Microstrip Patch Antenna Design Principles

Ben Horwath

Outline

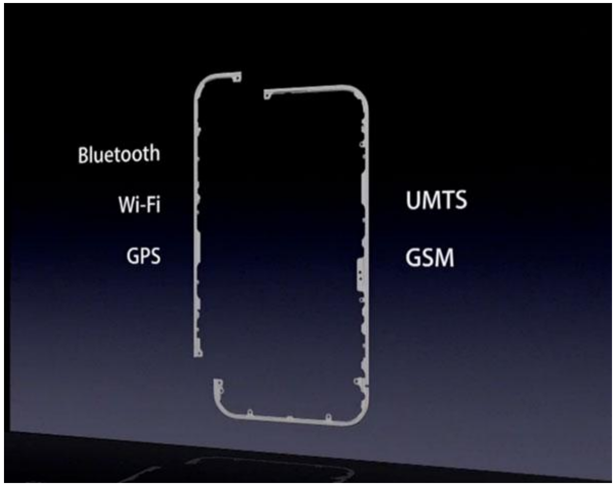
- Introduction
- Antenna basics
- Microstrip antennas
- Design methodology
- Design guidelines
- Footprint equations
- Circuit equivalent equations
- Quick example
- EM solvers
- PhD work-to-date
- Future efforts
- Some good references
- Questions

Introduction

- For consumer devices, wireless is everywhere!
  - LTE (700 MHz), GSM (850MHz/1.9GHz), Wi-Fi (2.4 GHz), Bluetooth (2.4 GHz), GPS (1.575 GHz)

With more coming: 5G (or whatever), Wireless Display, Wireless USB, etc.

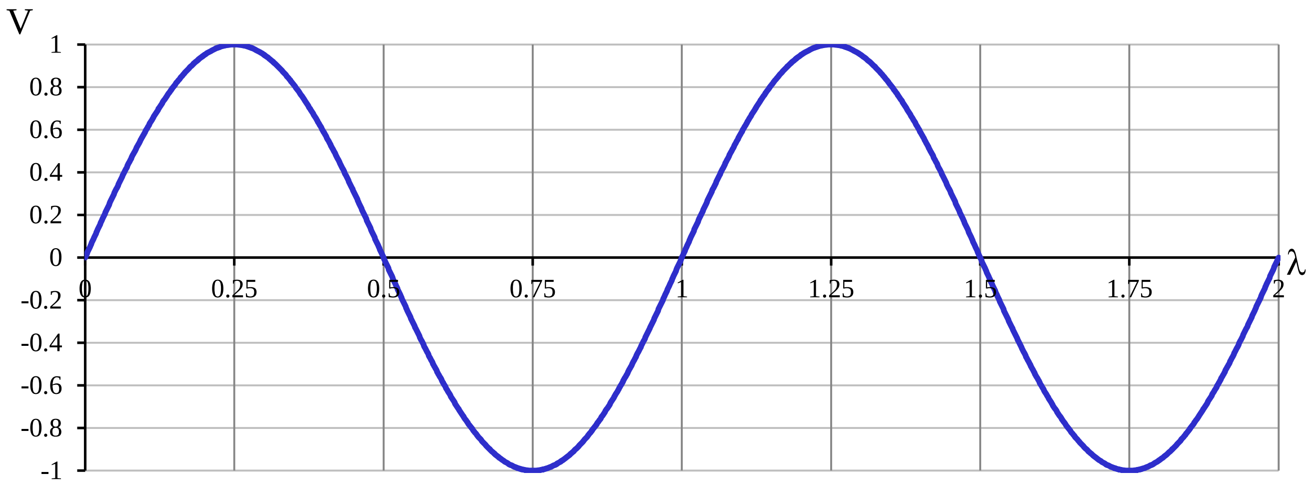
- Apple's iPhone 4 is popular science
  - But illustrates sizes and importance of good antenna design

