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EEC 133

Final Project

Design Parameters:

$$\varepsilon_r = 3.0$$

$$h = 0.5\ mm$$

$$t = 0.05\ mm$$

$$f_r = 3\ GHz$$

1.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{3*10^8}{2*3*10^9}\sqrt{\frac{2}{3+1}} = 0.035355\ m = 35.355\ mm$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} = \frac{3+1}{2} + \frac{3-1}{2}\left[1+12\frac{0.5}{35.355}\right]^{-\frac{1}{2}} = 2.9246$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)}$$

$$= 0.412*0.5*\frac{(2.9246+0.3)\left(\frac{35.355}{0.5}+0.264\right)}{(2.9246-0.258)\left(\frac{35.355}{0.5}+0.8\right)} = 0.24723\ mm$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L = \frac{3*10^8}{2*3*10^9\sqrt{2.9246}} - 2*0.2472m = 28.742\ mm$$

2.

$$\lambda_0 = \frac{c}{f_r} = \frac{3*10^8}{3*10^9} = 0.1\ m = 100\ mm$$

$$FBW_{10\ dB} \cong 3.771\left[\frac{\varepsilon_r-1}{(\varepsilon_r)^2}\right]\frac{h}{\lambda_0}\left(\frac{W}{L}\right) = 3.771\left[\frac{3-1}{(3)^2}\right]\frac{0.5}{100}\left(\frac{35.355}{28.742}\right) = 0.005154$$
$$= 0.5154\ \%$$

$$X = k_0W = \frac{2\pi}{100}35.4 = 2.2242$$

$$I_1 = -2 + \cos(X) + XSi(X) + \frac{\sin(X)}{X}$$

$$= -2 + \cos(2.2242) + 2.2242Si(2.2242) + \frac{\sin(2.2242)}{2.2242} = 1.5222$$

$$G_1 = \frac{I_1}{120\pi^2} = \frac{1.5222}{120\pi^2} = 0.00128$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(k_0 L\sin\theta)\sin\theta^3\, d\theta = 5.6642 * 10^{-4}$$

$$R_{in} = \frac{1}{2(G_1 + G_{12})} = \frac{1}{2(0.00128 + 5.6642 * 10^{-4})} = 270.79\ \Omega$$

3.a

$$Z_1 = \sqrt{Z_c R_{in}} = \sqrt{50 * 270.79} = 116.35\ \Omega$$

$$Z_1 = 116.35 = \frac{120}{2\sqrt{2}\pi\sqrt{\varepsilon_{reff} + 1}}\, ln\left[1 + \frac{4h}{W_2{}'}\left(\frac{14 + \frac{8}{\varepsilon_{reff}}}{11} * \frac{4h}{W_2{}'} + \sqrt{\frac{14 + \frac{8}{\varepsilon_{reff}}}{11}^2 * \frac{4h}{W_2{}'}^2 + \frac{1 + \frac{1}{\varepsilon_{reff}}}{2}\pi^2}\right)\right]$$

$W_2' = 0.23190\ mm$ (MATLAB Equation Solver)

$$W_2 = W_2' - \frac{t}{\pi}\ln\left[\frac{4e}{\left(\frac{t}{h}\right)^2 + \left(\frac{\frac{1}{\pi}}{\frac{W_2}{t} + 1.1}\right)^2}\right]\left(\frac{1 + \frac{1}{\varepsilon_{reff}}}{2}\right)$$

$W_2 = 0.16184\ mm$ (MATLAB Solver Approximation)

$$Z_c = 50 = \frac{120}{2\sqrt{2}\pi\sqrt{\varepsilon_{reff} + 1}}\, ln\left[1 + \frac{4h}{W_3{}'}\left(\frac{14 + \frac{8}{\varepsilon_{reff}}}{11} * \frac{4h}{W_3{}'} + \sqrt{\frac{14 + \frac{8}{\varepsilon_{reff}}}{11}^2 * \frac{4h}{W_3{}'}^2 + \frac{1 + \frac{1}{\varepsilon_{reff}}}{2}\pi^2}\right)\right]$$

$W_3' = 1.2679\ mm$ (MATLAB Equation Solver)

$$W_3 = W_3' - \frac{t}{\pi}\ln\left[\frac{4e}{\left(\frac{t}{h}\right)^2 + \left(\frac{\frac{1}{\pi}}{\frac{W_3}{t}+1.1}\right)^2}\right]\left(\frac{1+\frac{1}{\varepsilon_{reff}}}{2}\right)$$

$W_3 = 1.1934\ mm$ (MATLAB Solver Approximation)

$$A = \frac{W - W_2}{2} = \frac{35.355m - 0.16212m}{2} = 17.596\ mm$$

3.b.

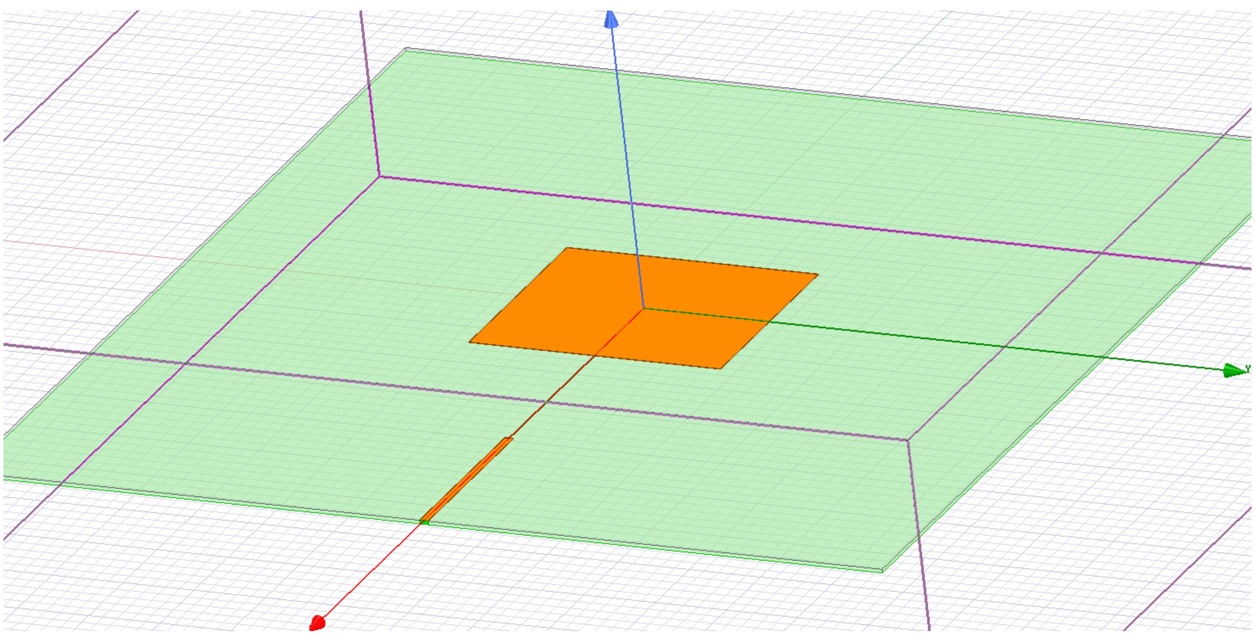
$W_3 = 1.1934\ mm$ (Same as 3.a)

$$A_2 = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{Z_0}{R_{in}}} = \frac{28.742m}{\pi}\cos^{-1}\sqrt{\frac{50}{270.79}} = 10.307\ mm$$

