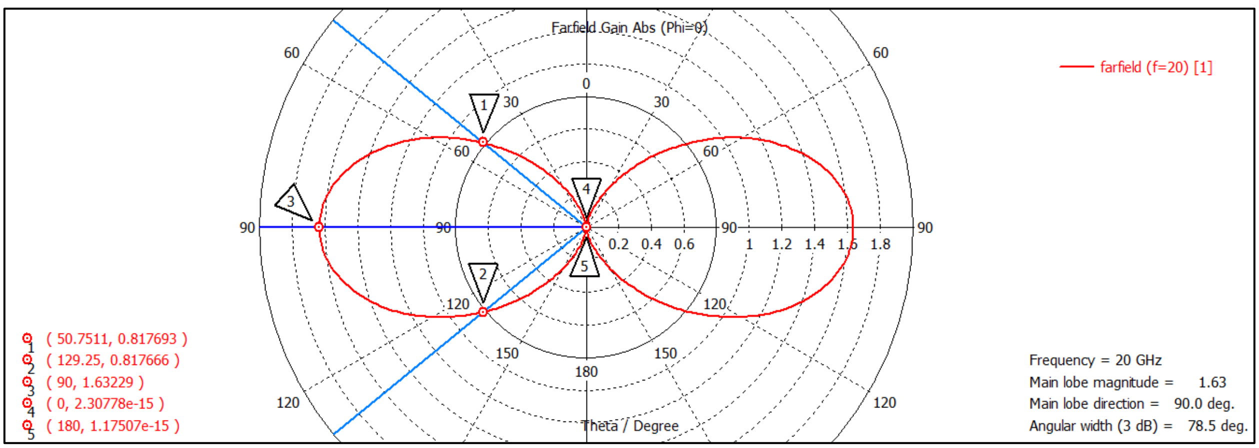
ii- H-plane:

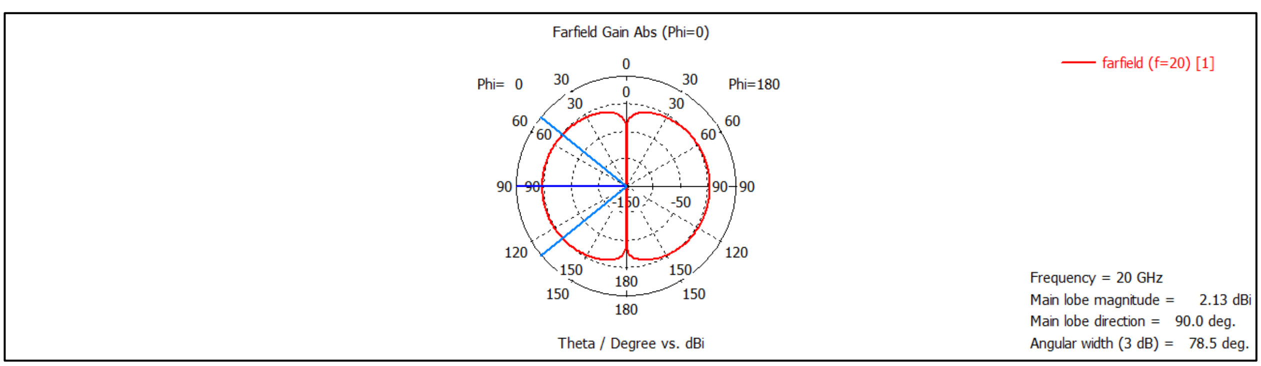
$@\ \theta = 90°\ (\text{xy}\ plane)$



H-plane

d) ***FNBW, HPBW and maximum gain:***





From the above radiation patterns, we get the following values:

$\mathbf{FNBW = 180°}$ $\qquad$ $\boldsymbol{HPBW_{(3dB)} = 78.5°}$ $\qquad$ $\mathbf{Gain_{(max)} = 2.13dBi}$

Hand Analysis:

i- Maximum Gain calculation:

Generally, for a for a finite length dipole antenna, the electric field is given by :

$\underline{E} = \frac{j\omega\mu I_o}{4\pi r}\frac{2}{k}\frac{\cos(0.5kl\cos(\theta)) - \cos(0.5kl)}{\sin(\theta)}\hat{a}_\theta$ $\quad\quad \because$ *the dipole antenna is length* $l = \frac{\lambda}{2}$

$$\therefore E = \frac{j\omega\mu I_o}{2\pi r k}\frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)}$$