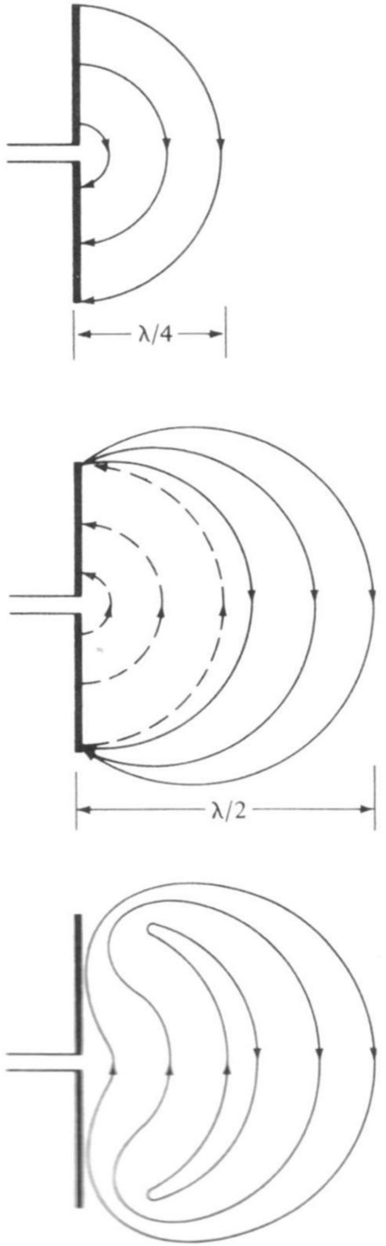


- Why microstrip antennas?
  - The patch antenna is a good place to start for antenna fundamentals

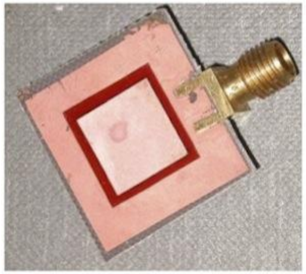
Antenna Basics

- How is radiation achieved?
- Wavelength is key: $\frac{\lambda}{2}$, $where\ \lambda = \frac{c_o}{f_r\sqrt{\epsilon_r}}$

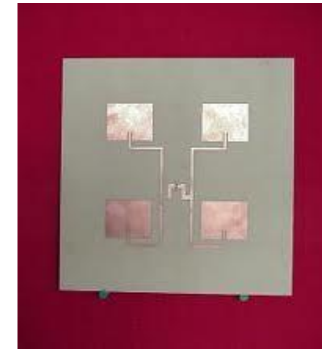




* Balanis, Constantine A. *Antenna Theory: Analysis and Design*. Hoboken, NJ: John Wiley, 2005.



Microstrip Antennas



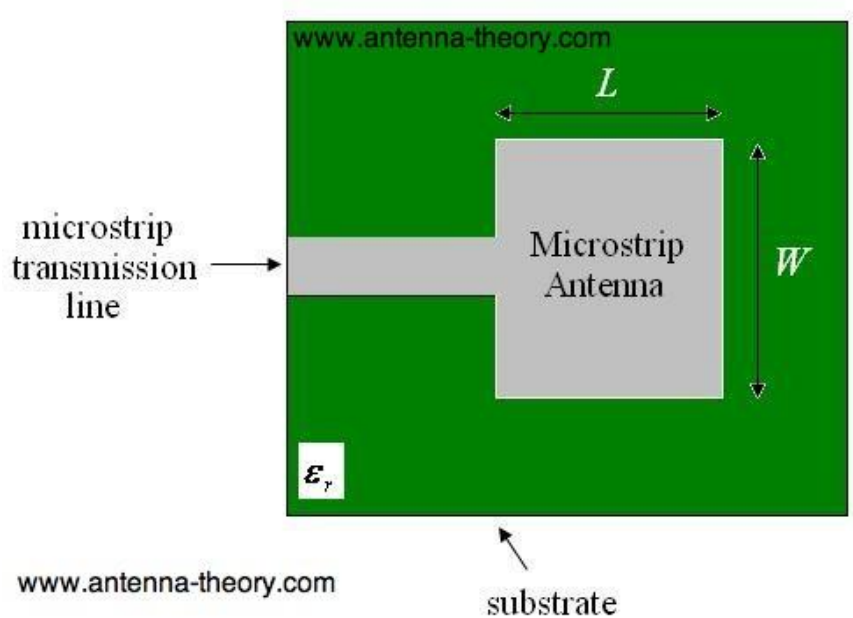
- With the microstrip antenna, $\lambda/2$ is a bit too big for consumer mobile devices
- Typically for space and military applications
- Easy to design/manufacture, yet very capable
  - Good value, great for antenna arrays
- Scale is better for millimeter wave RF (60+ GHz)