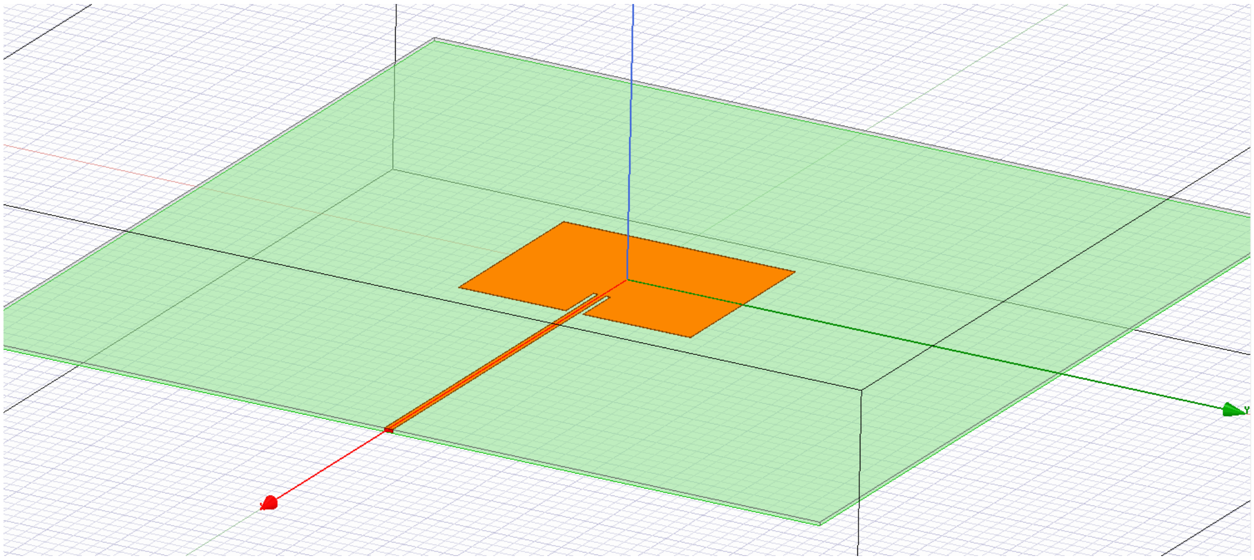
$$A_3 = \frac{W}{40} = \frac{35.355m}{40} = 0.8839\ mm$$

$$A = \frac{W - W_3 - 2A_3}{2} = \frac{35.355m - 1.1934m - 2 * 1.7677m}{2} = 15.313\ mm$$

4.

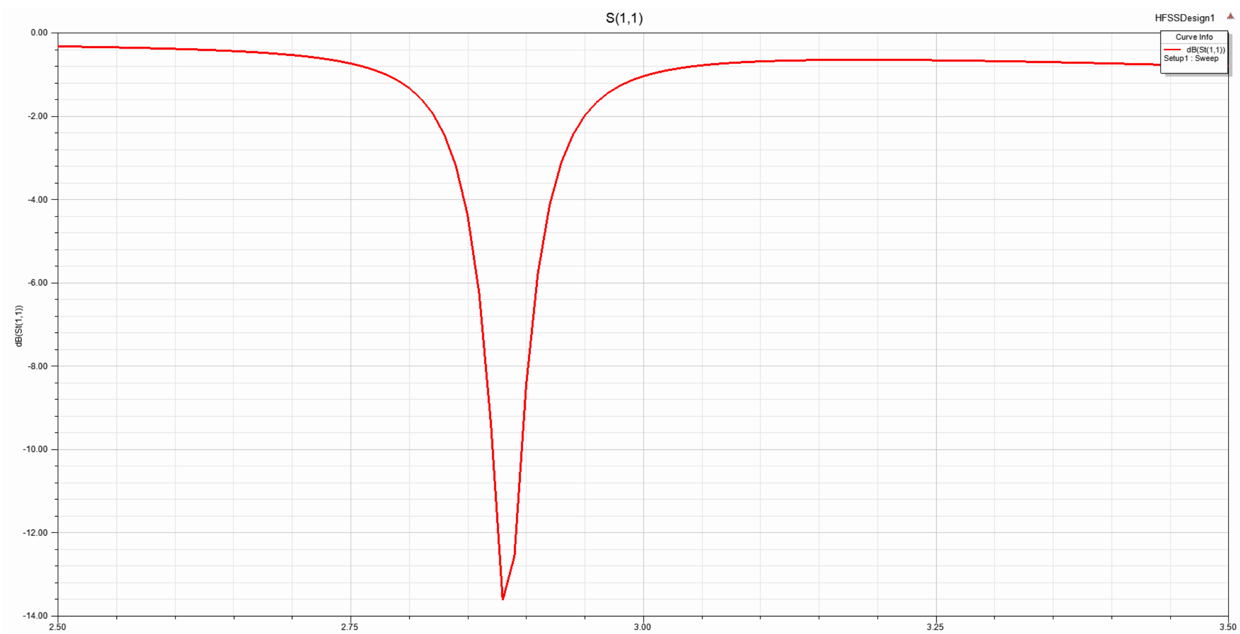


$\lambda/4$ Transmission Line Patch Antenna.

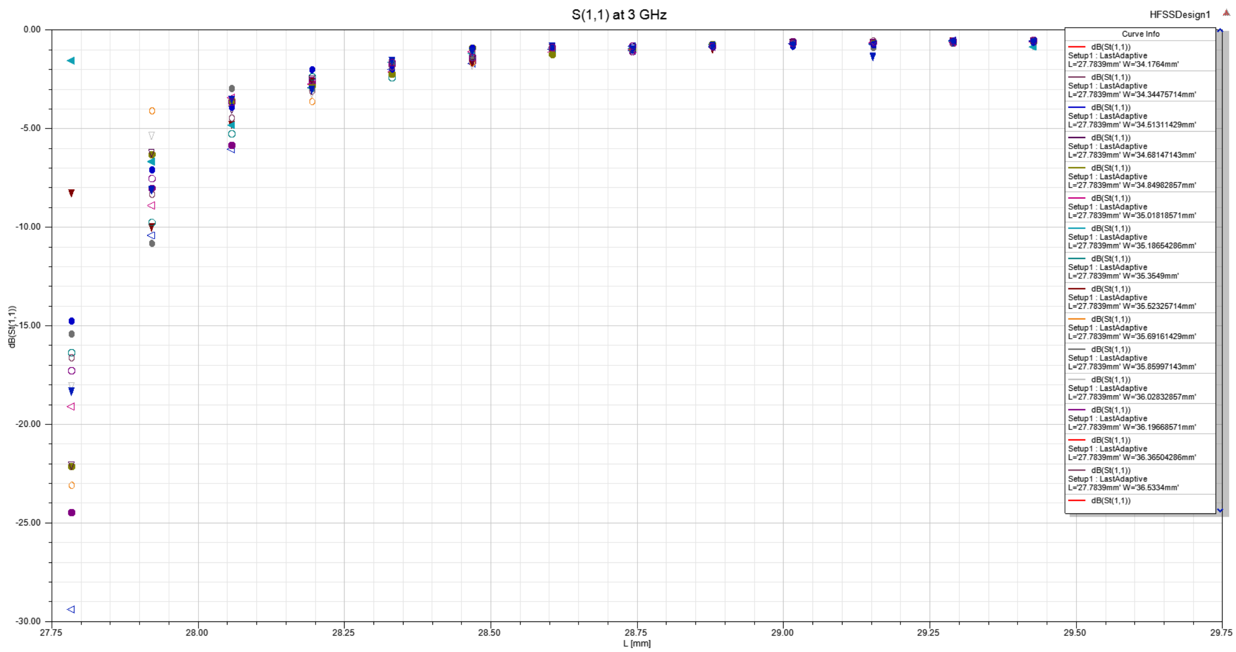


Recessed Patch Antenna.

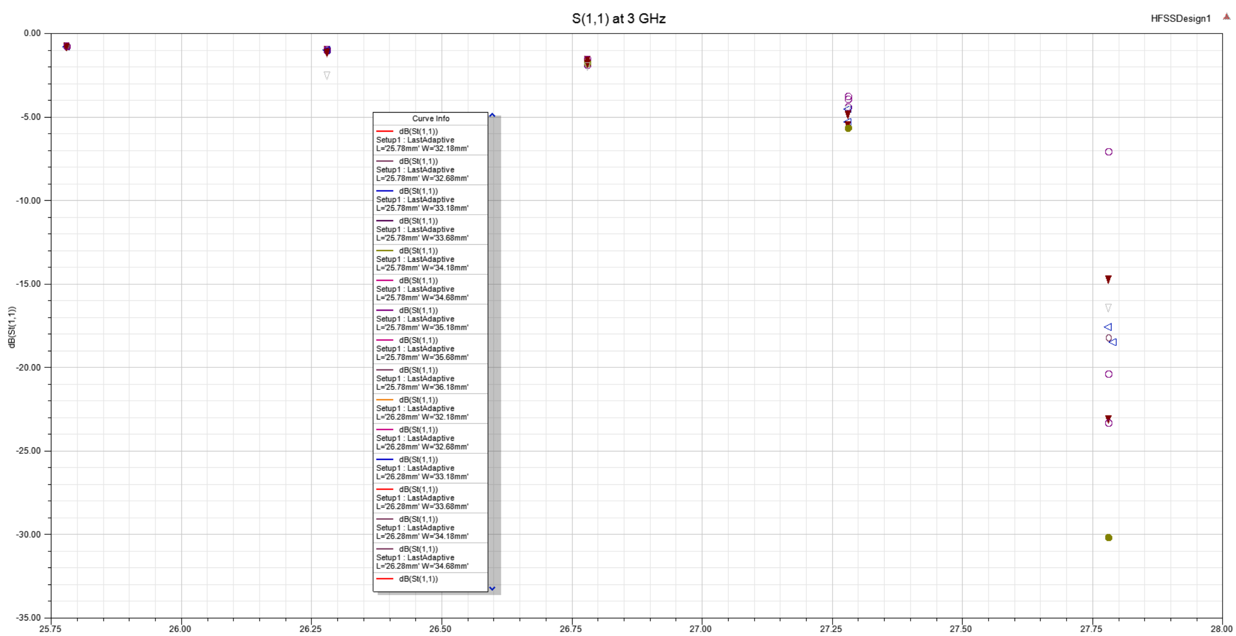
4.a.



