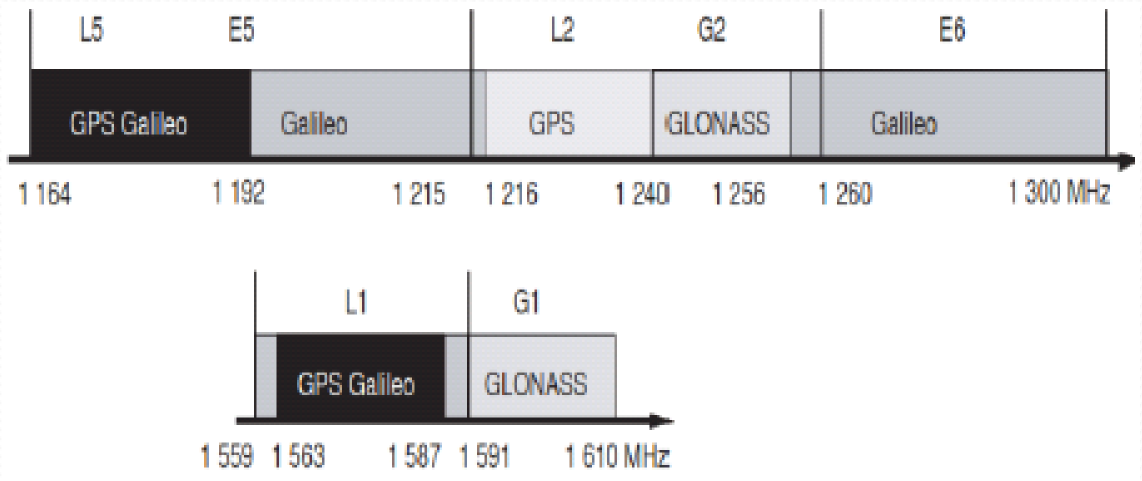
Dual-Band Rectangular CPW Folded Slot Antenna for GNSS/GPS Applications

By Troy Pandhumsoporn

Introduction

- **Main Objective**: Simulate and Design a Dual-Band rectangular CPW folded slot antenna for GNSS applications at the correct S11 and gain.
  - The research paper uses an outer rectangular copper ring slot and another slot in near the feed connecting to the patch antenna (my version uses a conductor –backed CPW version)
- All bands of GNSS Systems (L1-L2-L5-E5-E6-G1-G2), max gain around 0.2 dB and 2.9 dB in the band of 1.2-1.8 GHz. [1] (and the figure below)



GPS, GALIELEO, GLOSNASS operating frequency bands

- GPS transmit signals[1]:
  - L1:1575.42 MHz, L2: 1227.60 MHz, L5: 1176.45 MHz
- GALILEO satellite transmit signals[1]:
  - L1:1575.42 MHz, E6: 1278.75 MHz, E5: 1191.79 MHz
- GLONASS satellite transmit signals [1]:
  - G1: 1248 MHz, G2: 1600 MHz

Design Features and Assumptions

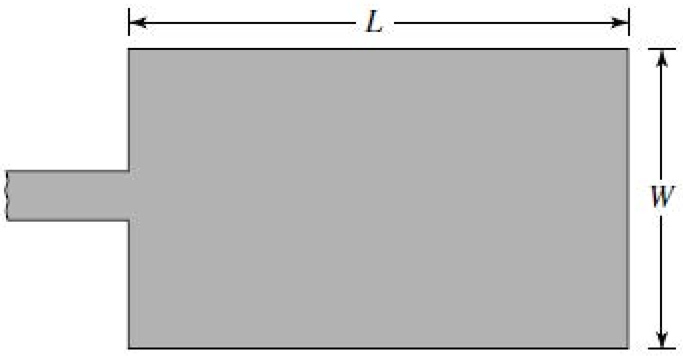
- Thickness assumed to be 0.01778 mm (Assignment 2)
- The feed is composed of a coplanar waveguide + microstrip line, where the setup has inherent mismatches in impedance.
- HFSS over FEKO simulation (different results)
- FR4 substrates occupies whole box volume rather than a hollow box
- Design parameters based on the transmission line model.

Transmission Line Model

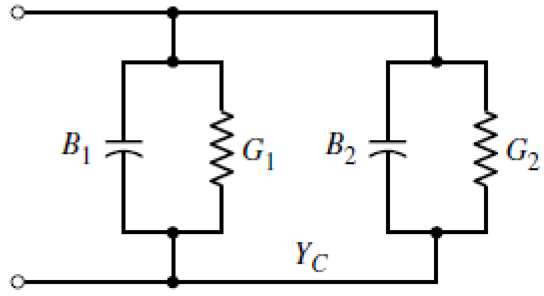
- The easiest method of analysis for micro-strip antennas, giving good insight though less accurate results
- the transmission-line model represents the microstrip antenna by two slots, separated by a low-impedance Z_c transmission line of length L. [11]

- HFSS uses the full wave method (thru FEM analysis)

[11]



(a) Rectangular patch

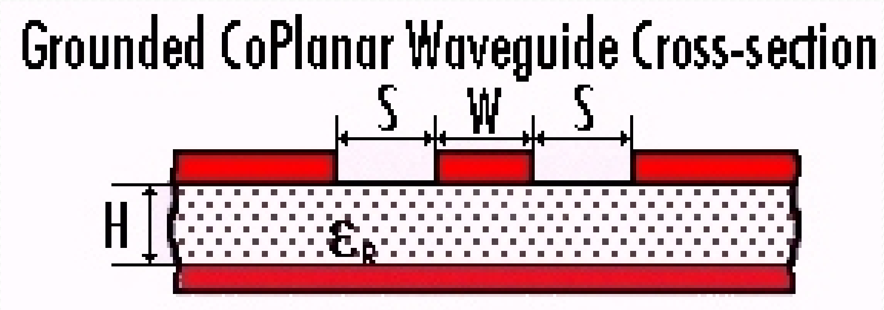


[11]

(b) Transmission model equivalent

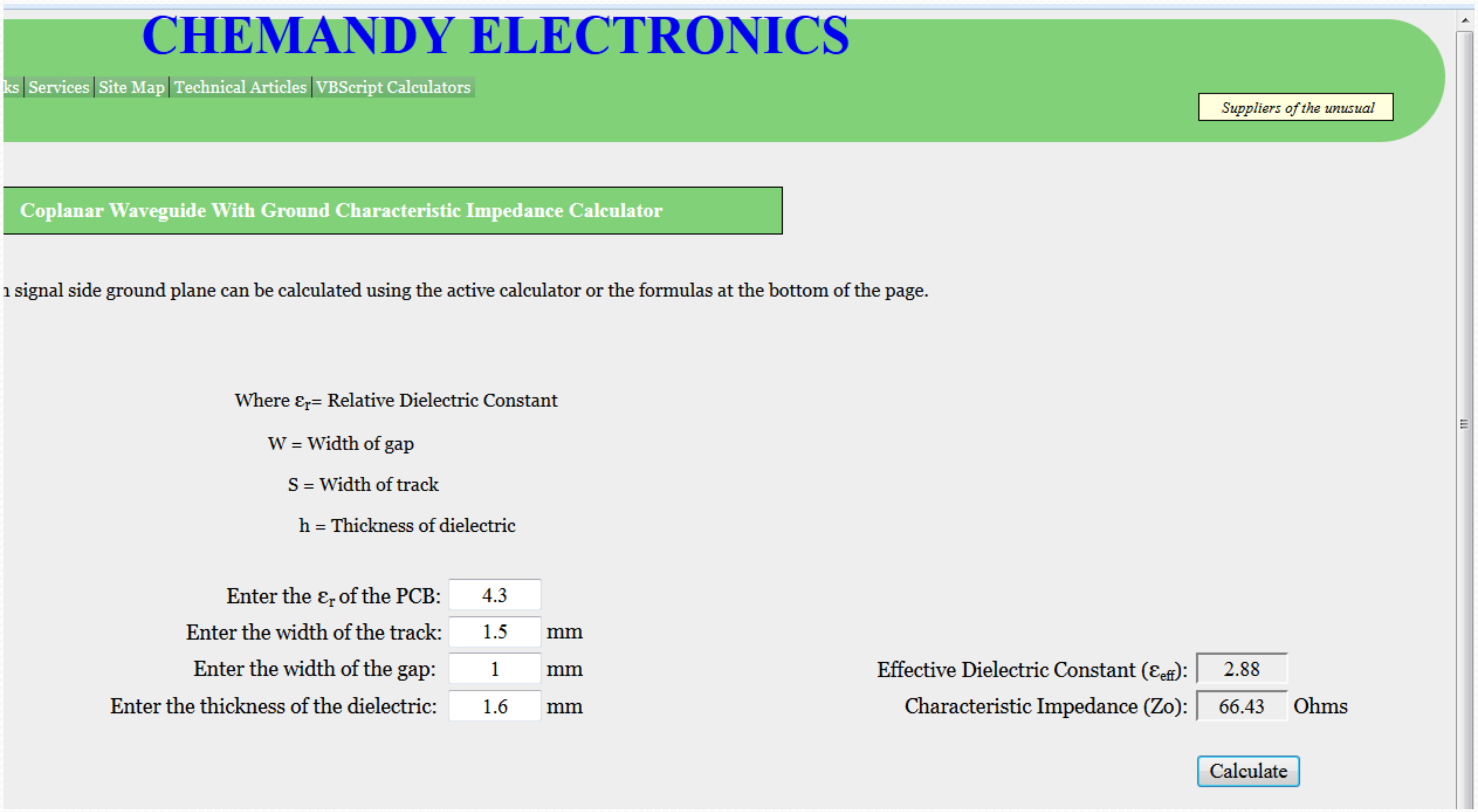
Coplanar Waveguide

- Invented by Chen P. Wen in 1969 RCA's Sarnoff Labs. [10]
- A conductor separate from a pair of ground planes, all in the same plane, atop a dielectric medium. [10]
- It can provide extremely high frequency response (100 GHz or more) since connecting to CPW does not entail any parasitic discontinuities in the ground plane [10],but has poor heat dissipation.
- No design equations for the characteristic impedance of a CPW in textbooks (not even Pozar has this) or CAD to support it.



Both figures [10]

Coplanar Waveguide Calculator



[9]

Coplanar Waveguide for 50 ohms

Where ε_r= Relative Dielectric Constant

W = Width of gap

S = Width of track

h = Thickness of dielectric

Enter the ε_r of the PCB:	8.17	
Enter the width of the track:	1.5	mm
Enter the width of the gap:	1	mm
Enter the thickness of the dielectric:	1.6	mm