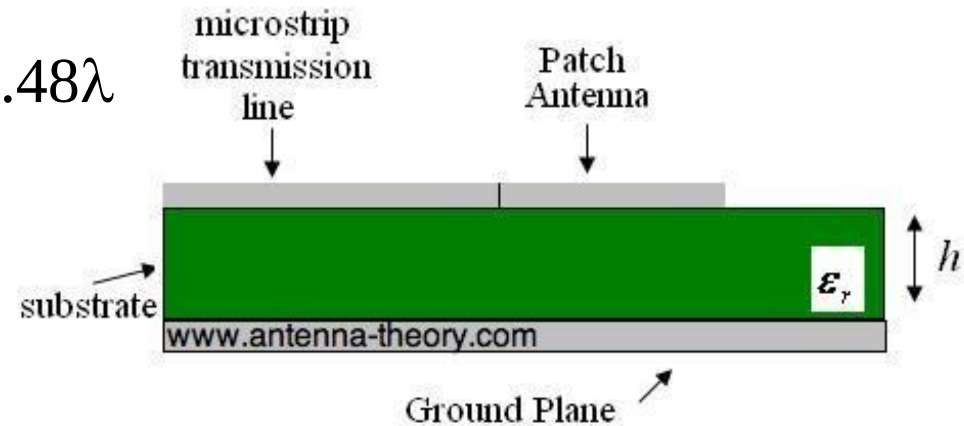
Design Methodology

- Find a “comfortable” model
  - Transmission Line – easiest, can be done in Excel
  - Cavity – higher accuracy, higher complexity
  - Full Wave – very accurate/adaptable, super complex
- Using specifications, generate initial design
  - Resonance frequency, gain, substrate, footprint, etc.
- Compare with an EM solver
  - Tune parameters such as ε_{reff} and ΔL (more details soon)
- Re-iterate design, prototype, measure
- Finalize design for manufacturing

Design Guidelines

- For microstrip antennas, a good 1st step is to assume a standard substrate
  - like Rogers RT/duroid 5880
- Importance of ε_r, h
- To avoid cross polarization, keep 1 < W/L <1.5
- Rule of $\lambda/2$ versus $\sim 0.48\lambda$





Santa Clara University

Footprint-Generating Equations

An initial guess at the patch width:

$$[1] \quad W = \frac{c_o}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}}, c_o \textit{ is speed of light}$$

Find effective parameters:

$$[2] \quad \epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}, W/_h > 1$$

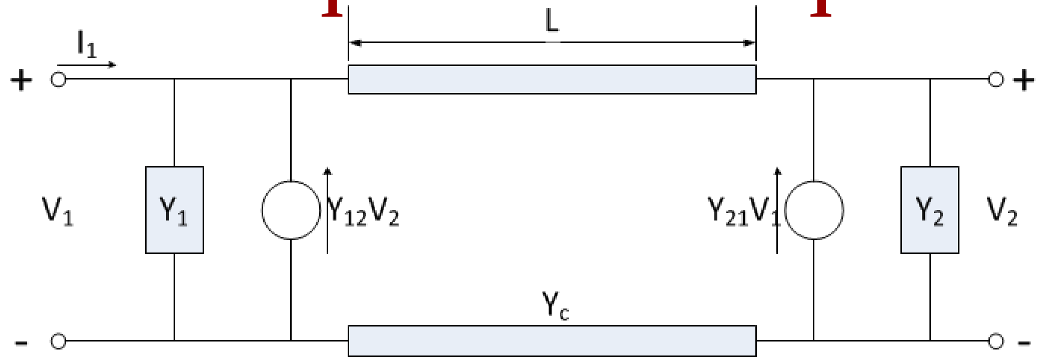
$$[3] \quad \frac{\Delta L}{h} = 0.412\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