Unoptimized $\lambda/4$ Transmission Line Patch Antenna S11. $W = 35.355\ mm$ and $L = 28.742\ mm$. Resonant frequency off from 3 GHz by 3%.



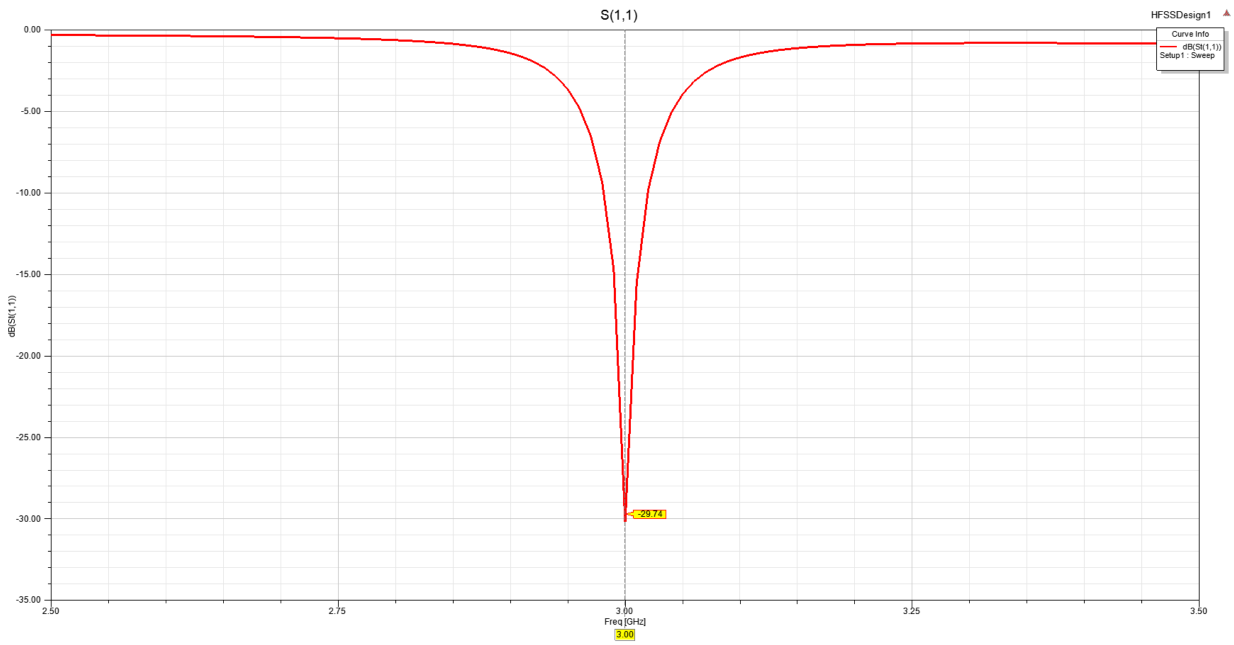
$\lambda/4$ Transmission Line Patch Antenna L $\pm$ 3% and W $\pm$ 3% sweep using Optimetrics to plot S11 at 3 GHz. Minimum S11 at $W = 34.18\ mm$ and $L = 27.78\ mm$.



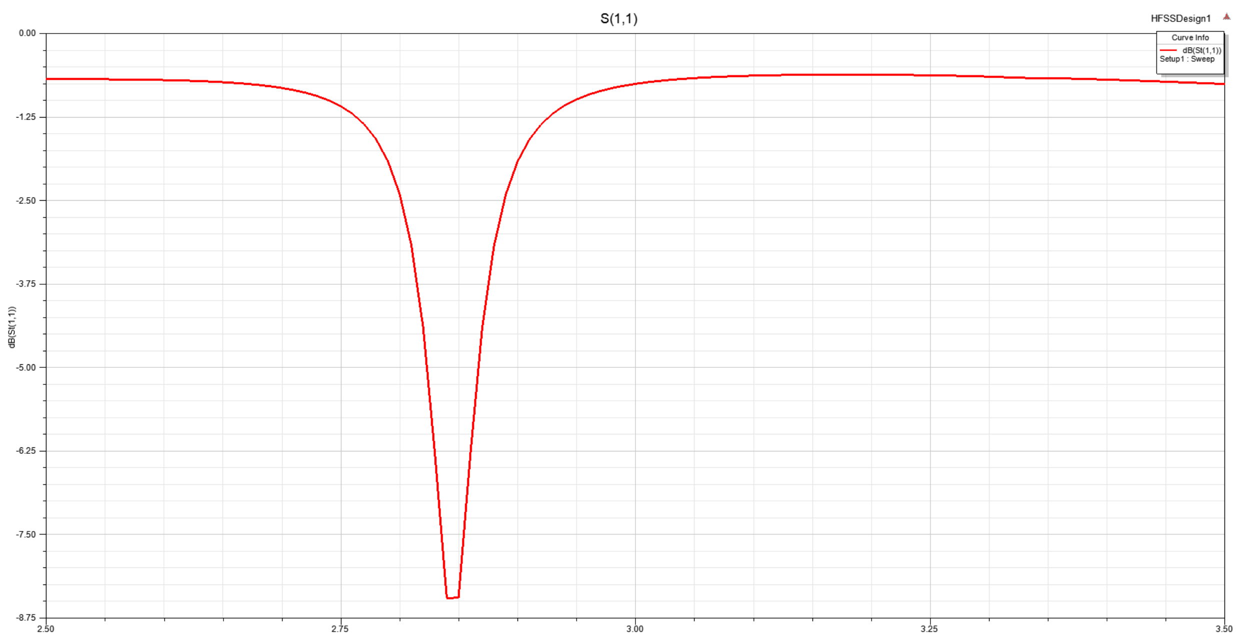
$\lambda/4$ Transmission Line Patch Antenna Lower L and W $\pm$ 3% sweep using Optimetrics to plot S11 at 3 GHz. Minimum S11 at $W = 33.68\ mm$ and $L = 27.78\ mm$.

$\lambda/4$ Transmission Line Patch Antenna Final Dimensions:

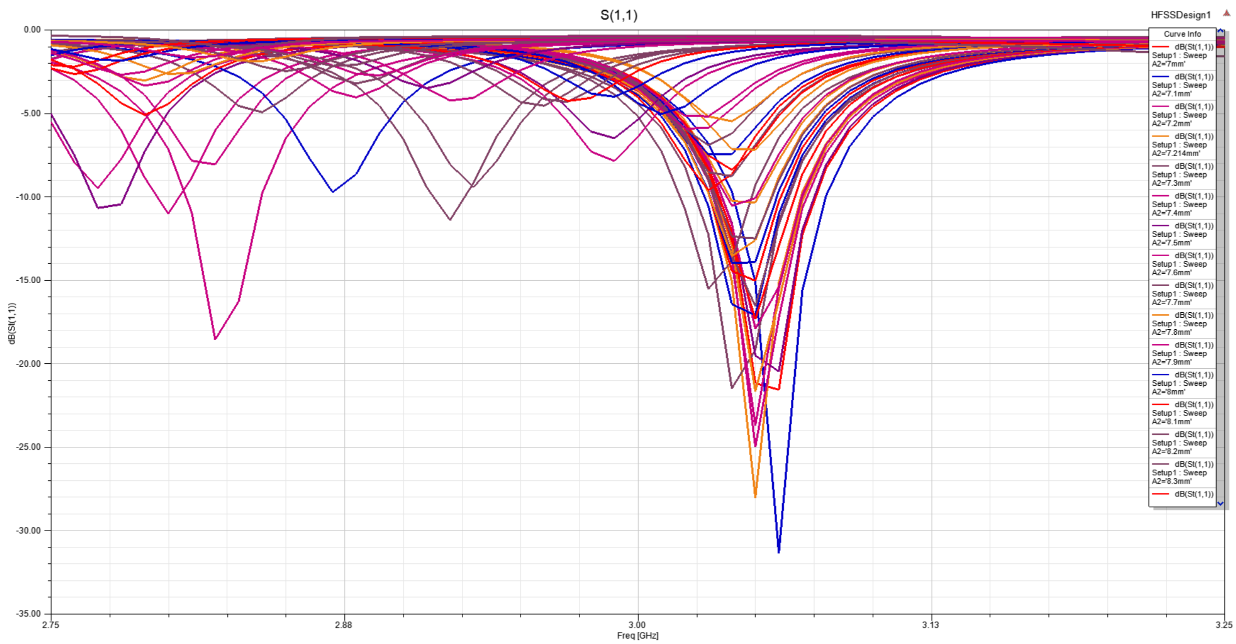
$W = 33.68\ mm$, $L = 27.78\ mm$, $W_2 = 0.16184\ mm, W_3 = 1.1934\ mm, A = 16.759\ mm$.