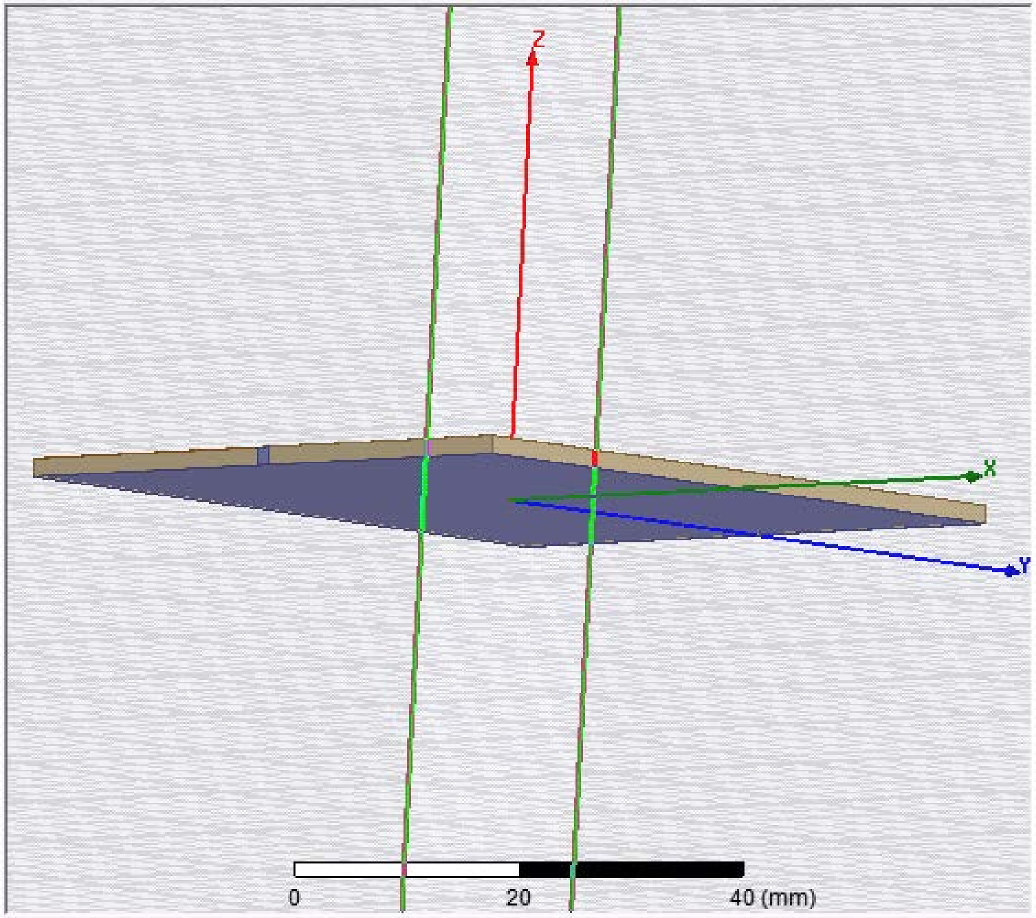
The closest substrate with the a relative dielectric constant of 8.17 is marble

Effective Dielectric Constant (ε_{eff}):	5.085	
Characteristic Impedance (Zo):	50	Ohms

Calculate

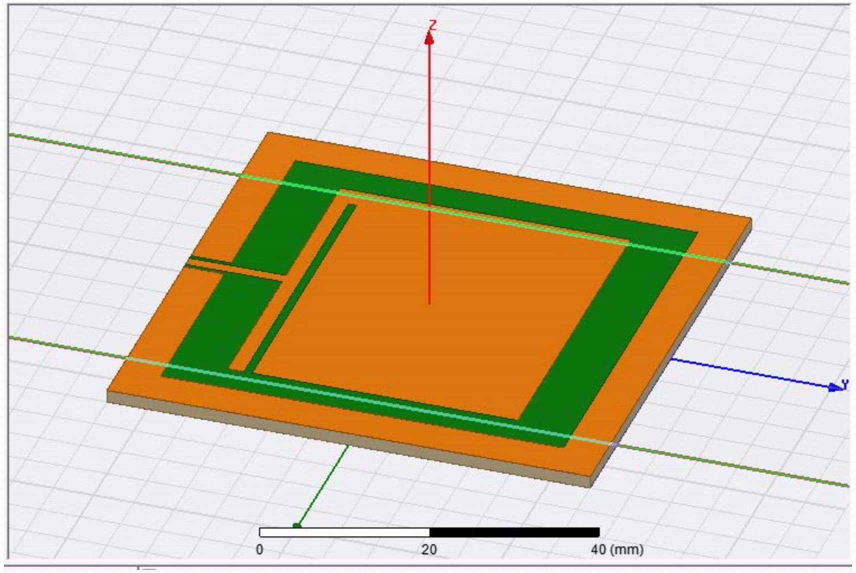
[9]

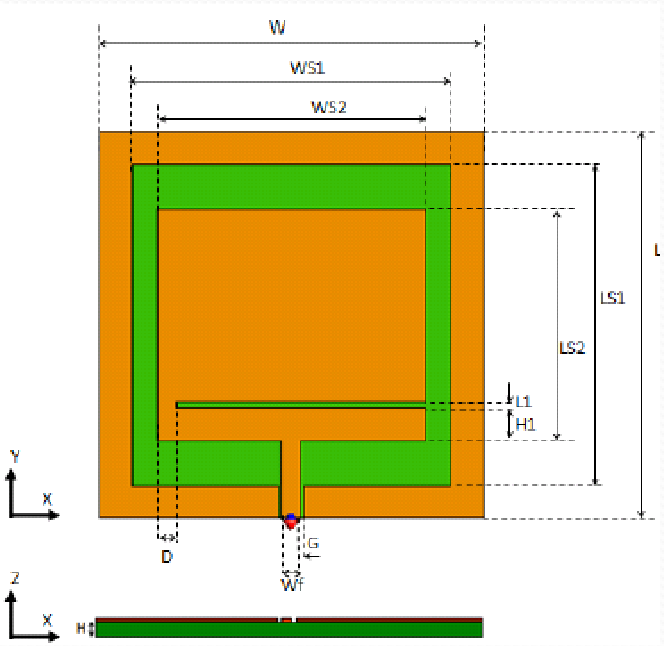
GCWP (Grounded Coplanar Waveguide)



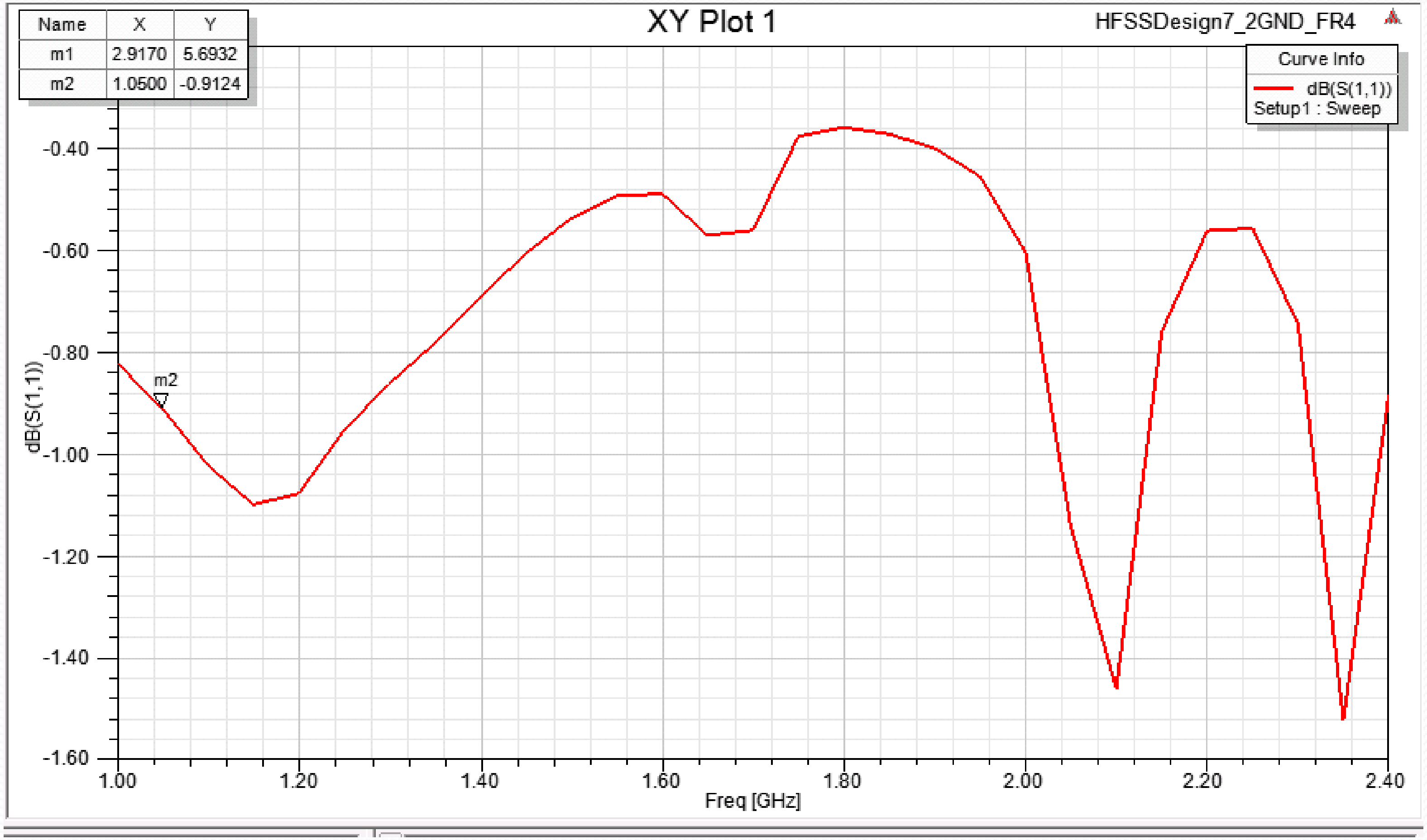
Antenna Layout

Name	Value	Unit	Evaluated Value	Ty
W	60	mm	60mm	Design
L	60	mm	60mm	Design
Wf	1.5	mm	1.5mm	Design
Lf	12	mm	12mm	Design
Wm	0.247	mm	0.247mm	Design
ext	100	mm	100mm	Design
h	1.6	mm	1.6mm	Design
t	0.01778	mm	0.01778mm	Design
Ws1	50	mm	50mm	Design
Ws2	42	mm	42mm	Design
Ls1	50	mm	50mm	Design
Ls2	36	mm	36mm	Design
G	0.5	mm	0.5mm	Design
D	3	mm	3mm	Design
L1	1	mm	1mm	Design
H1	2	mm	2mm	Design
Lm	20.243	mm	20.243mm	Design
Winslt	Ws2-D		39mm	Design
Lftp	(Ls1-Ls2)/2		7mm	Design
Lfbot	(L-Ls1)/2		5mm	Design