$\therefore$ *Radiation intensity is given by*:

$$U = \frac{r^2|E|^2}{2\eta} = \frac{(\omega\mu I_o)^2}{2\eta(2\pi k)^2}\frac{\cos^2\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin^2(\theta)}$$

$\therefore$ *The total radiated power*:

$$W_{rad} = \int U\, d\Omega = \frac{1}{2\eta} * \left(\frac{2\omega\mu I_o}{4\pi k}\right)^2 * \int_{\theta=0}^{\pi}\int_{\varphi=0}^{2\pi}\frac{\cos^2\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin^2(\theta)} sin\theta\, d\theta\, d\varphi$$

Solving the above integration numerically, we get: $W_{\text{rad}} = \frac{(\omega\mu I_o)^2}{2\eta(2\pi k)^2} * 7.6581$

Definite integral | More digits

$$\int_0^{\pi}\int_0^{2\pi}\frac{\cos^2\left(\frac{1}{2}\pi\cos(x)\right)}{\sin(x)}\,dy\,dx = \pi\left(-\text{Ci}(2\pi) + \gamma + \log(2\pi)\right) \approx 7.65811$$

$\text{Ci}(x)$ is the cosine integral

$\log(x)$ is the natural logarithm

γ is the Euler-Mascheroni constant

$\therefore$ *The directivity is given by*:

$$\text{D} = \frac{4\pi\text{U}}{\text{W}_{\text{rad}}} = 1.64\frac{\cos^2\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin^2(\theta)}$$

$\therefore$ *The maximum directivity is at* $\theta = 90°$: $D_{max} = 1.64 = 2.15\ dBi$

$G = \eta_{eff} * D$ $\quad\quad\quad\quad$ $\eta_{eff} = \frac{w_{\text{rad}}}{w_{\text{rad}} + w_{\text{Loss}}}$

Since we are using PEC, therefore, there are no losses hence: $\eta_{eff} = 1$

$$\therefore \boldsymbol{G_{max} = D_{max} = 2.15\ dBi}$$

***ii-* FNBW calculaiton:**

The angle (θ) ajdacent to the main lobe at which the gain (or directivity or intensity) is equal to zero. Put $\mathrm{D} = 0$:

$\therefore \cos^2\left(\frac{\pi}{2}\cos(\theta)\right) = 0$ $\qquad$ $\therefore \cos\left(\frac{\pi}{2}\cos(\theta)\right) = 0$ $\qquad$ $\therefore \cancel{\frac{\pi}{2}}\cos(\theta) = (2n+1)\cancel{\frac{\pi}{2}}$

$\therefore \theta = \cos^{-1}(2n+1)$ $\qquad$ $(at\ n = 0)$: $\qquad$ $\theta = 0°$

$(at\ n = -1)$: $\qquad$ $\theta = 180°$

Notice that $n \in \{0,1\}$

$$\therefore \mathbf{FNBW = 180°}$$

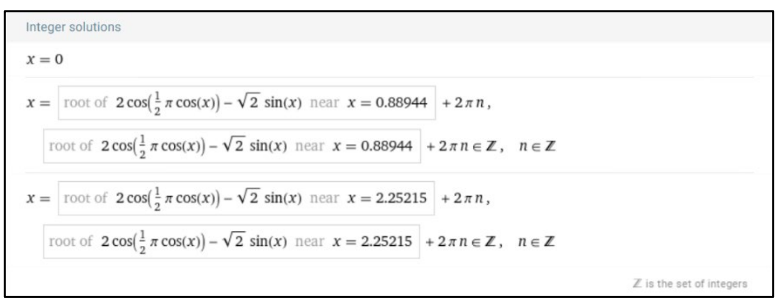
***iii-* HPBW calculation:**

The angle (θ) at which the gain (or directivity or intensity) is equal to half it's maximum value.
Put $\mathrm{D} = {}^{1}\!/_{2}$:

$\frac{\cos^2\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin^2(\theta)} = {}^{1}\!/_{2}$ $\qquad$ $\therefore \cos\left(\frac{\pi}{2}\cos(\theta)\right) = \frac{1}{\sqrt{2}}\sin(\theta)$

solving the equation numerically, we get: $\quad \theta = 50.96°$ or $\theta = 129.039°$

$$HPBW_{(3\mathrm{dB})} = 129.039° - 50.961° = \mathbf{78.078}°$$



Integer solutions

$x = 0$

$x =$ root of $2\cos\left(\frac{1}{2}\pi\cos(x)\right) - \sqrt{2}\sin(x)$ near $x = 0.88944$ $+ 2\pi n$,

root of $2\cos\left(\frac{1}{2}\pi\cos(x)\right) - \sqrt{2}\sin(x)$ near $x = 0.88944$ $+ 2\pi n \in \mathbb{Z}, \quad n \in \mathbb{Z}$