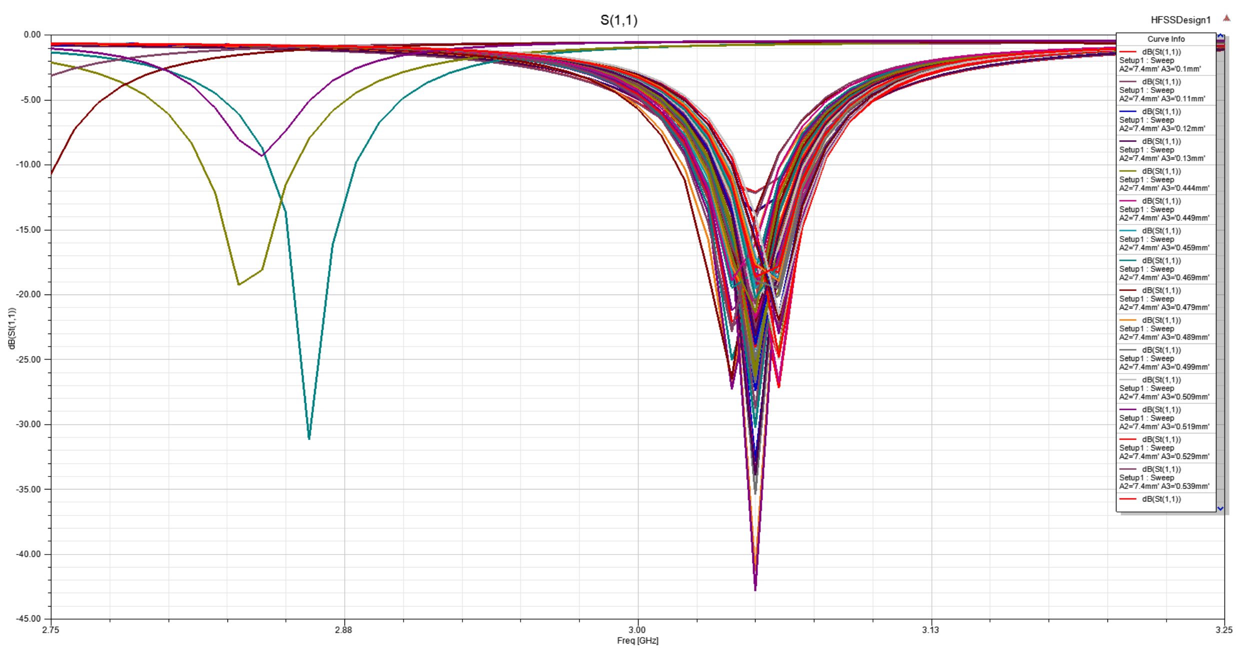
$\lambda/4$ Transmission Line Patch Antenna S11. S11 = -29.74 dB at 3 GHz.



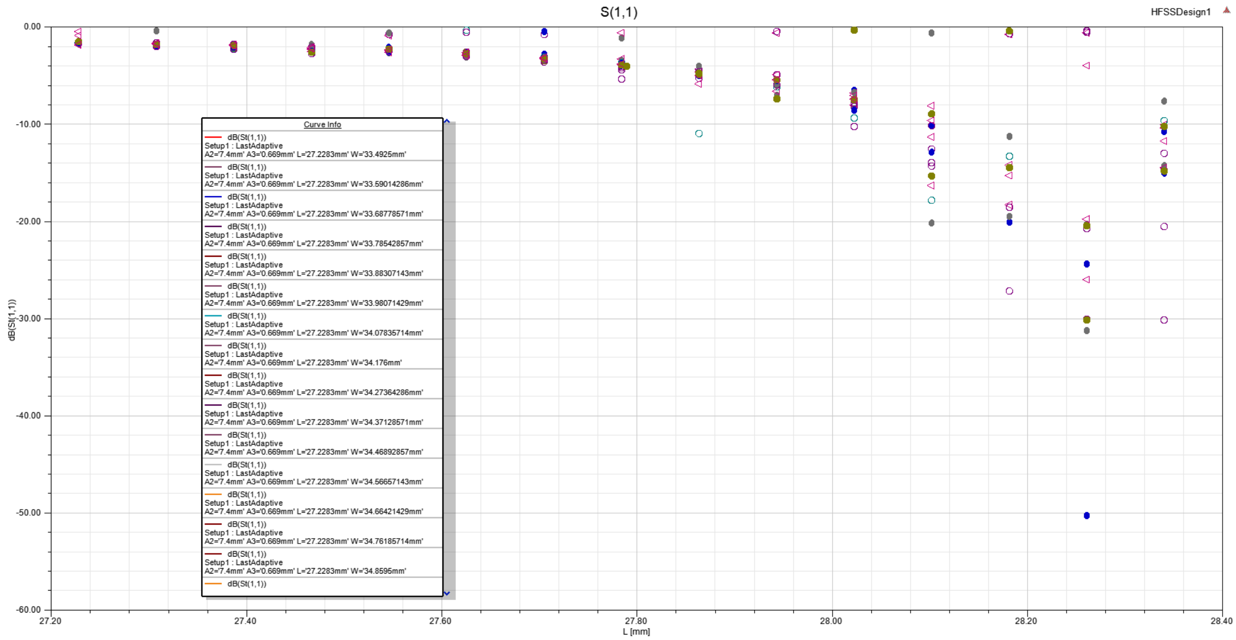
Unoptimized Recessed Patch Antenna S11. $A_2 = 10.307\ mm$ and $A_3 = 0.8839\ mm$. Resonant frequency off from 3 GHz by 6%.



Recessed Patch Antenna $A_2 \pm 30\%$ sweep using Optimetrics to plot S11. $\pm 30\%$ chosen after trial and error. Try $A_2 = 7.4\ mm$.



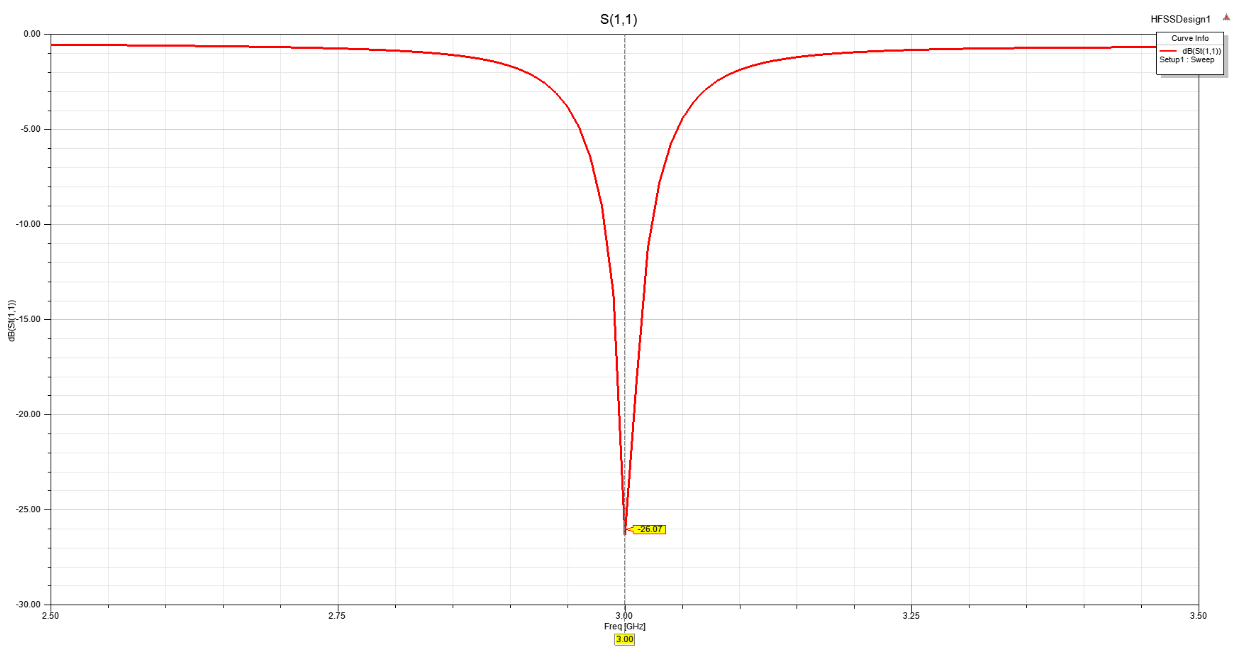
Recessed Patch Antenna $A_3 \pm 50\%$ sweep using Optimetrics to plot S11. $\pm 30\%$ chosen after trial and error. Try $A_3 = 0.669\ mm$.