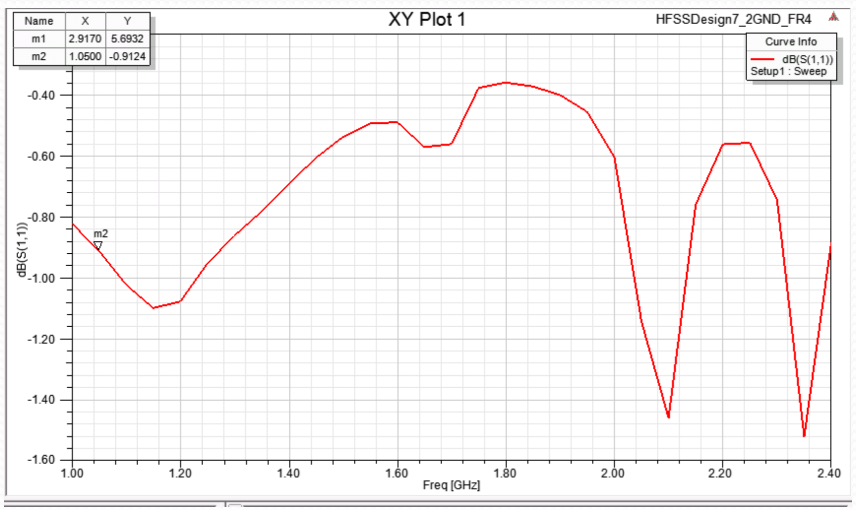




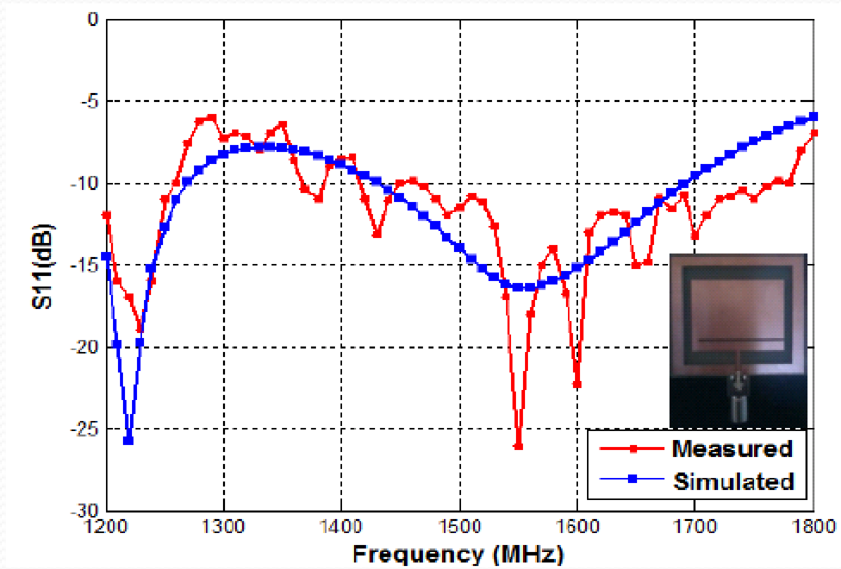
S11 Plot Conductor-Backed CPW



S11 Comparison

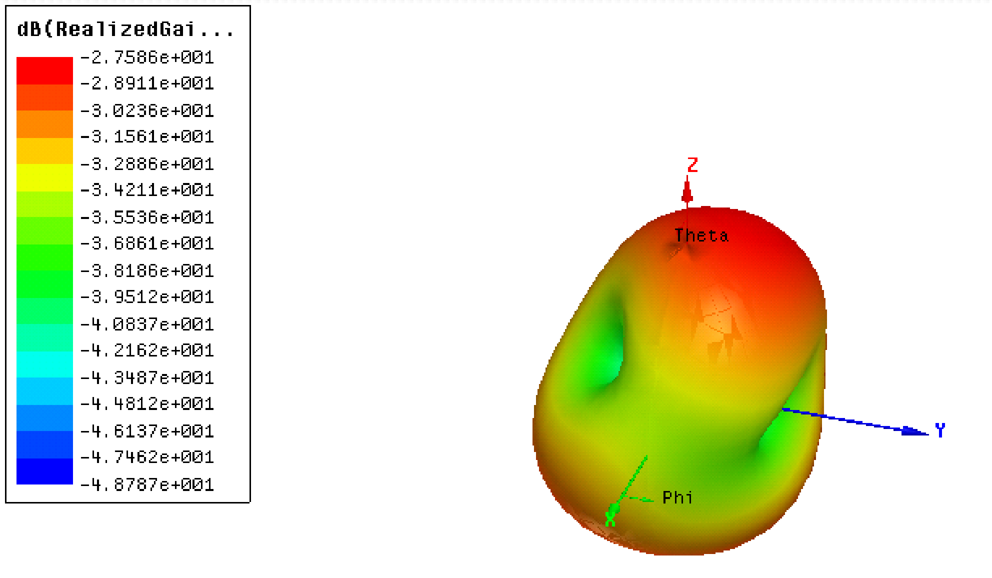


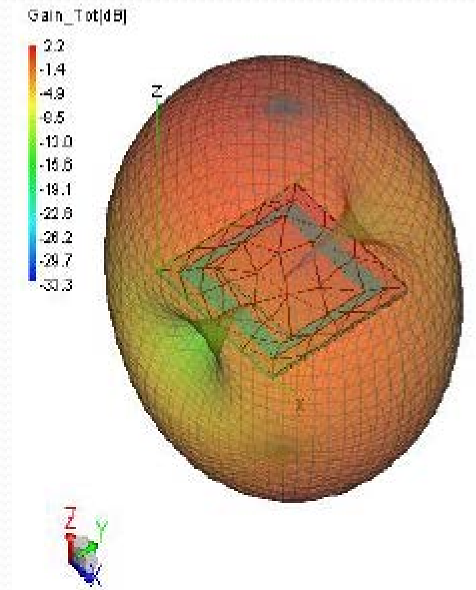
1-1.3 GHz, 1.4-1.8GHz



1.2-1.3 GHz, 1.4-1.7 GHz[1]

3D Polar Plot Comparison





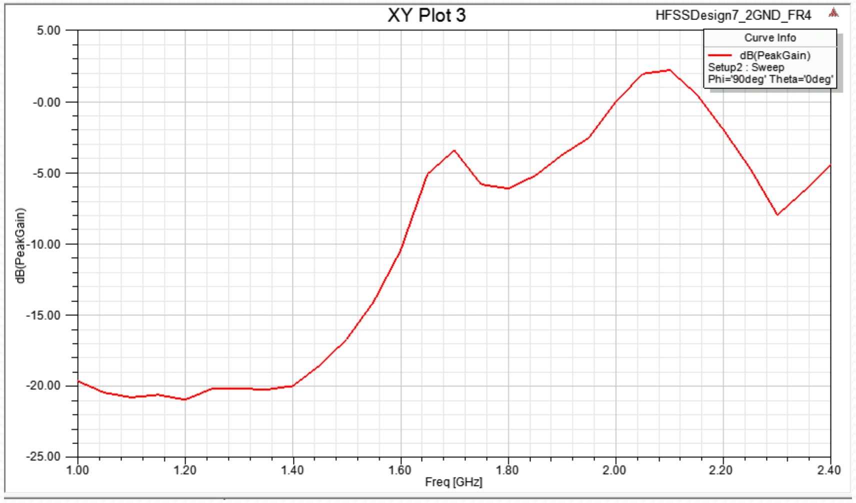
[1]

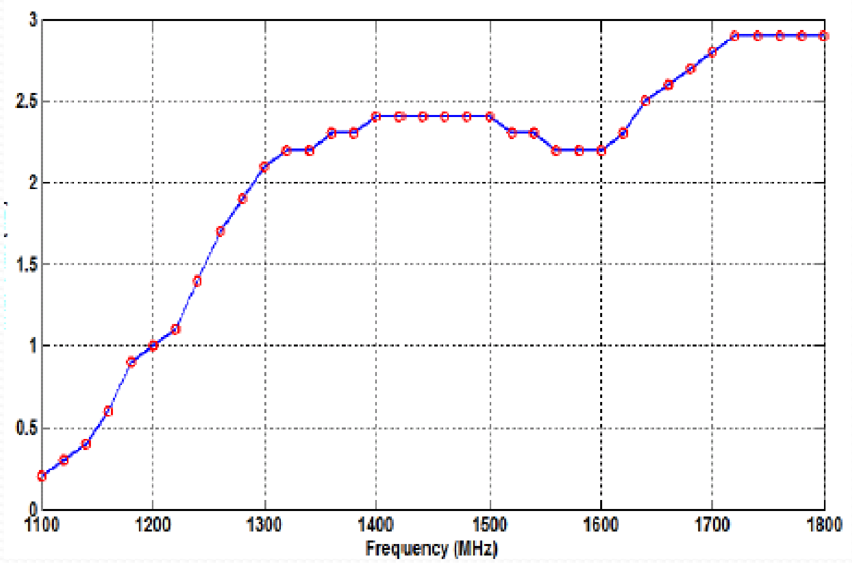
Antenna Parameters:

	Quantity	Freq	Value	
	Max U	1.2GHz	0.00013875 W/sr	
	Peak Directivity		2.3781	
	Peak Gain		0.0079317	
	Peak Realized Gain		0.0017436	
	Radiated Power		0.00073319 W	

	Accepted Power		0.21982 W
	Incident Power		1 W
	Radiation Efficiency		0.0033354
	Front to Back Ratio		3.8153
	Decay Factor		0

Maximum Gain vs. Antenna Freq.