Get patch length:

$$[4] \quad L = \frac{c_o}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L$$

* Balanis, Constantine A. *Antenna Theory: Analysis and Design*. Hoboken, NJ: John Wiley, 2005.

Circuit Equivalent Equations



[5] $Y_1 = G_1 + jB_1, Y_2 = G_2 + jB_2$

[6] $G_1 = \frac{W}{120\lambda_o}\left[1 - \frac{1}{24}(k_o h)^2\right], k_o = {}^{2\pi}/_{\lambda_o}$

[7] $B_1 = \frac{W}{120\lambda_o}[1 - 0.636\ln(k_o h)]$

[8] $G_2 = G_1, B_2 = B_1$

Via admittance transfer function:

[9] $\widetilde{Y_2} = \widetilde{G_2} + j\widetilde{B_2} = G_1 - jB_1$

[10] $Y_{in} = Y_1 + \widetilde{Y_2} = 2G_1$

[11] $Z_{in} = \frac{1}{Y_{in}} = R_{in}$

For this discussion we will ignore mutual effects

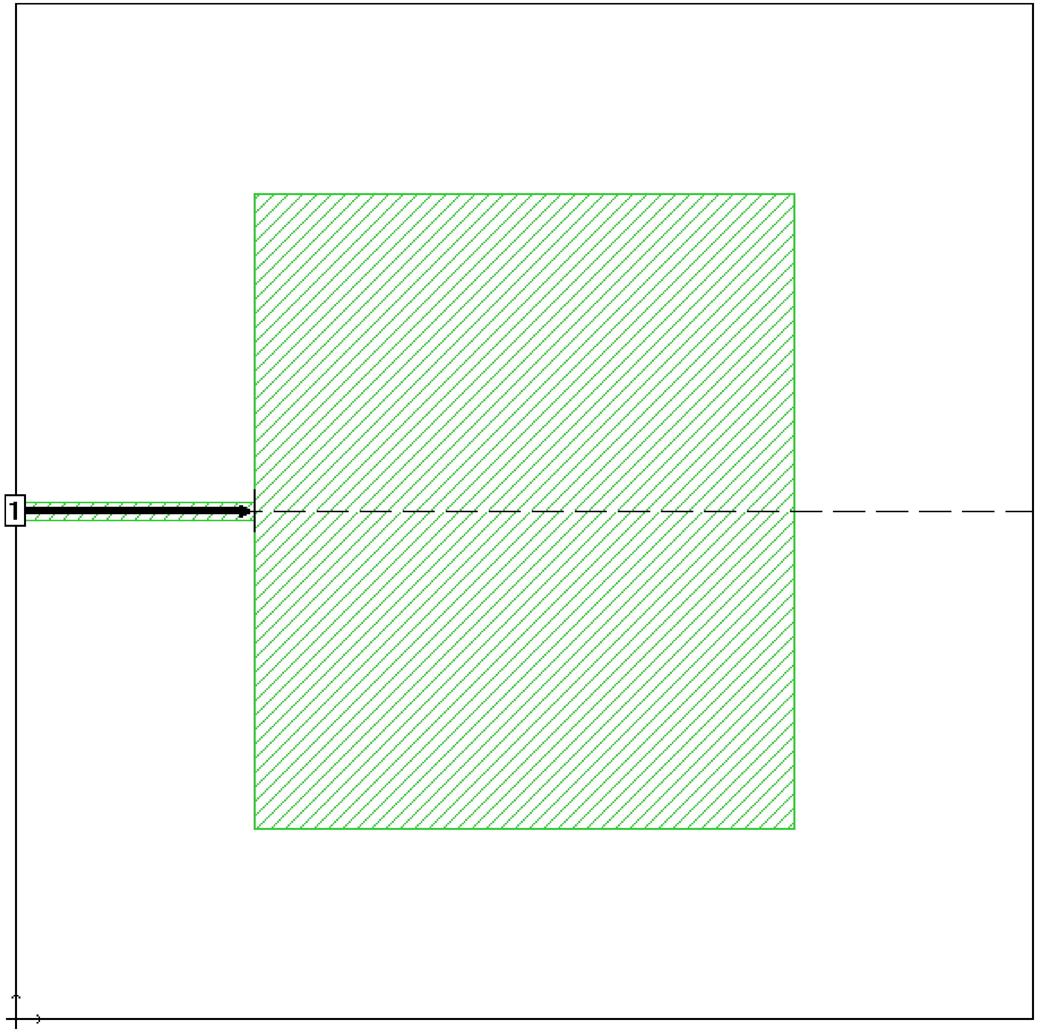
Quick Example

- Rogers RT/duroid 5880 chosen:
  - h=0.508mm, 100mm x 100mm board, ε_r=2.2
- Want an antenna for GSM, f_r=1.9GHz
- Use equations in Microsoft Excel
  - W=6.24cm, L=5.30cm, Z_{in}=151.8Ω
  - Feed set to be 50Ω (standard): W_o=1.6mm
- Confirm antenna using an EM solver
  - Sonnet yields Z_{in}=209.7Ω at 1.88GHz

