Microstrip Patch Antenna Design Principles

Ben Horwath
Outline

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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)

• 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

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

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

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 $\varepsilon_{\text{reff}}$ and $\Delta L$ (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 $\varepsilon_r$, $h$
- To avoid cross polarization, keep $1 < W/L < 1.5$
- Rule of $\lambda/2$ versus $\sim 0.48\lambda$
Footprint-Generating Equations

An initial guess at the patch width:

\[ W = \frac{c_o}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}, \text{ } c_o \text{ is speed of light} \]  

Find effective parameters:

\[ \varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-1/2}, W/h > 1 \]

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

Get patch length:

\[ L = \frac{c_o}{2f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \]

Circuit Equivalent Equations

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

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

Via admittance transfer function:

\[ \tilde{Y}_2 = \tilde{G}_2 + j\tilde{B}_2 = G_1 - jB_1 \]

\[ Y_{in} = Y_1 + \tilde{Y}_2 = 2G_1 \]

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

For this discussion
we will ignore
mutual effects
Quick Example

• Rogers RT/duroid 5880 chosen:
  – h=0.508mm, 100mm x 100mm board, \( \varepsilon_r=2.2 \)
• Want an antenna for GSM, \( f_r=1.9\text{GHz} \)
• Use equations in Microsoft Excel
  – \( W=6.24\text{cm}, L=5.30\text{cm}, Z_{\text{in}}=151.8\Omega \)
  – Feed set to be 50\( \Omega \) (standard): \( W_0=1.6\text{mm} \)
• Confirm antenna using an EM solver
  – Sonnet yields \( Z_{\text{in}}=209.7\Omega \) at 1.88GHz
Equations Implemented in Excel

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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<tbody>
<tr>
<td>er</td>
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<tr>
<td>h</td>
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<tr>
<td>co</td>
<td>299792458 m/s</td>
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<tr>
<td>fr</td>
<td>1.900E+09 Hz</td>
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<tr>
<td>lo</td>
<td>1.578E-01 m</td>
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<tr>
<td>ko</td>
<td>39.821055 rad/m</td>
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<tr>
<td>ereff</td>
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<td>DL</td>
<td>0.0003 m</td>
</tr>
<tr>
<td>L</td>
<td>0.0530 m</td>
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<tr>
<td>Le</td>
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<tr>
<td>G</td>
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<tr>
<td>B</td>
<td>0.0115</td>
</tr>
<tr>
<td>Yin</td>
<td>0.0066</td>
</tr>
<tr>
<td>Zin</td>
<td>151.8 Ohms</td>
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<tr>
<td>Wo</td>
<td>0.00158 m</td>
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<tr>
<td>ereff2</td>
<td>1.8721</td>
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<tr>
<td>Zc</td>
<td>50.00 Ohms</td>
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<tr>
<td>Gamma</td>
<td>0.504438 -2.97192 dB</td>
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<tr>
<td>VSWR</td>
<td>3.0358218</td>
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Sonnet Implementation
Sonnet S11 Response

1.88 GHz
## Sonnet Radiation Patterns

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Gain [dBi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.89 GHz</td>
<td>None</td>
</tr>
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</table>

### Table of Parameters

- **Frequency [GHz]**: 1.89 GHz
- **Gain [dBi]**: None

### Diagram Details

- **Gain**: 6.5 dBi
- **Orientation**:
  - **Phi**: 0.0 Degrees (Blue)
  - **Phi**: 90.0 Degrees (Red)

### Logo and Affiliation

- **SCU Center for Analog Design and Research**
- **Santa Clara University**
A Few EM Solvers

- Microwave Office (AXIEM)*
- HFSS*
- Agilent Technologies ADS*
- SCU Design Center

SCU Center for Analog Design and Research
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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