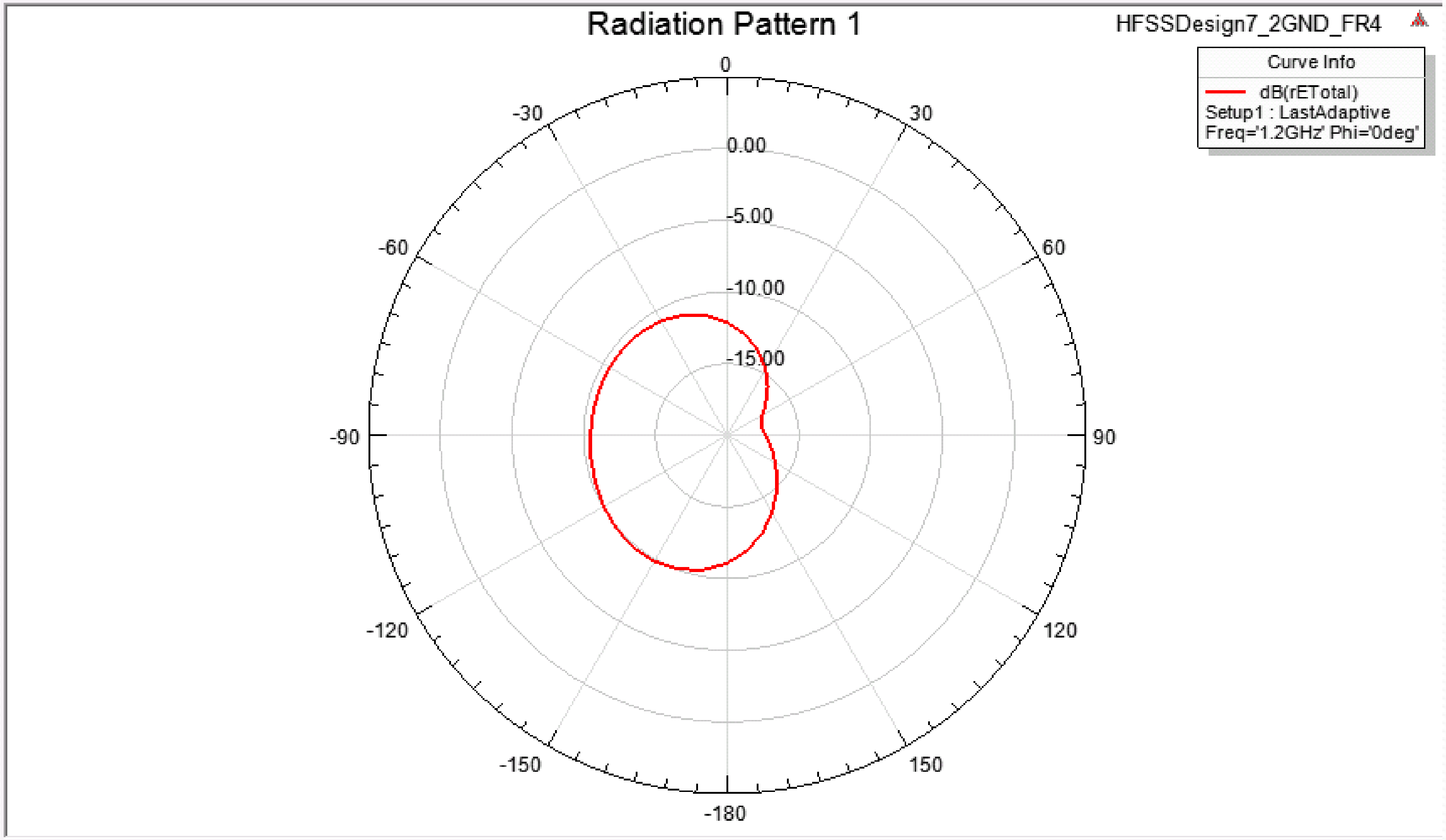




-21 dB to -5 dB

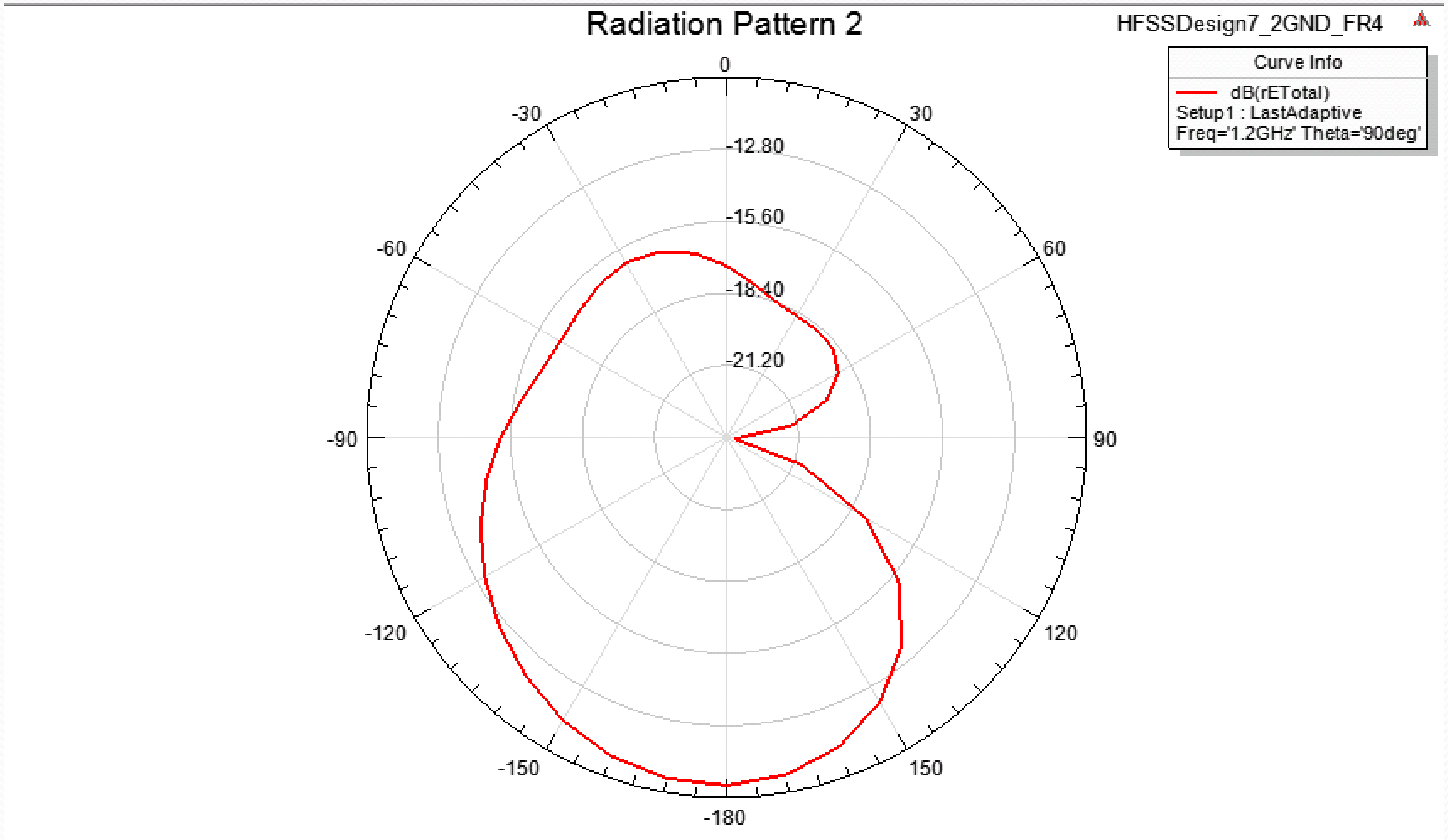
0.2dB to 2.9 dB, [1]

E-plane



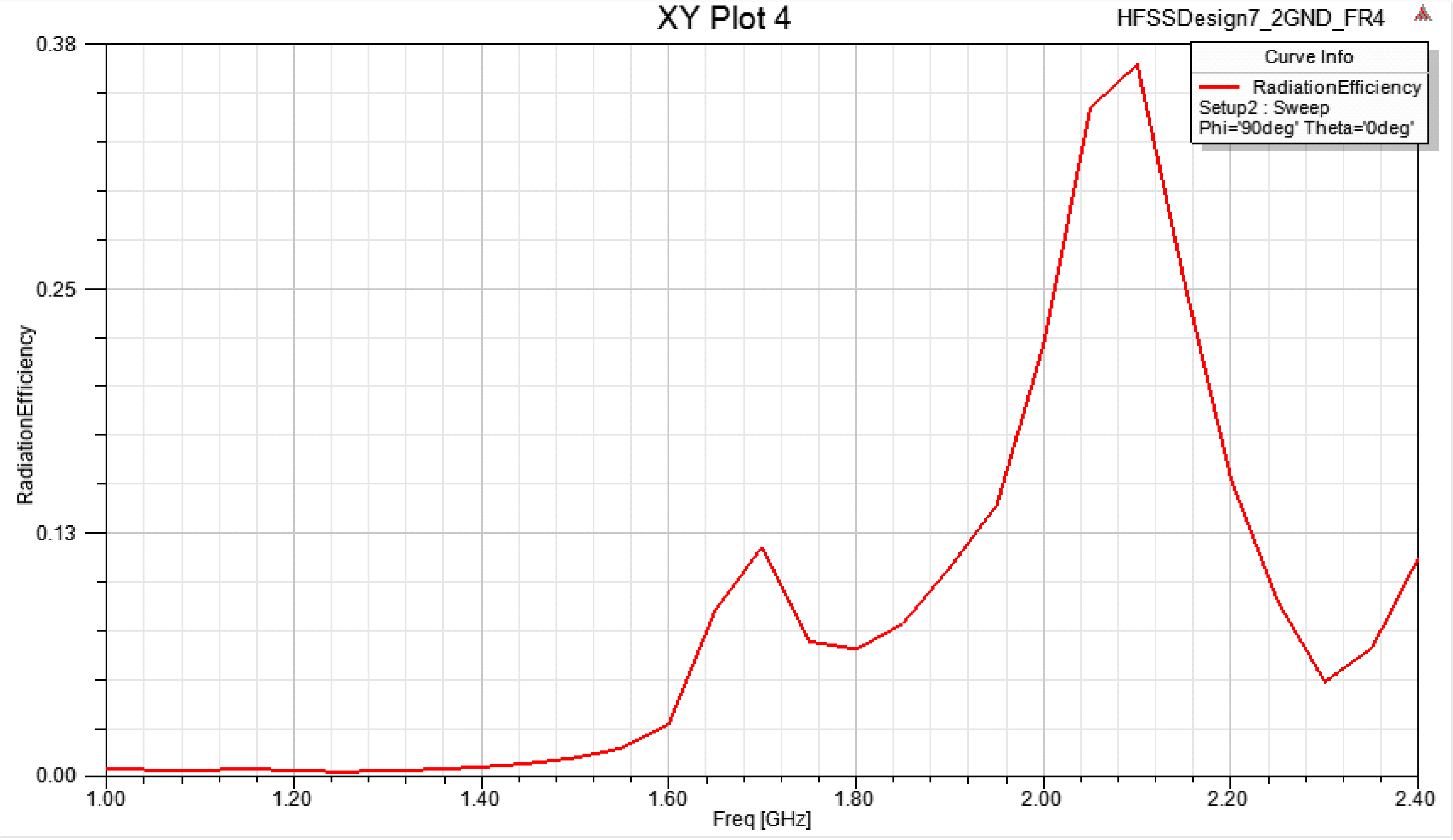
Radiation Pattern 1
HFSSDesign7_2GND_FR4
Curve Info
dB(rETotal)
Setup1 : LastAdaptive
Freq='1.2GHz' Phi='0deg'
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
0.00
-5.00
-10.00
-15.00

H-plane

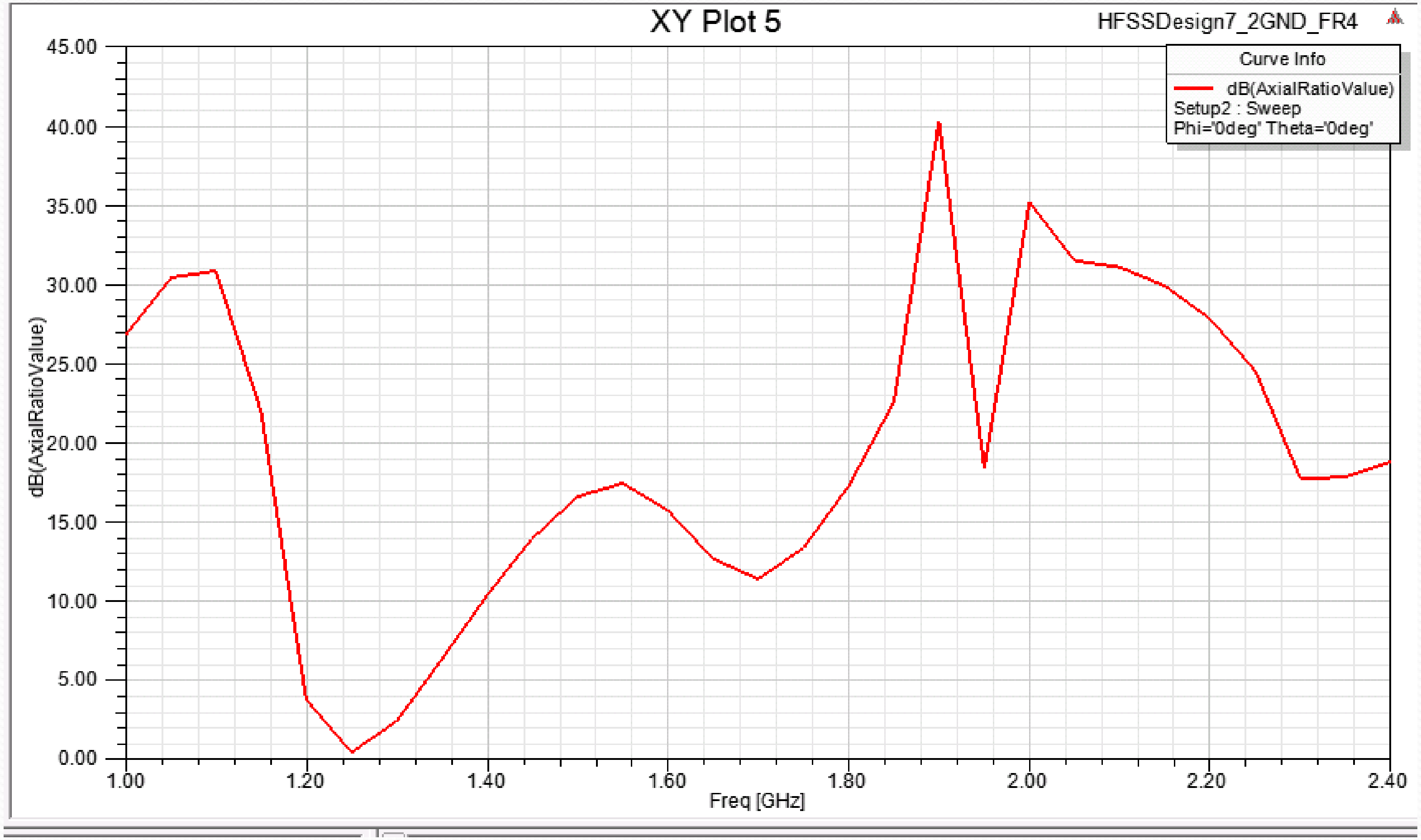


Radiation Pattern 2
HFSSDesign7_2GND_FR4
Curve Info
dB(rETotal)
Setup1 : LastAdaptive
Freq='1.2GHz' Theta='90deg'
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
-12.80
-15.60
-18.40
-21.20

Rad. Efficiency vs Freq.