$x =$ root of $2\cos\left(\frac{1}{2}\pi\cos(x)\right) - \sqrt{2}\sin(x)$ near $x = 2.25215$ $+ 2\pi n$,

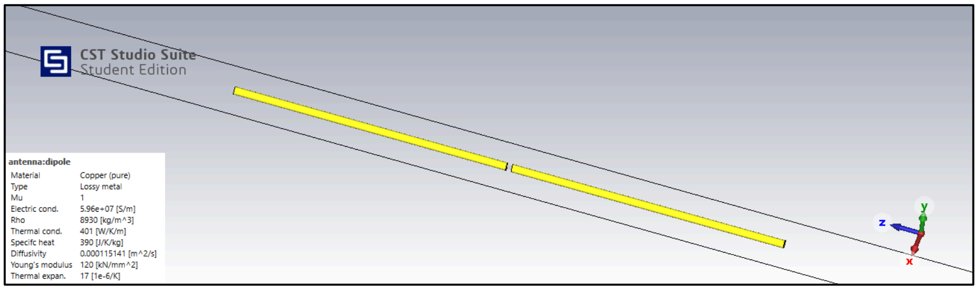
root of $2\cos\left(\frac{1}{2}\pi\cos(x)\right) - \sqrt{2}\sin(x)$ near $x = 2.25215$ $+ 2\pi n \in \mathbb{Z}, \quad n \in \mathbb{Z}$

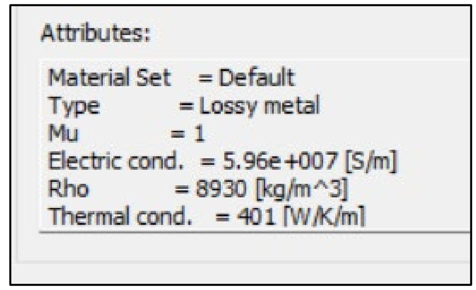
$\mathbb{Z}$ is the set of integers

	Simulated values	**Analytically calculated values**
FNBW	**180°**	**180°**
$\boldsymbol{HPBW}_{(3\mathrm{dB})}$	**78.5°**	**78.078°**
$\mathbf{Gain}_{(\mathbf{max})}$	**2.13dBi**	**2.15 *dBi***

We notice that there is a small difference between the calculated and the simulated values, due to adjusting (slightly) the antenna length for resonance (the new length is 0.4578ʎ). Also, the assumptions that were made to ease the analytical solution, such as uniform volumetric current distribution and the neglection of the antenna thickness.

e) ***Copper dipole antenna:***





Electric conductivity of copper (pure) is $\sigma = 5.96 \times 10^7\ S/m$, $\quad f = 20GHz$

$R_{loss} = \frac{1}{2} R_{hf} = \frac{l}{2p} R_s$ (eqn 2-90b) (p is the perimeter of wire cross-section)

$R_s = \sqrt{\frac{\pi f \mu}{\sigma}} = 0.0364\ \Omega$ $\quad l = 6.86625\ mm$ $\quad p = 2\pi * 0.050535\ mm$

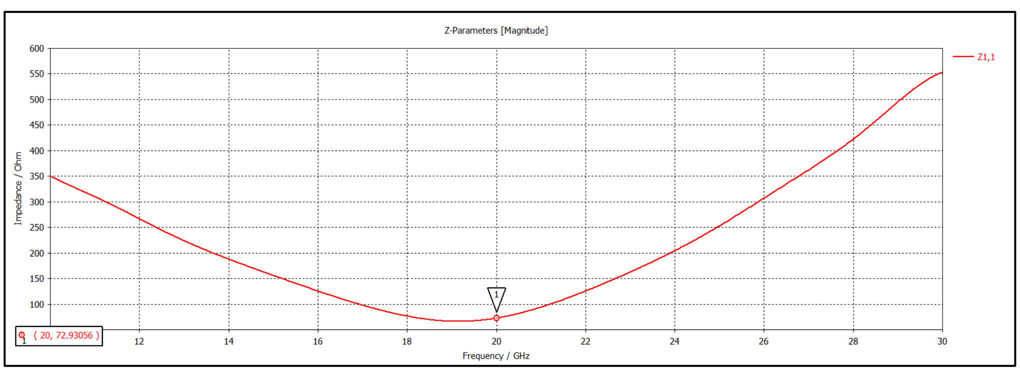
$R_{loss} = \frac{1}{2} R_{hf} = \frac{l}{2p} R_s = 0.3936\Omega$ $\quad \because W_{\text{rad}} = \frac{(\omega\mu I_o)^2}{2\eta(2\pi k)^2} * 7.6581 = \frac{1}{2}(I_o)^2 * R_{rad}$