Recessed Patch Antenna L $\pm$ 2% and W $\pm$ 2% sweep using Optimetrics to plot S11 at 3 GHz. Minimum S11 at $W = 34.47\ mm$ and $L = 28.26\ mm$.

Recessed Patch Antenna Final Dimensions:

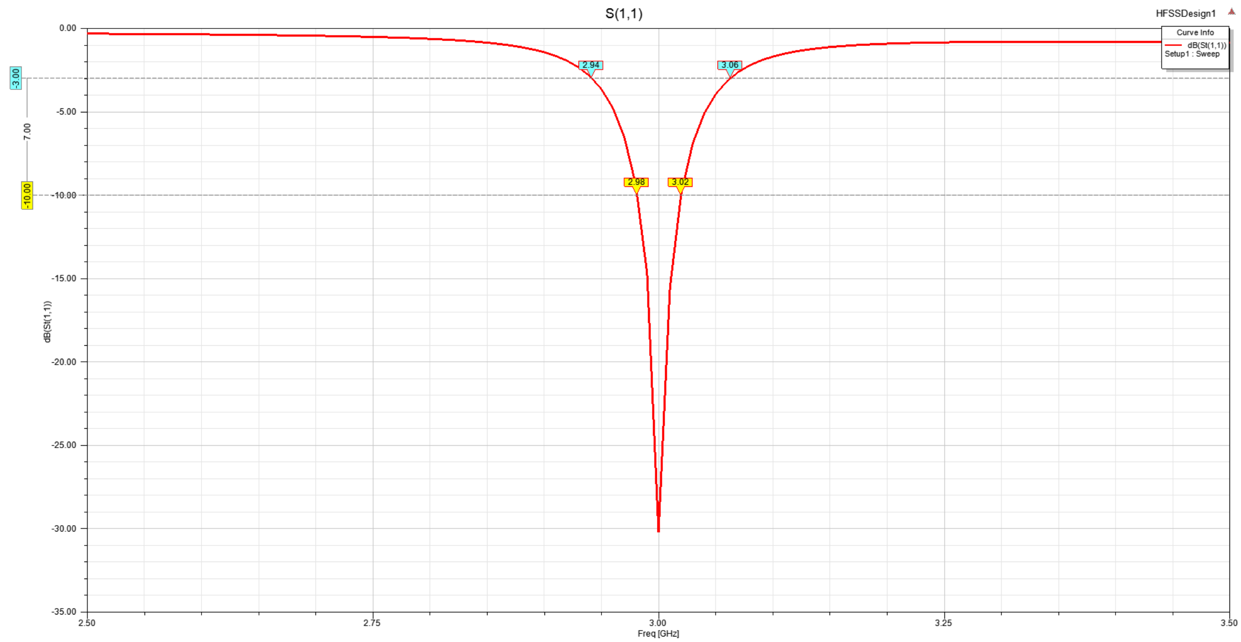
$W = 34.47\ mm, L = 28.26\ mm, W_3 = 1.1934\ mm, A_2 = 7.4\ mm, A_3 = 0.669\ mm, A = 16.566\ mm.$



Recessed Patch Antenna S11. S11 = -26.07 dB at 3 GHz.

$\lambda/4$ Transmission Line Patch Antenna gives a better return loss at resonant frequency.

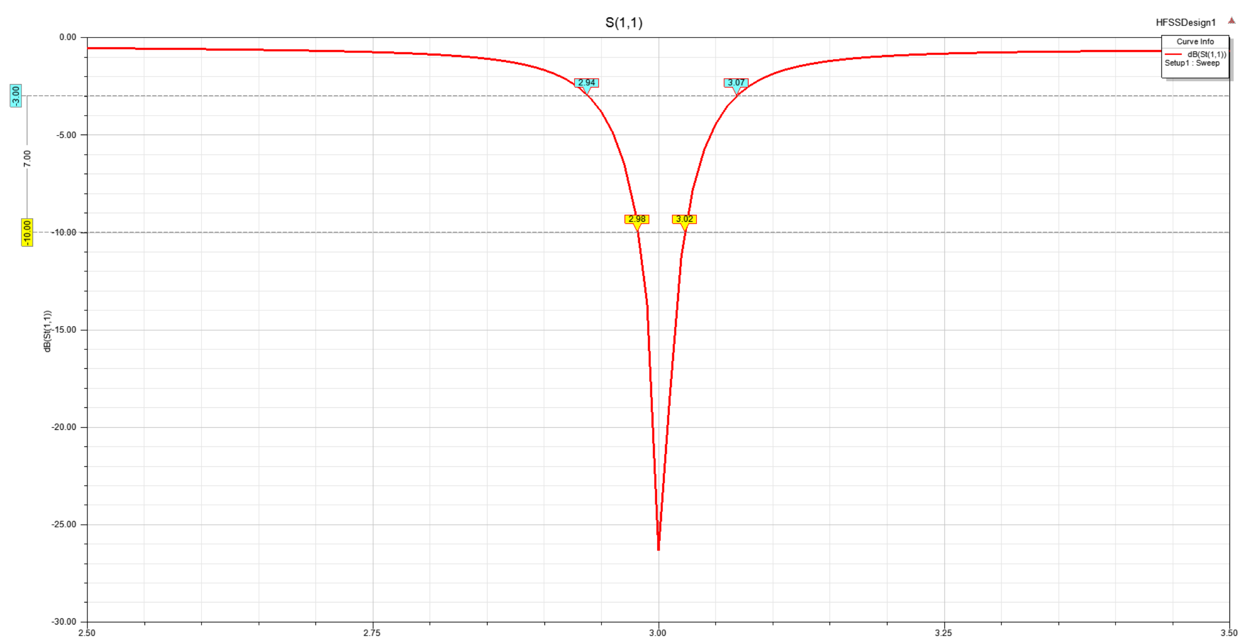
4.b.



$\lambda/4$ Transmission Line Patch Antenna S11. $FBW_{10\ dB} = \frac{3.02\ GHz - 2.98\ GHz}{3\ GHz} = 1.33\%$

$\lambda/4$ Transmission Line Patch Antenna FBW comparison $\Delta FBW_{10\ dB} = 1.33\% - 0.515\% = 0.815\%$

$\lambda/4$ Transmission Line Patch Antenna S11. $FBW_{3\ dB} = \frac{3.06\ GHz - 2.94\ GHz}{3\ GHz} = 4\%$