Axial Ratio (Dual-Band Rect. CPW Antenna)

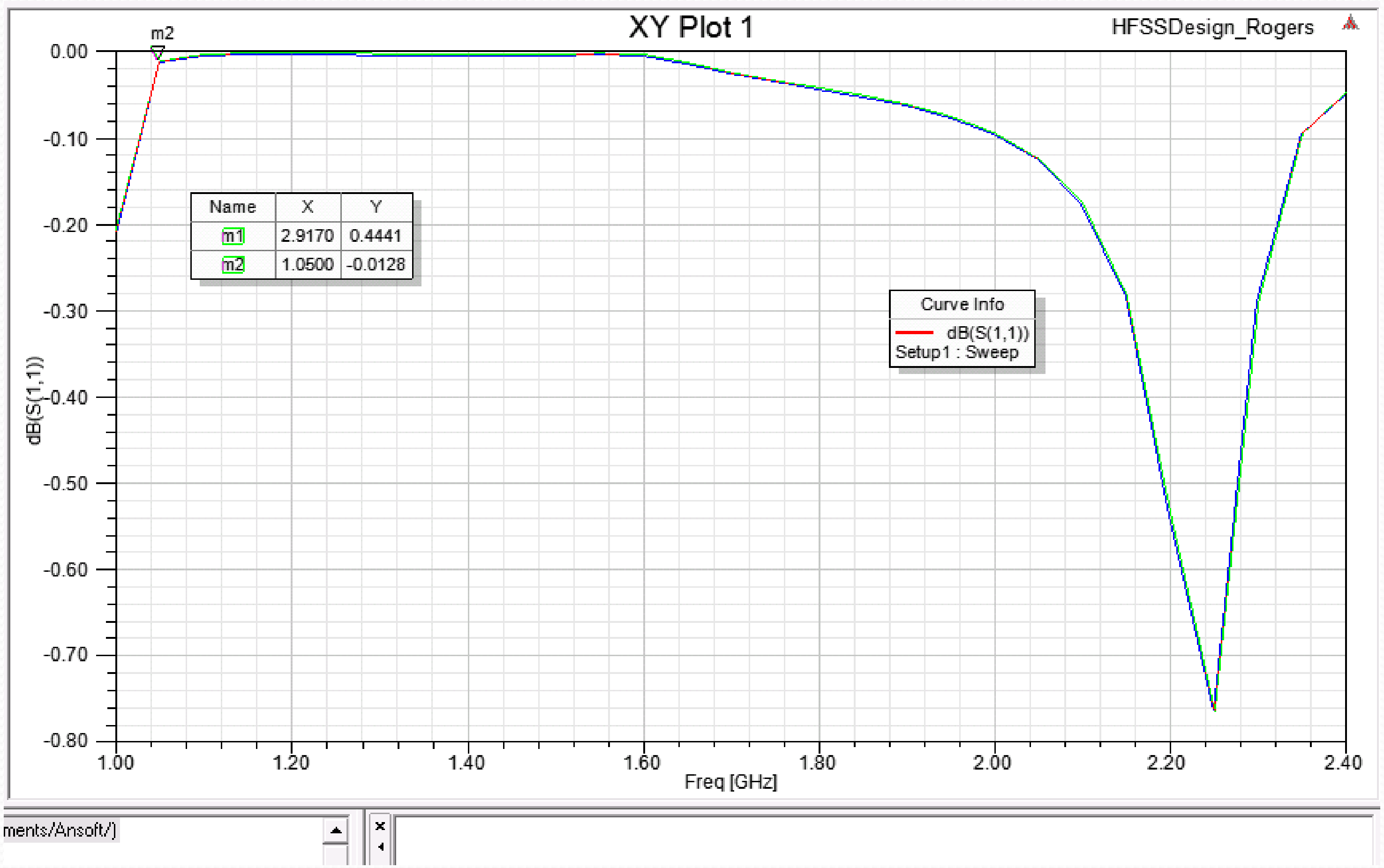


Dielectric Substrates for GNSS Microstrip Antennas

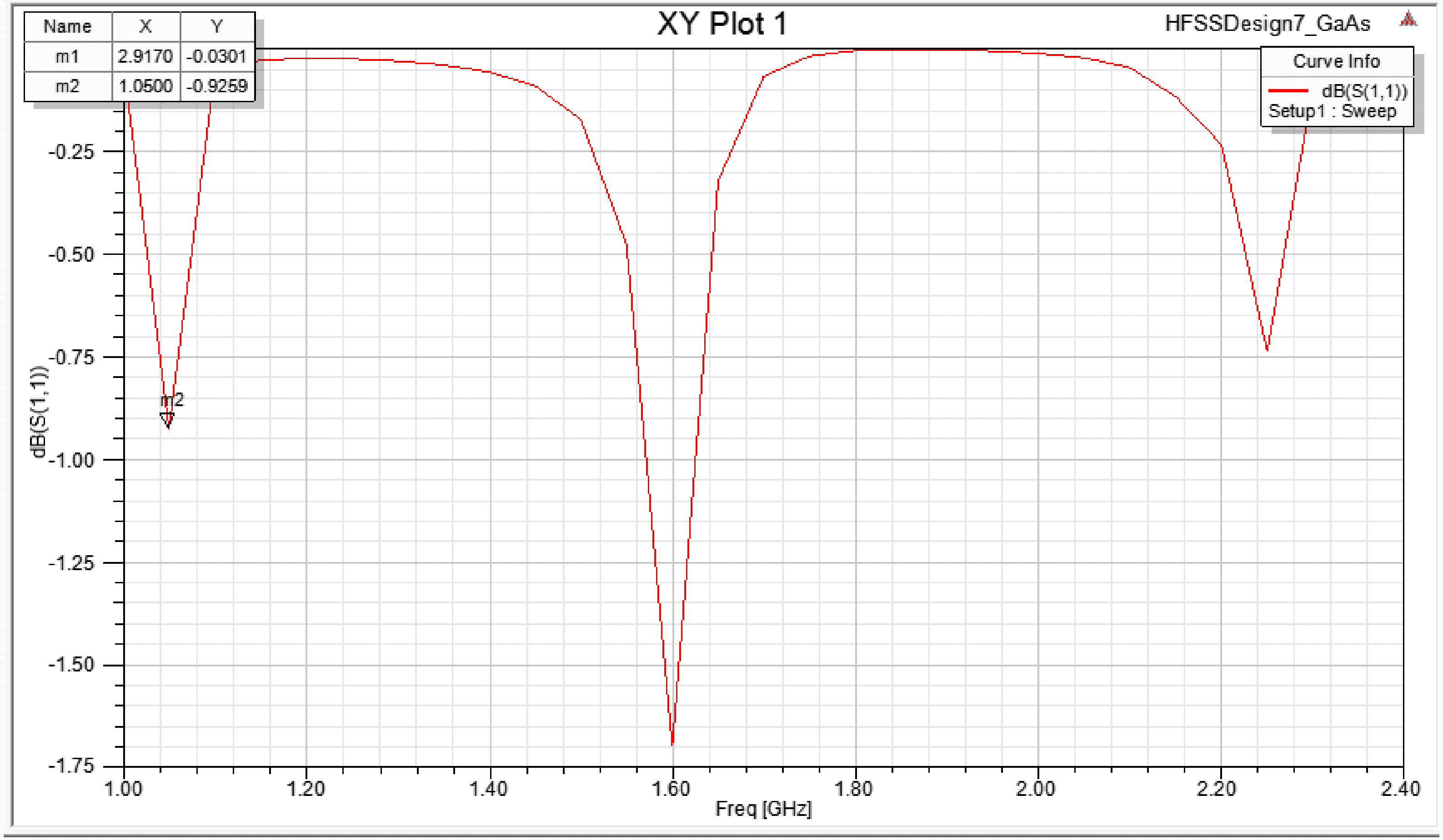
Name of Substrate	*Dielectric Constant*	*Loss Tangent*	*Manufacturer*
Rohacell Foam	1.07	0.001	Rohm
Arlon Foam-Clad 100	1.15–1.35	0.002–0.004	Arlon; www.arlom-med.com
Duroid 5870	2.35	0.005	Rogers Corp.;www.rogerscorporation.com
RO3003	3.00	0.0013	Rogers Corp.
TMM4	4.50	0.0017	Rogers Corp.
TMM6	6.0	0.0018	Rogers Corp.
TMM10	9.2	0.0017	Rogers Corp.
RO3010	10.2	0.0023	Rogers Corp.
TMM13i	12.78	0.002	Rogers Corp.
SM200 (ceramic)	20	0.001	Kyocera North America; americas.kyocera.com
SB 350 (ceramic)	35	0.001	Kyocera North America
D88 (ceramic)	88 ± 2	Temperature coefficient = 0 $\pm$ 5 ppm^0 C^2	Morgan Electro Ceramics, U.K.; www.morgan-electroceramics.com

[6]

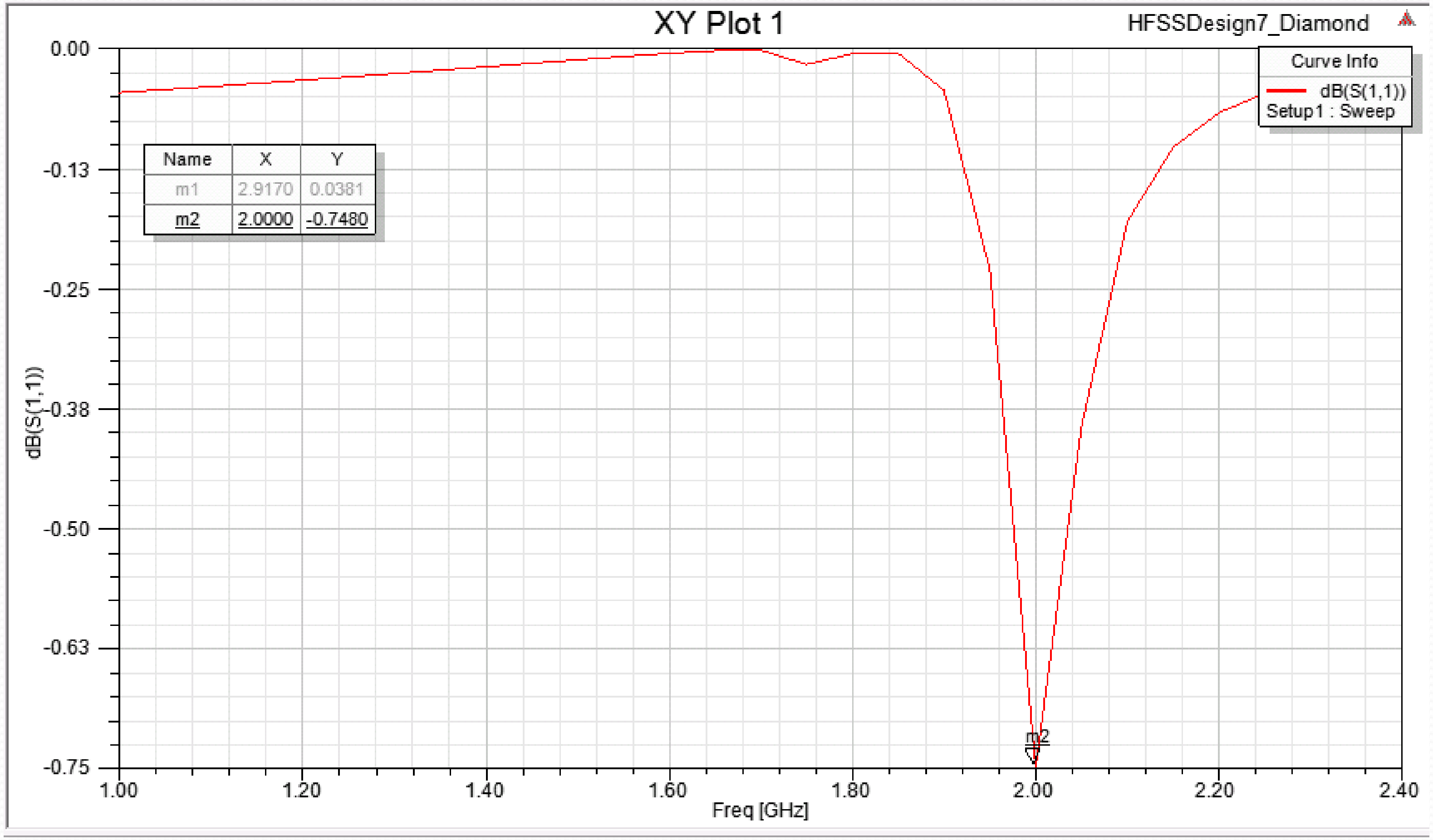
Rogers TMM4 S11 plot (not that great)