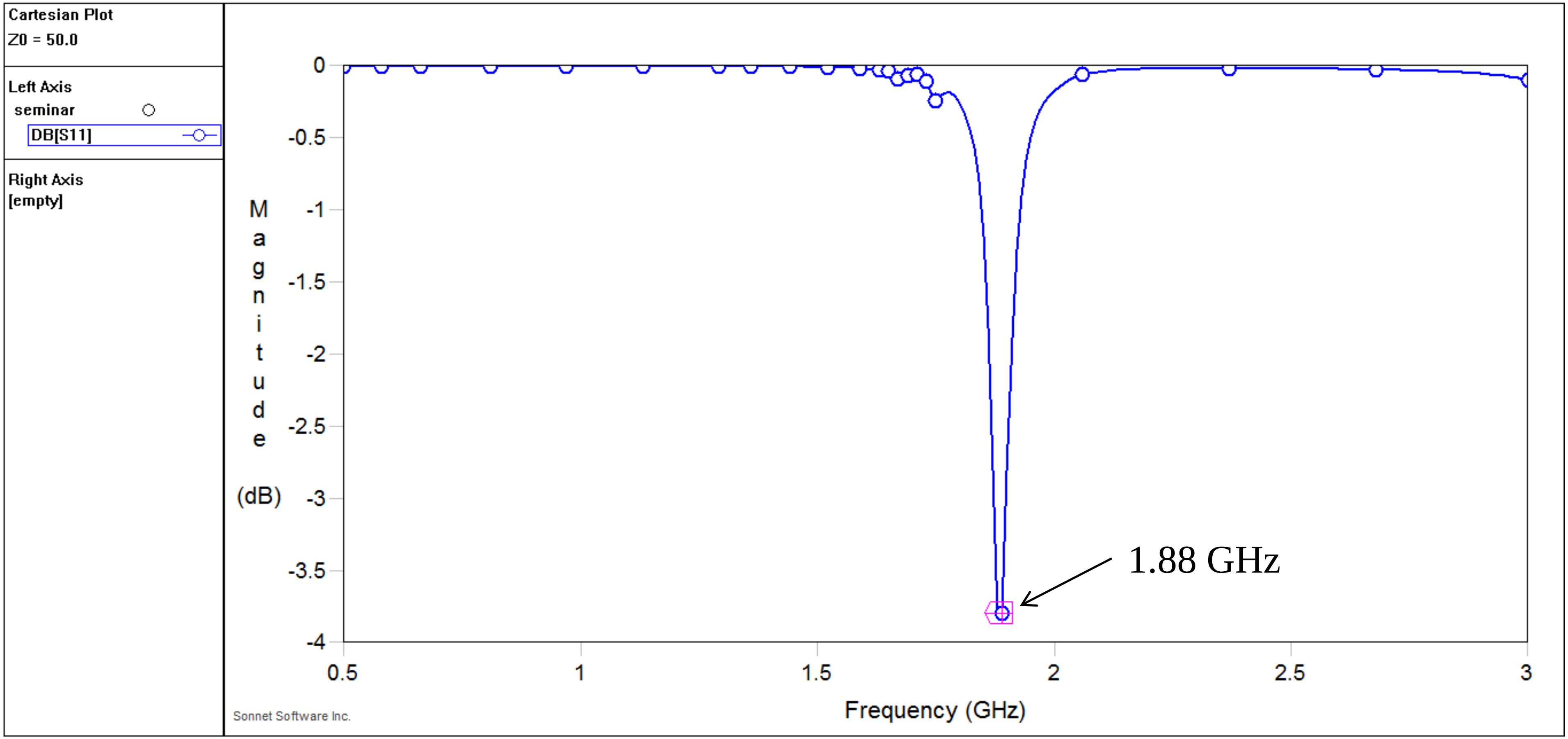
Equations Implemented in Excel

er	2.2		
h	0.000508	m	
co	299792458	m/s	
fr	1.900E+09	Hz	
lo	1.578E-01	m	
ko	39.821055	rad/m	
W	0.0624	m	
ereff	2.1727		
DL	0.0003	m	
L	0.0530	m	
Le	0.0535	m	
G	0.0033		
B	0.0115		
Yin	0.0066		
Zin	151.8	Ohms	
Wo	0.00158	m	
ereff2	1.8721		
Zc	50.00	Ohms	
Gamma	0.504438	-2.97192	dB
VSWR	3.0358218		