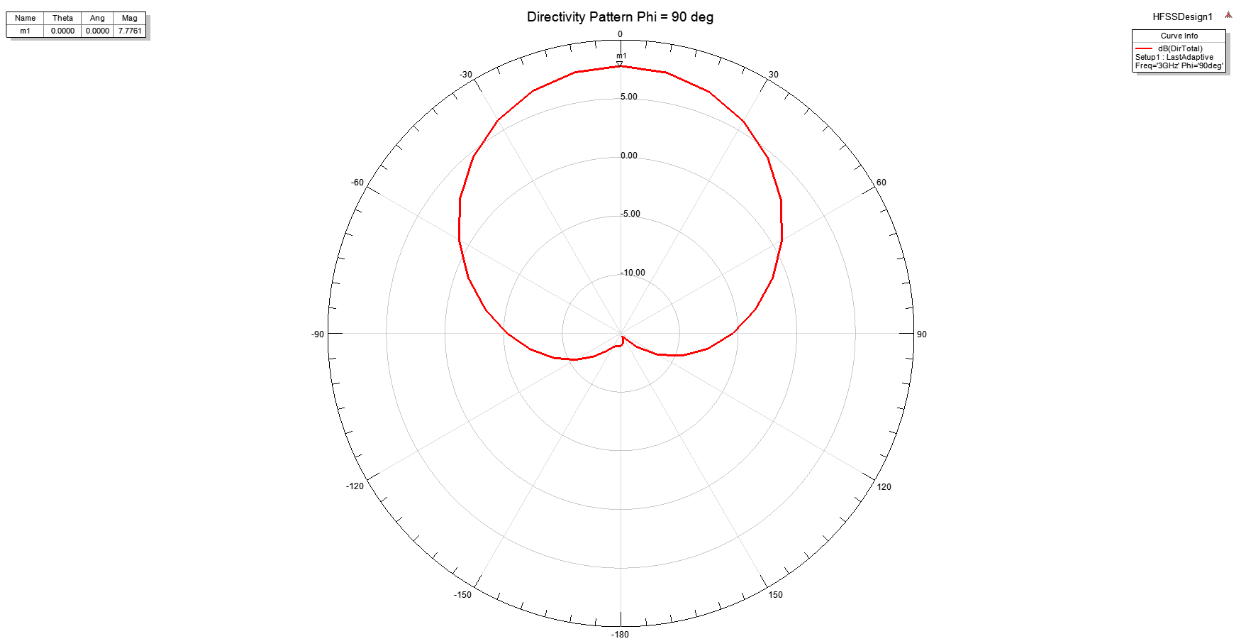
Recessed Patch Antenna S11. $FBW_{10\ dB} = \frac{3.02\ GHz - 2.98\ GHz}{3\ GHz} = 1.33\%$

Recessed Patch Antenna FBW comparison $\Delta FBW_{10\ dB} = 1.33\% - 0.515\% = 0.815\%$

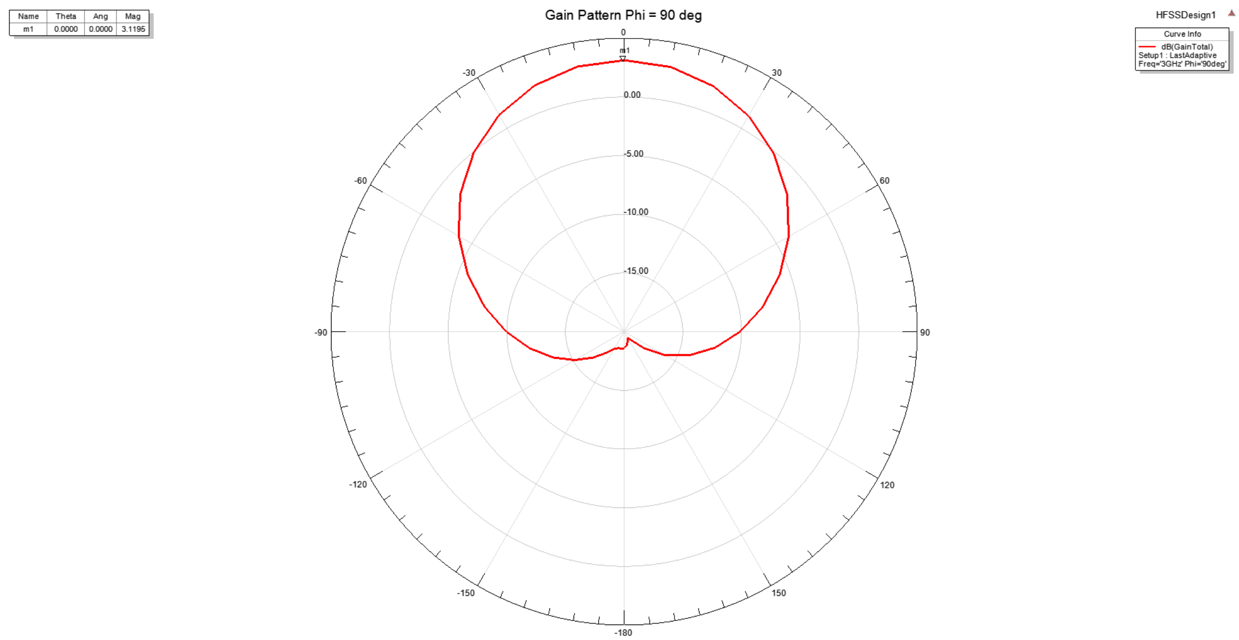
Recessed Patch Antenna S11. $FBW_{3\ dB} = \frac{3.07\ GHz - 2.94\ GHz}{3\ GHz} = 4.33\%$

While the $\lambda/4$ Transmission Line Patch Antenna gives a better return loss at resonant frequency, the Recessed Patch Antenna gives a better 3 dB bandwidth.

4.c.

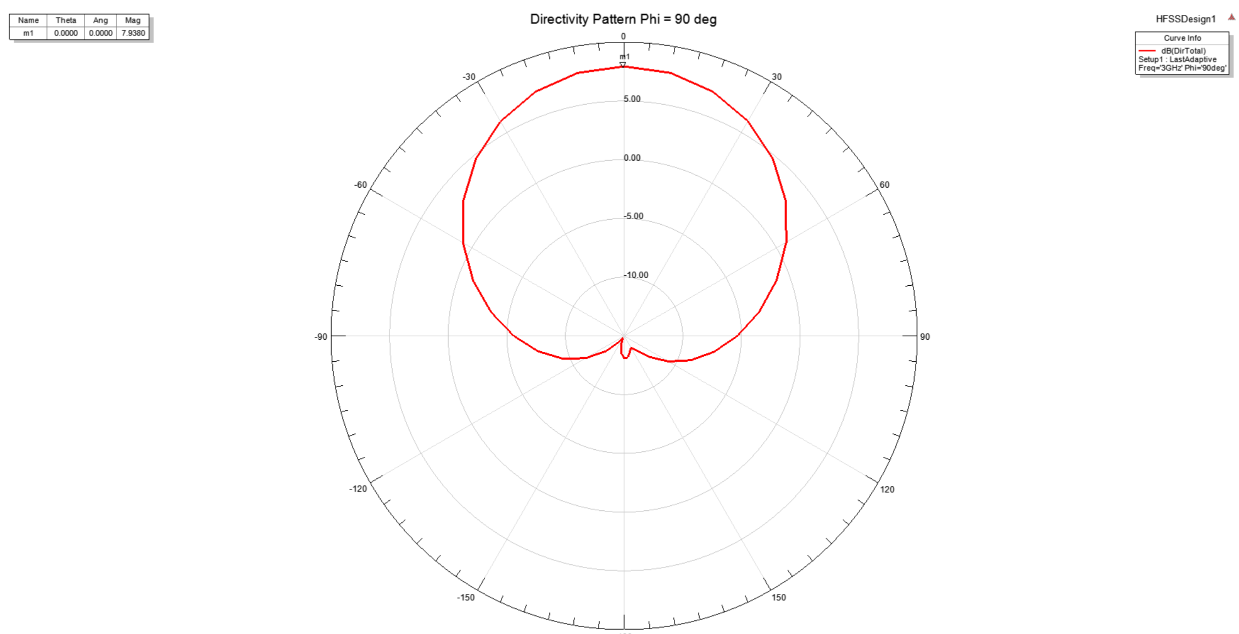


$\lambda/4$ Transmission Line Patch Antenna Directivity Pattern. $D_0 = 7.7761\ dB$