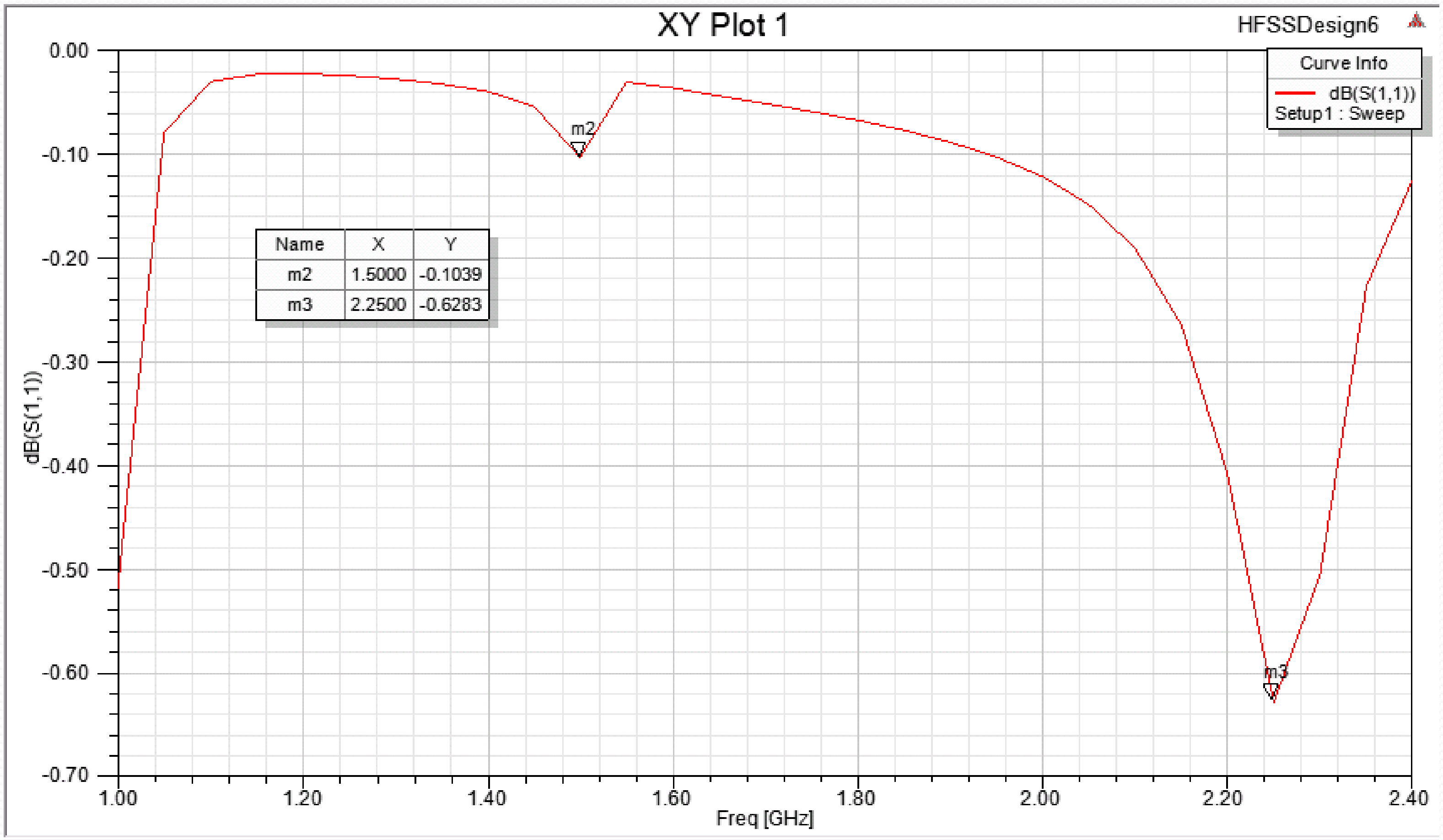
GaAs S11 plot (return loss is well-defined)



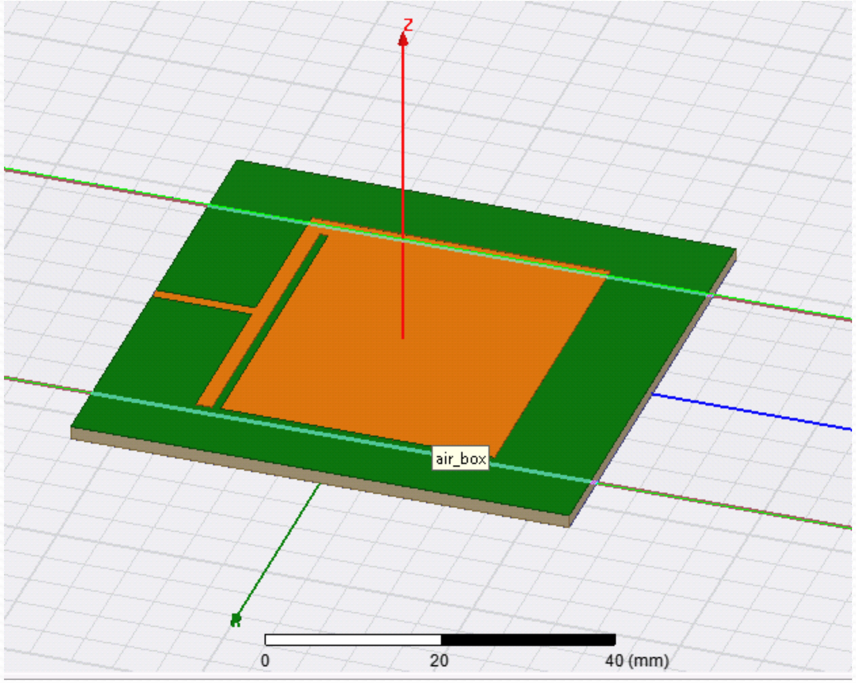
Diamond S11 plot



S11 plot FR4 (no bottom ground plane)



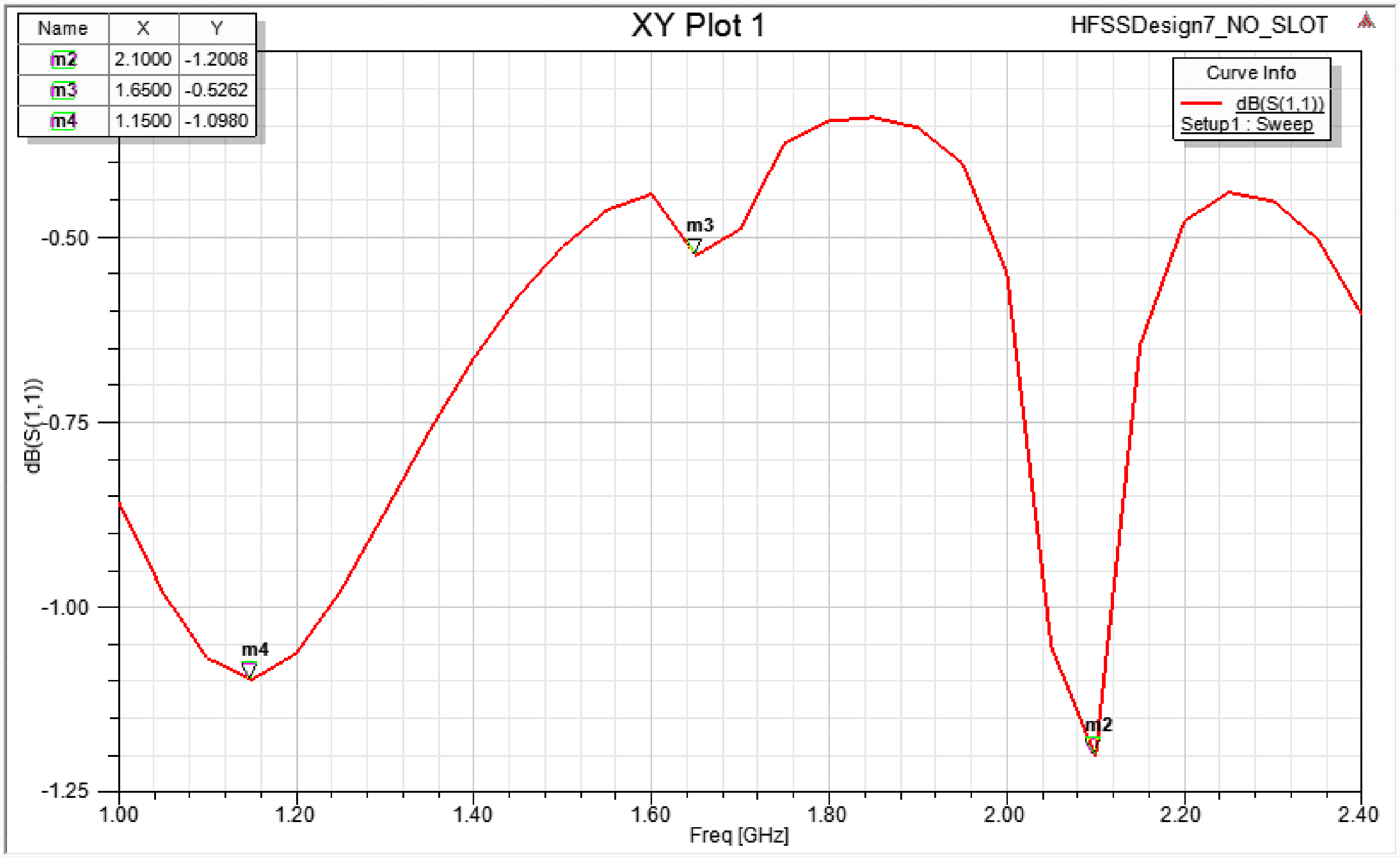
GNSS Patch Antenna Layout (No Outer Slot)



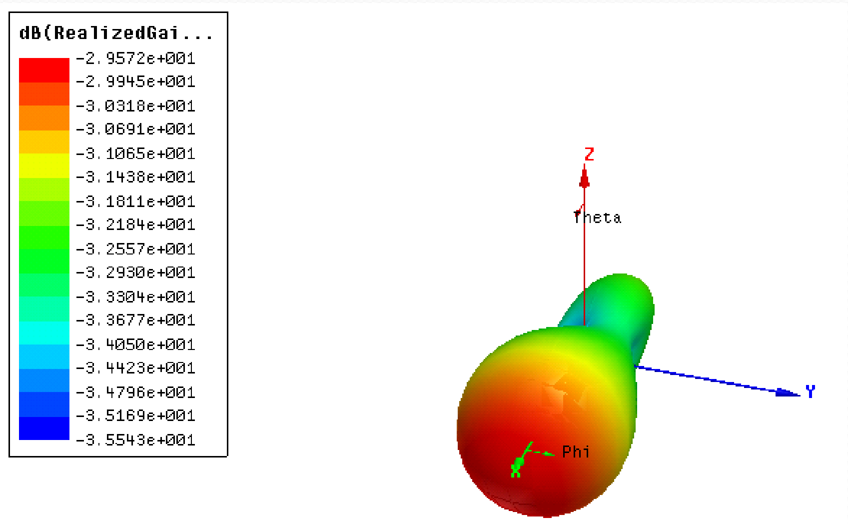
Properties

Name	Value	Unit	Evaluated Value
W	60	mm	60mm
L	60	mm	60mm
gnd_ext	38.713	mm	38.713mm
Wf	1.5	mm	1.5mm
Lf	12	mm	12mm
Wm	0.247	mm	0.247mm
ext	100	mm	100mm
h	1.6	mm	1.6mm
t	0.01778	mm	0.01778mm
Ws1	50	mm	50mm
Ws2	42	mm	42mm
Ls1	50	mm	50mm
Ls2	36	mm	36mm
G	0.5	mm	0.5mm
D	3	mm	3mm
L1	1	mm	1mm
H1	2	mm	2mm
Lm	20.243	mm	20.243mm
Winslt	Ws2-D		39mm
Lftp	(Ls1-Ls2)/2		7mm

GNSS Patch Antenna (No Outer Slot)