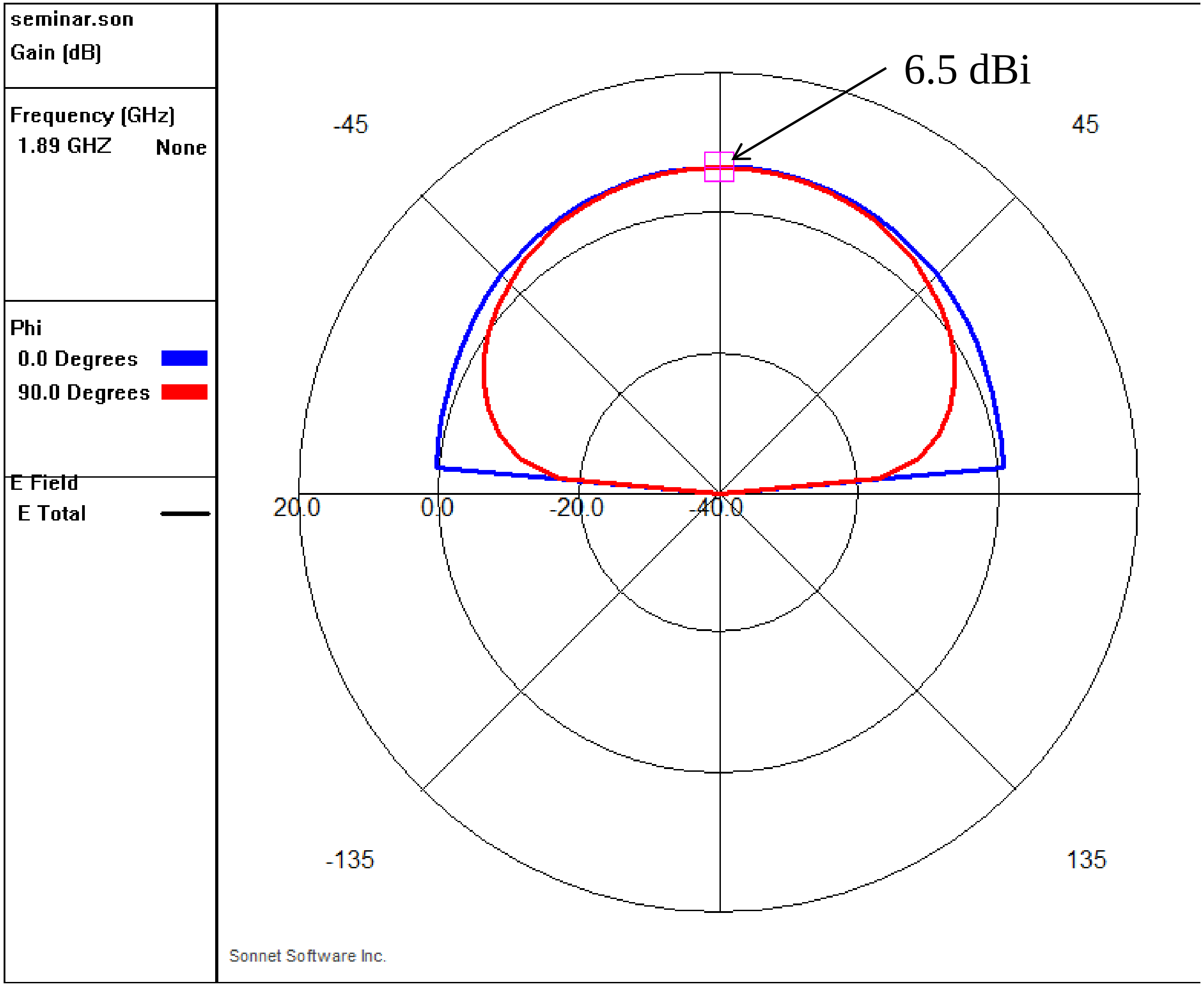
Sonnet Implementation



Sonnet S11 Response



Sonnet Radiation Patterns



A Few EM Solvers

SONNET *

AWR Microwave Office (AXIEM)*

ANSYS HFSS*

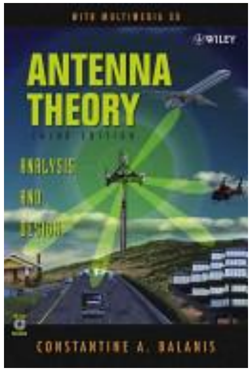
Agilent Technologies ADS*

FEKO
Comprehensive Electromagnetic Solutions

* SCU Design Center

Some Good References

- Antenna Theory – Constantine Balanis
  - Used for Antennas I (ELEN 715)



- Microstrip Antenna Design Handbook – Garg et al
  - Title says it all, but a few inaccuracies have been found

- Antenna Theory and Microstrip Antennas – D.G. Fang

- www.antenna-theory.com

PhD Work-to-date

- Focus on tunable antennas
  - Add impedance elements to electrically change the characteristics of the antenna (Z_{in}, E field)
- 60 GHz on-chip tunable antennas and array
  - Adaptive field patterns tuned by IMPATT diodes
- Mantenna
  - Wearable antenna array operating at 50-500 MHz
  - Direction finding for military applications
- 77 GHz system optimization
  - Extending Prof. Al-Attar's monolithic transmitter work

Future Efforts

- Gain full theoretical control of the antenna
  - Change bandwidth, f_r, E field/directivity at will
  - Use a range of IMPATT locations and values
- Investigate adaptive array pattern control
  - Optimize via array geometry
- OTA for PhD completion
  - Develop a test system, work with industry
    - RF tx/rx chains plus control

Questions?

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