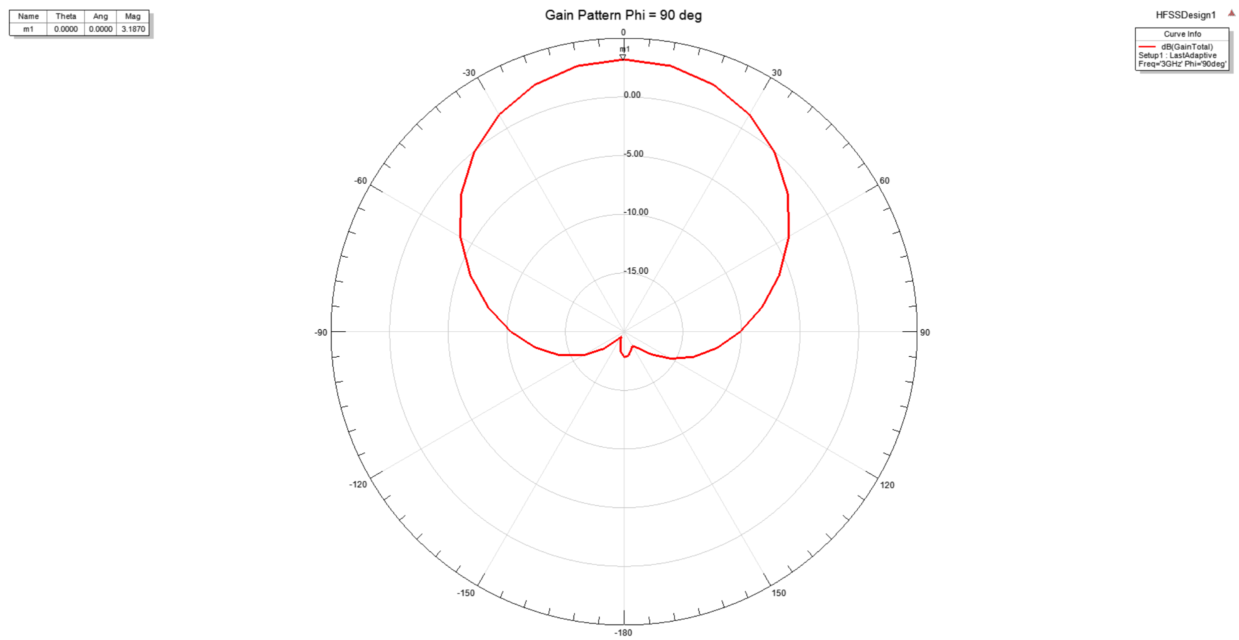


$\lambda/4$ Transmission Line Patch Antenna Gain Pattern. $G = 3.1195\ dB$

$\lambda/4$ Transmission Line Patch Antenna Radiation Efficiency $\eta = G - D = 3.1195 - 7.7761 = -4.6566\ dB = 0.3422 = 34.22\%$



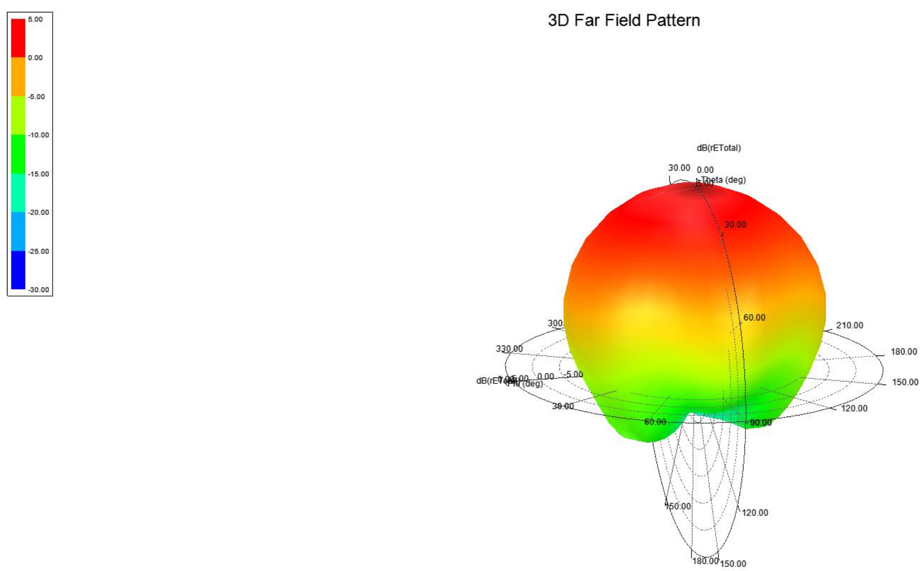
Recessed Patch Antenna Directivity Pattern. $D_0 = 7.938\ dB$



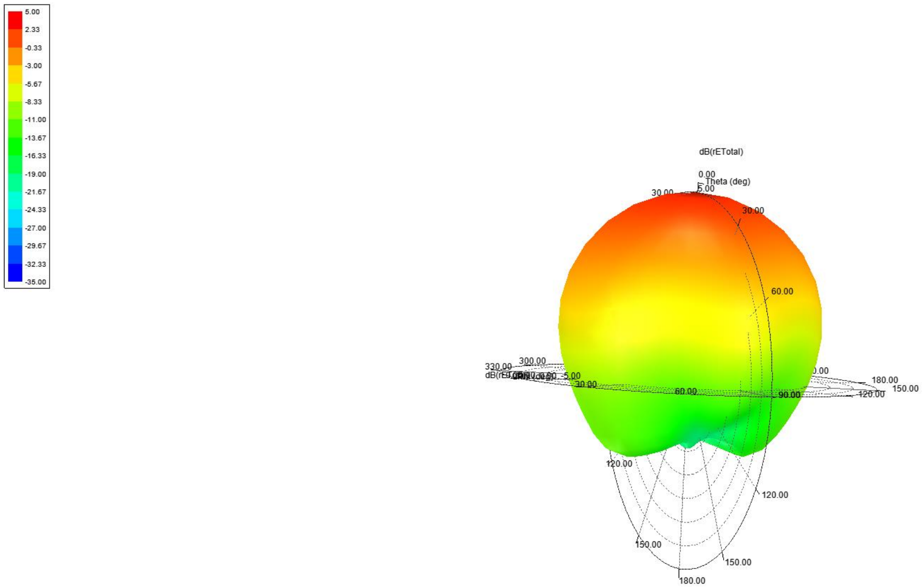
Recessed Patch Antenna Gain Pattern. $G = 3.187\ dB$

$\lambda/4$ Transmission Line Patch Antenna Radiation Efficiency $\eta = G - D = 3.187 - 7.938 = -4.7510\ dB = 0.3349 = 33.49\%$

4.d.