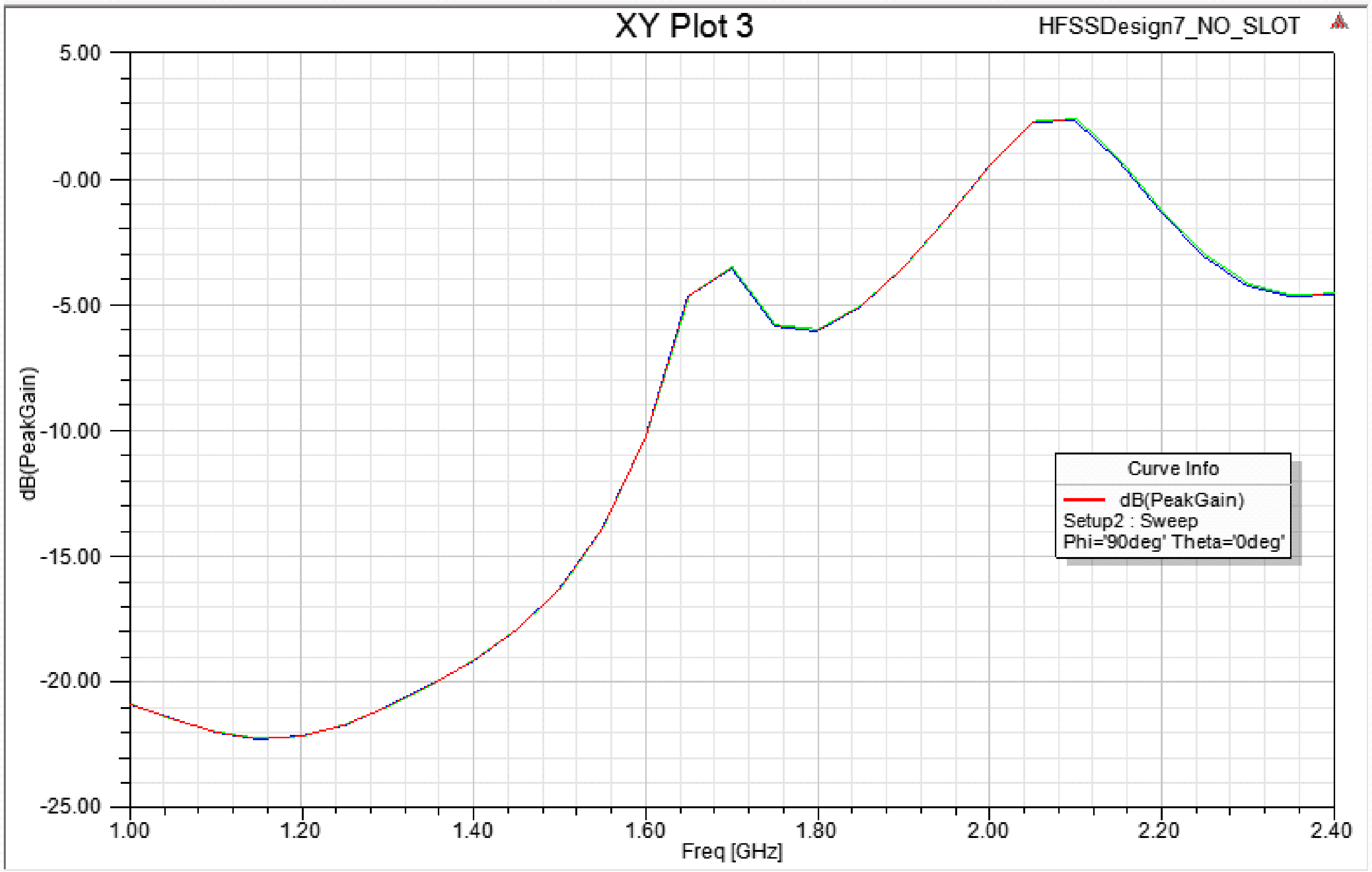
3D Polar Plot and Ant. Parameters



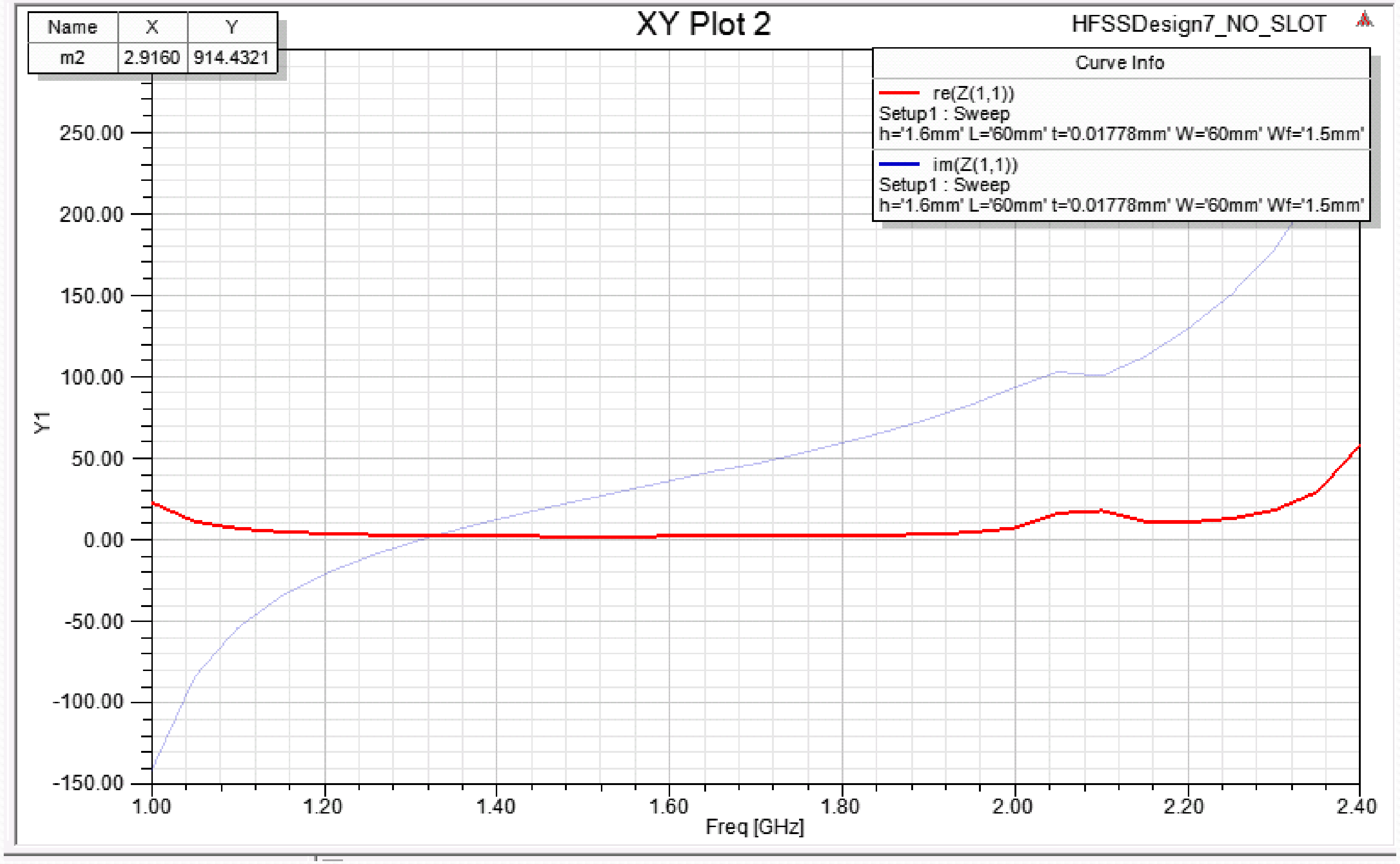
Antenna Parameters:

Quantity	Freq	Value
Max U	1.2GHz	8.7819E-005 W/sr
Peak Directivity		1.976
Peak Gain		0.0050845
Peak Realized Gain		0.0011036
Radiated Power		0.00055851 W
Accepted Power		0.21705 W
Incident Power		1 W
Radiation Efficiency		0.0025732
Front to Back Ratio		1.8035
Decay Factor		0

dB(PeakGain)

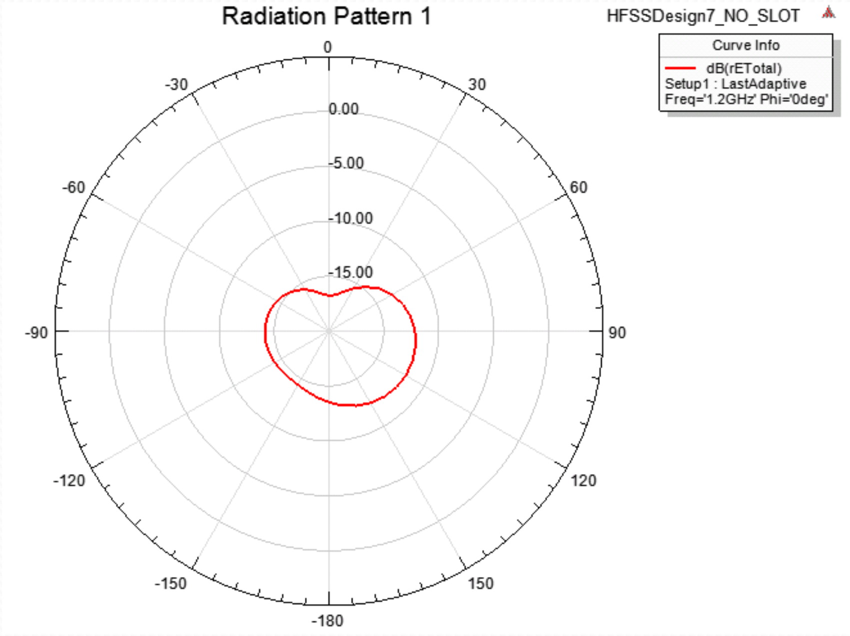

XY Plot 3
HFSSDesign7_NO_SLOT
5.00
-0.00
-5.00
-10.00
-15.00
-20.00
-25.00
dB(PeakGain)
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
Freq [GHz]
Curve Info
dB(PeakGain)
Setup2 : Sweep
Phi='90deg' Theta='0deg'