$$\therefore \boldsymbol{R_{rad} = 7.6581 * \frac{(\omega\mu)^2}{\eta(2\pi k)^2} = 73.14\ \Omega}$$

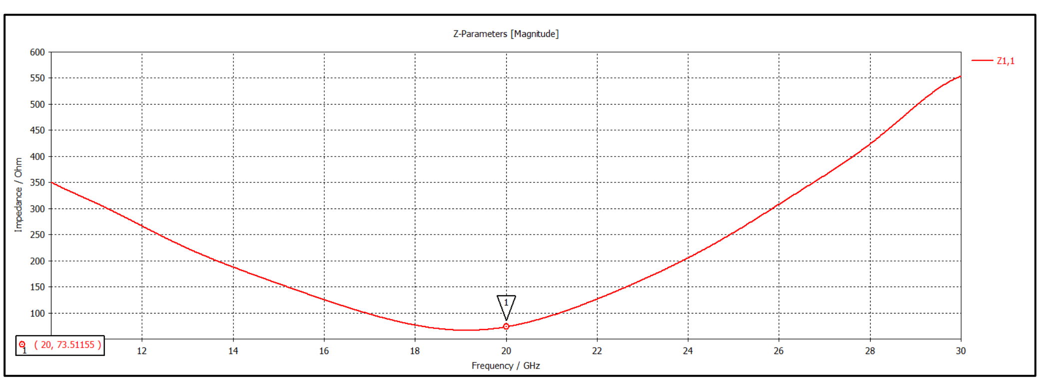
$$\therefore \boldsymbol{\eta_{\text{rad}} = \frac{R_{\text{rad}}}{R_{\text{rad}} + R_L} = 99.46\%}$$

Simulation:

when the material is PEC, $R_{loss} = 0$, hence, $R_{total} = R_{rad}$:



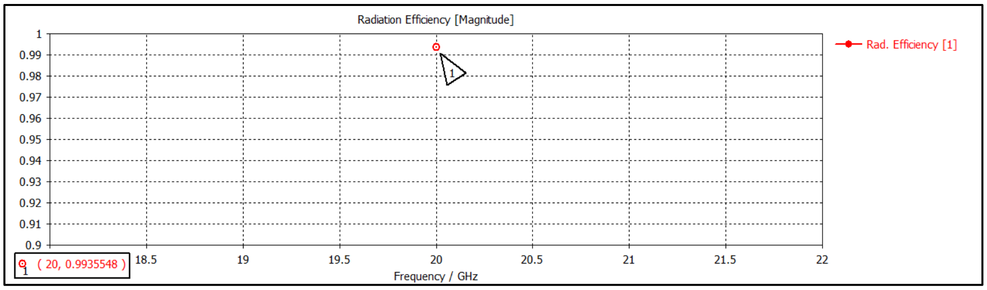
when the material is copper, $R_{loss} \neq 0$, hence, $R_{total} = R_{rad} + R_{loss}$:



$$\therefore R_{loss} = R_{total} - R_{rad} = 73.51155 - 72.93056 = 0.58099\Omega$$

$$\therefore \eta_{\text{rad}} = \frac{R_{\text{rad}}}{R_{total}} = 99.3\%$$

Or directly calculating the efficiency:



From the graph: $\eta_{\text{rad}} = 99.355\%$

The radiation efficiency calculated by the simulator is slightly different from the calculated value, this is due to the simplifications in the analytical calculations like neglecting the effects of feeding gap dimensions. Also, due to neglecting the effect of nearfield impedance ($Z_{total} = R_{rad} + R_{loss} + jX_a$), hence, the value of the analytically calculated efficiency is smaller than the simulated value.