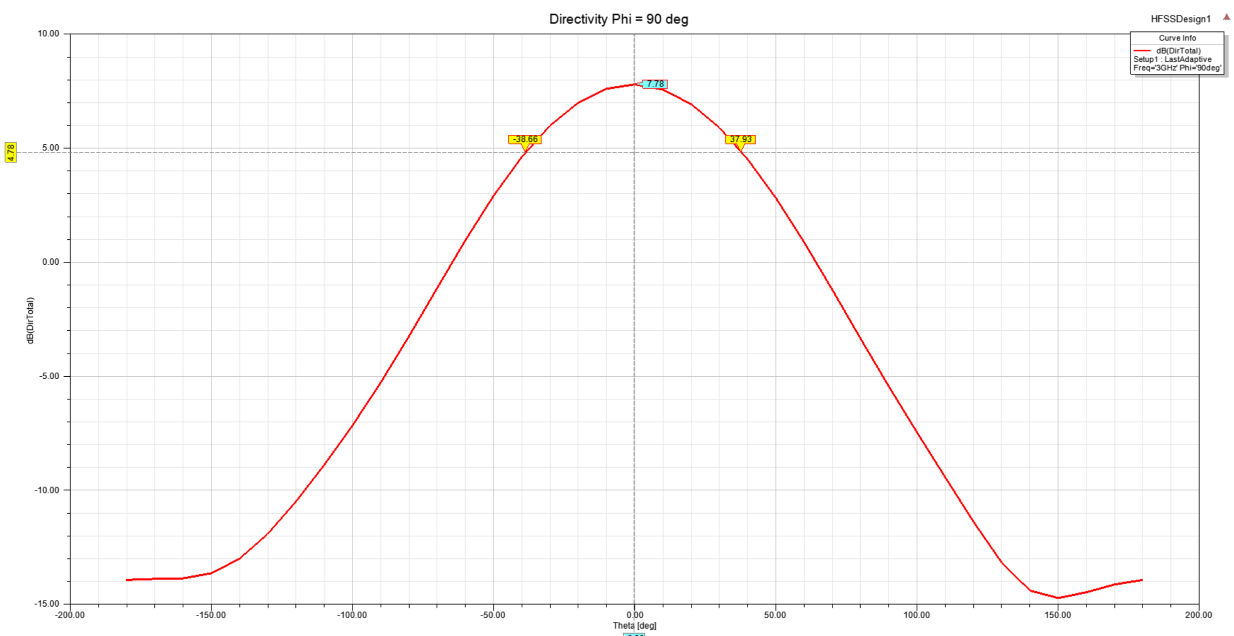


$\lambda/4$ Transmission Line Patch Antenna 3D Far Field Pattern

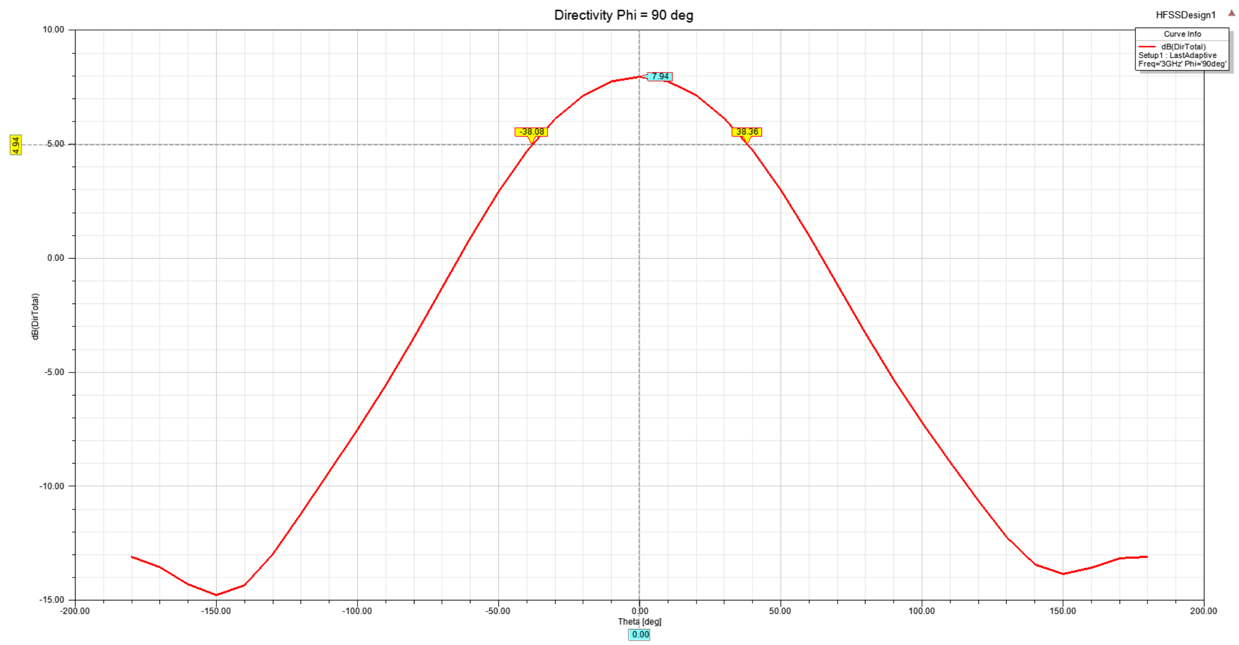


Recessed Patch Antenna 3D Far Field Pattern

4.e.



$\lambda/4$ Transmission Line Patch Antenna Directivity at Phi = 90°. $HPBW = 38.66° + 37.93° = 76.59°$



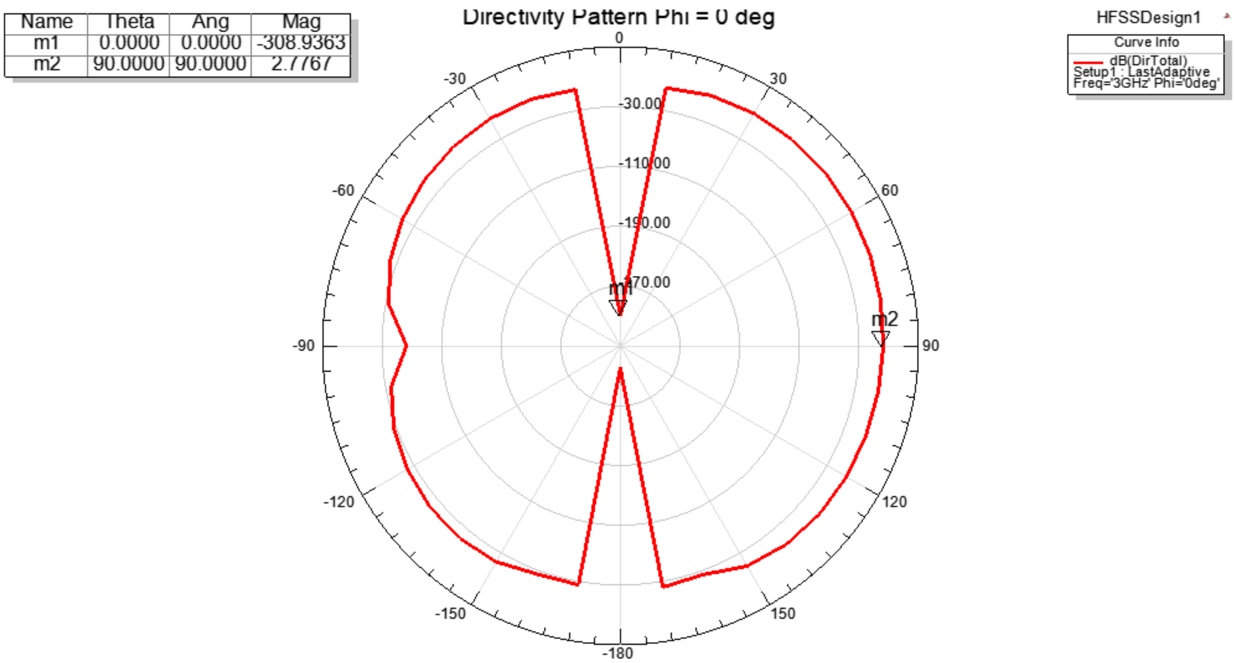
Recessed Patch Antenna Directivity at Phi = 90°. $HPBW = 38.36° + 38.08° = 76.44°$

5.

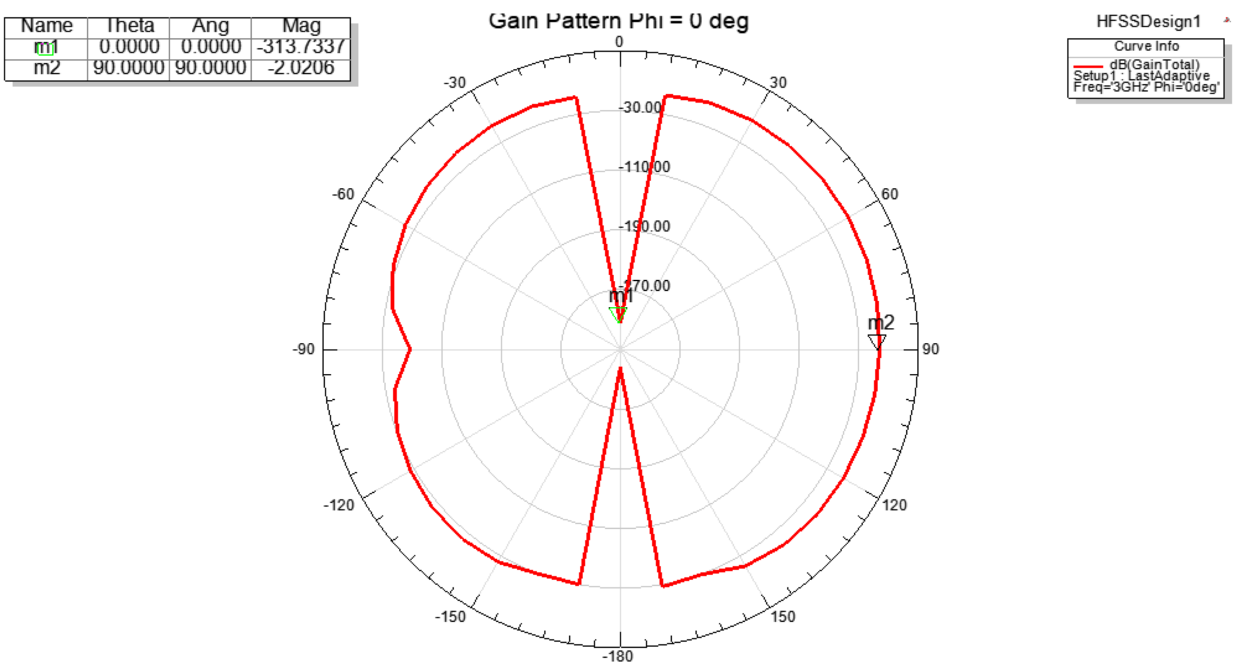
$$\frac{\lambda}{2} \geq d = \frac{\lambda}{4} = \frac{100m}{4} = 25\ mm$$

$$\psi = 0 = \beta d\cos\theta + \phi = \beta d\cos 0 + \phi = \beta d + \phi$$

$$\phi = -\beta d = -\frac{2\pi}{\lambda}\frac{\lambda}{4} = -\frac{\pi}{2}$$



Recessed Patch Antenna N=4 Array Directivity Pattern. $D_0 = 2.7767\ dB$



Recessed Patch Antenna N=4 array Gain Pattern. $G = -2.0206\ dB$

Recessed Patch Antenna N=4 array Radiation Efficiency $\eta = G - D = -2.0206 - 2.7767 = -4.7973\ dB = 0.3313 = 33.13\%$