No Outer Slot Z11 plot

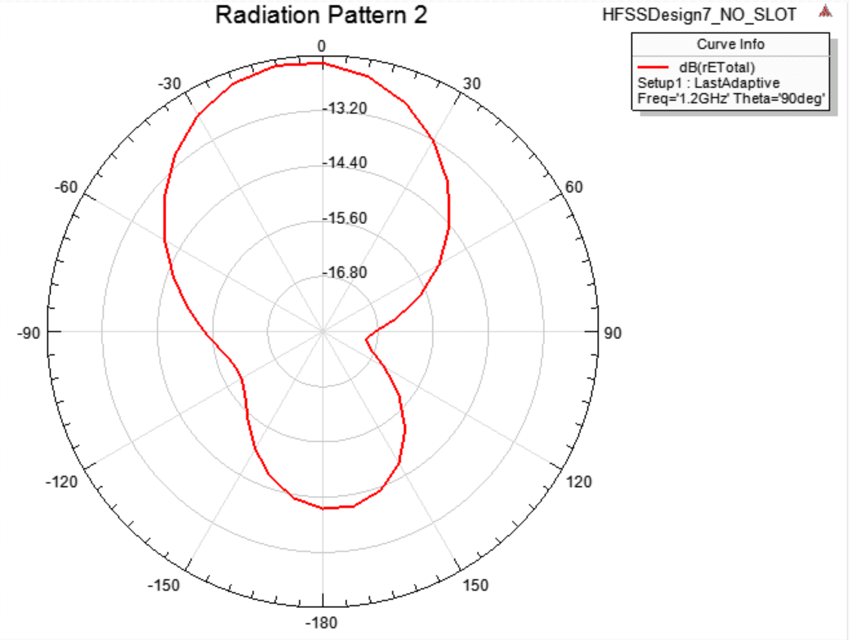


2D Radiation Pattern

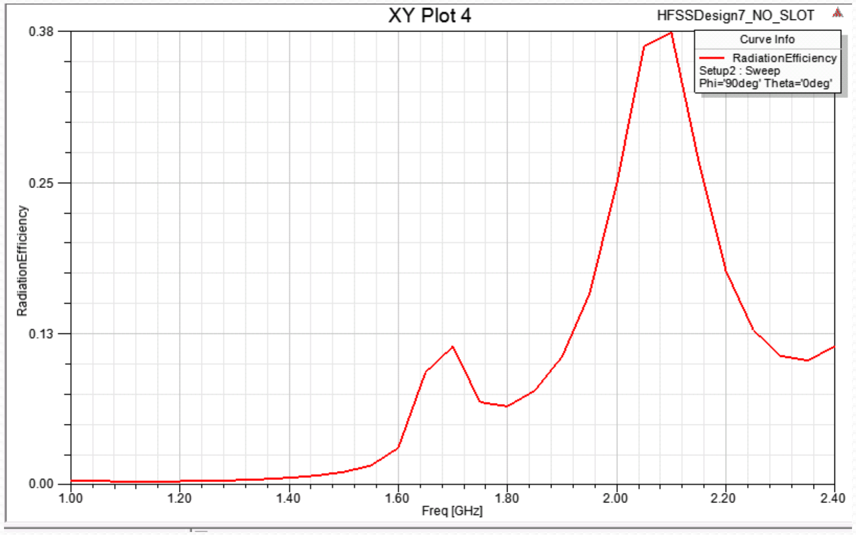
E-plane

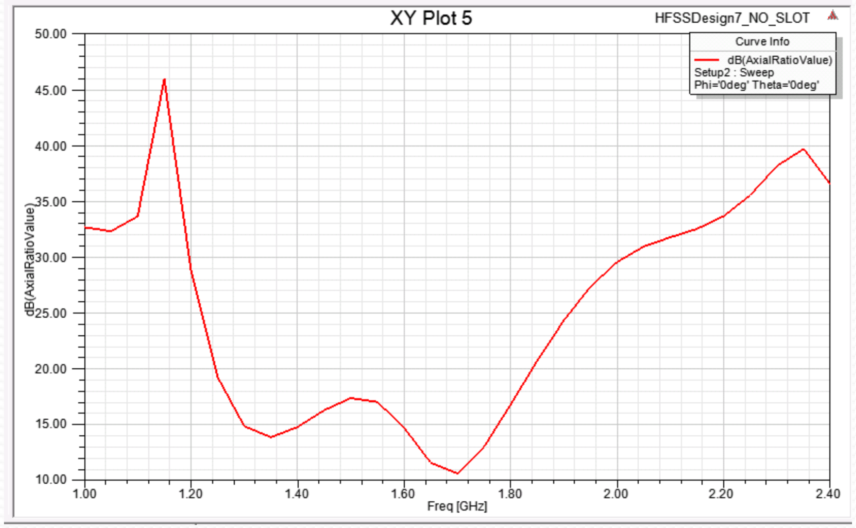


H-plane



Rad Efficiency and Axial Ratio





Conclusion: Overall Observations

- The effect of leaving out the bottom ground plane removes the resonant frequency band at 1100 MHz to 1500 MHz on the S11 plot, though improves the gain and radiation characters/antenna parameters, and vice versa.
- Changing the dielectric increases the resonant frequency (not the right one) at different points of the plot.
- Lumped Port need two conductors to work, for a regular CPW patch antenna (gnd on the top of the substrate), the results may not be accurate.
- Gain could be increased by varying L (the area), though there's not much room on the GCPW to expand.

Works Cited

- [1] Reha, Abdelati, and Marouan Bouchouirbat. "A Dual-Band Rectangular CPW Folded Slot Antenna for GNSS Applications." *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* 3.8 (2014): 11055-1061. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*. Ess & Ess Research Publications, Aug. 2014. Web. 12 Feb. 2014. <http://www.ijareeie.com/upload/2014/august/3_A.pdf>.

- [2] Du Li; Pengfei Guo; Qing Dai; Yunqi Fu, "Broadband Capacitively Coupled Stacked Patch Antenna for GNSS Applications," *Antennas and Wireless Propagation Letters, IEEE* , vol.11, no., pp.701,704, 2012

- [3] Hamoudi, H.; Haddad, B.; Lognonne, P., "Study of a L2 patch antennas array for GNSS/GPS network," *Antennas and Propagation (EuCAP), 2013 7th European Conference on* , vol., no., pp.2187,2191, 8-12 April 2013

- [4] Panther, Gyles. "Patch Antennas for the New GNSS." *GPS World: The Business & Technology of GNSS*. North Coast Media LLC, 1 Feb. 2012. Web. 05 Feb. 2015. http://gpsworld.com/wirelesspatch-antennas-new-gnss-12552/

Works Cited (continued)

- [5] Lili Wang; Lijuan Deng; Xiaoli Xi; Yongxing Du, "A miniature GPS microstrip antenna," *Antennas, Propagation & EM Theory (ISAPE), 2012 10th International Symposium on* , vol., no., pp.250,252, 22-26 Oct. 2012

- [6] Rao, Basur R. "Chapter 2: FRPAs and High-Gain Directional Antennas." *GPS/GNSS Antennas*. 1st ed. N.p.: Artech House, 2012. 63-151. *Google Books*. Google. Web. 5 Feb. 2015.

- [7] Microsoft Office ClipArt

- [8] Chen, Luyi. *DUAL FREQUENCY PATCH ANTENNA DESIGN FOR GLOBAL NAVIGATION SATELLITE SYSTEM*. Russ College of Engineering and Technology, 2007. Web. 5 Feb. 2015. <https://etd.ohiolink.edu/!etd.send_file?accession=ohiou1178633247&disposition=inline>.

- [9] "Coplanar Waveguide With Ground Characteristic Impedance Calculator." *Coplanar Waveguide With Ground Calculator*. CHEMANDY ELECTRONICS Ltd, 19 June 2014. Web. 13 Mar. 2015. <http://chemandy.com/calculators/coplanar-waveguide-with-ground-calculator.htm>.

- [10] "Microwave Encyclopedia Calculators Design Vswr RF." *Microwaves101*. IEEE, MTT-S, P-N Designs, Inc, n.d. Web. 13 Mar. 2015. <http://www.microwaves101.com/encyclopedias/327-coplanar-waveguide-microwave-encyclopedia-microwaves101-com>.

- [11] Balanis, Constantine A. "14.2 Rectangular Patch." *Antenna Theory: Analysis and Design*. Hoboken, NJ: Wiley Interscience, 2005. 815-21. Print.

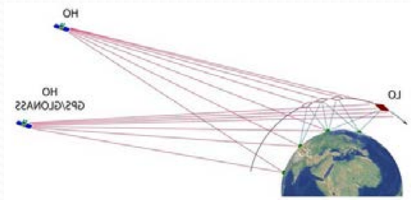
Appendix A

Design Equations (Optional)

Reference for standard patch antenna.

[7]

Analytical Derivations [6]



- Radiation efficiency e_r – radio of radiated power Pr to the input power Pi.

$$e_r = \frac{P_r}{P_i} = \frac{P_r}{(P_r + P_c + P_d + P_{sur})} \approx \frac{P_r}{(P_r + P_{sur})}$$

- P_r – radiated power

$$P_r = 40k_0^2 (k_0 h)^2 \left[1 - \frac{1}{\varepsilon_r} + \frac{2}{5\varepsilon_r^2}\right]$$

- P_{sur} – surface wave power propagated in the grounded dielectric substrate

$$P_{sur} = 30\pi k_0^2 \frac{\varepsilon_r \left(x_0^2 - 1\right)}{\varepsilon_r \left[\frac{1}{\sqrt{x_0^2 - 1}} + \frac{\sqrt{x_0^2 - 1}}{\varepsilon_r - x_0^2}\right] + k_0 h \left[1 + \frac{\varepsilon_r^2 \left(x_0^2 - 1\right)}{\varepsilon_r - x_0^2}\right]}$$

- Ko =2π/λo (wave number)

- X_o = normalized phase constant of the TMo of the surface node which has no cutoff frequency

$$x_0 = \frac{\beta}{k_0} \approx 1 + \frac{1}{2}\left(\frac{\varepsilon_r - 1}{\varepsilon_r} k_0 h\right)^2$$

Analytical Derivations: TM_{10} and TM_{01} modes for Far-Field Radiation E_θ and E_φ components [6]

$$(E_0)_{TM_{10}} = -jk_0 V_0 L \frac{e^{-jk_0^r}}{4\pi r} \cos\varphi F_1 F_2$$

$$(E_0)_{TM_{10}} = -jk_0 V_0 L \frac{e^{-jk_0^r}}{4\pi r} \cos\theta \sin\varphi F_1 F_2$$

where

$$F_1 = \sin c \left\{ \frac{k_0 h \sin\theta \cos\varphi}{2} \right\} \sin c \left\{ \frac{k_0 L \sin\theta \sin\varphi}{2} \right\}$$

and

$$F_2 = 2\cos \left\{ \frac{k_0 W \sin\theta \cos\varphi}{2} \right\}$$

$$(E_0)_{TM_{01}} = jk_0 V_0 W \frac{e^{-jk_-^r}}{4\pi r} \sin\varphi F_1^I F_2^I$$

$$(E_\varphi)_{TM_{01}} = jk_0 V_0 W \frac{e^{-jk_-^r}}{4\pi r} \cos\theta \cos\varphi F_1^I F_2^I$$

where

$$F_1^I = \sin c \left\{ \frac{k_0 h \sin\theta \sin\varphi}{2} \right\} \sin c \left\{ \frac{k_0 W \sin\theta \cos\varphi}{2} \right\}$$

and

$$F_2^1 = 2\cos \left\{ \frac{k_0 L \sin\theta \sin\varphi}{2} \right\}$$

Analytical Derivations: HPBW and Directivity [6]

- HPBW θ_E in the E plane where $\phi = 0$, and HPBW θ_φ in the H plane where $\phi = 90$ for a single-layer patch antenna.

$$\theta_H = 2 \arcsin\left\{\frac{1}{2 + k_0 L}\right\}^{\frac{1}{2}}$$

$$\theta_E = 2 \arcsin\left\{\frac{7.03}{3k_0^2 W^2 + k_0^2 h^2}\right\}^{\frac{1}{2}}$$

- Directivity – ratio of max power density in main beam direction to ave. power density.

$$D = \frac{\left(\frac{r^2}{2\eta_0}\left\{\left|E_\theta\right|^2 + \left|E_\varphi\right|^2\right\}_{\theta=0}\right)}{\frac{P_r}{4\pi}}$$

$$D = \frac{4\left(k_0 a\right)^2}{\pi \eta_0 G_r}$$

Microstrip Patch Antennas Advantages & Disadvantages [6]

- 1.) They can be made to have a very low profile, suited for avionics to satisfy the design requirement for GPS antennas (the maximum antenna height may be no greater than 0.73” so as not to increase aerodynamic drag) [6]
- 2.) Using substrates with high dielectric constants allows the antenna size to be very small; microstrip antennas are ideally suited for densely packed antenna arrays. (GPS handsets) [6]
- 3.) Patch antennas are lightweight to be integrated into microwave integrated circuits (MMICs) used in GNSS receivers. Photolithography combined with etching techniques lowers fabrication costs for high-volume production. [6]
- 4.) Conformal mounting on surfaces/sleek aerodynamic shapes (cones/cylinders) make patch antennas popular for small missiles (projectiles), special flexible fabrics for putting GPS antennas on garments. [6]
- They also have simple fabrication/convenience of impedance bandwidth improvement by impedance matching network. [6]

- 1.) Have a very narrow bandwidth requiring special design techniques to achieve operation at two or more frequency GNSS bands such as stacking one patch on top of another or coupling to another parasitic patch, tuned to a specific frequency, or etching by etching slots into the metallic patch. [6]
- 2.) Dielectric substrates with high dielectric constants while reducing the size of the antenna also decrease the bandwidth and increase surface wave radiation at low-elevation angles near the horizon. Results in increased diffraction from the edges of the ground plane (susceptibility to multipath and interference, ripples in antenna gain and phase from interference with direct radiation from the patch antenna) [6]