Master Thesis

Development of a Broadband Circular Polarised Antenna for Over-The-Air Performance Test Applications

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Outline

• Motivation
• Introduction
• Frequency Independent Antenna
• Planar Spiral Antenna
• Simulation Results
• Measurement Results
• Conclusion
• Future Work
Motivation

- Over The Air (OTA) Test
  - Characterize the air interference of a mobile device.
  - Need a measurement system that can collect data on a spherical surface enclosing the DUT.

- Broadband antenna
  - GSM, UMTS & Higher order modes

- Circular Polarized
  - Planar Spiral Antenna
  - Conical Spiral Antenna
  - Cross Log-periodic Antenna
  - Unknown DUT Polarization
  - Balance feeding
  - Unidirectional pattern
Introduction

• Frequency Independent Antenna
  The antenna characteristics are invariant to change of the physical size of antenna.

• Frequency Independent Antenna Principles:
  • Angle principle
  • Truncation principle
  • Periodic principle

• Self-Complementary Structure

\[
Z_1 Z_2 = \left( \frac{Z}{2} \right)^2 = 188.5^2 \Omega
\]
<table>
<thead>
<tr>
<th>Selection Process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower Frequency Limit</strong></td>
</tr>
<tr>
<td><strong>Higher Frequency Limit</strong></td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
</tr>
<tr>
<td><strong>Power handling</strong></td>
</tr>
<tr>
<td><strong>BW limit</strong></td>
</tr>
</tbody>
</table>
## Selection Process (Cont.)

<table>
<thead>
<tr>
<th></th>
<th>Planner Spiral</th>
<th>Conical Spiral</th>
<th>Cross Log Periodic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Balun</strong></td>
<td>Balanced need Balun</td>
<td>Balanced need Balun</td>
<td>Balanced need Balun</td>
</tr>
<tr>
<td><strong>Feeding Circuit</strong></td>
<td>Simple feeding</td>
<td>Simple feeding</td>
<td>If the element is well aligned no need for hybrid.</td>
</tr>
<tr>
<td><strong>Phase center</strong></td>
<td>Stable</td>
<td>Change with Frequency</td>
<td>Change with Frequency</td>
</tr>
<tr>
<td><strong>Gain over the total BW</strong></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>Need cavity for unidirectional</td>
<td>Unidirectional</td>
<td>Unidirectional</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>Light</td>
<td>Medium</td>
<td>Heavy</td>
</tr>
<tr>
<td><strong>Reproducibility</strong></td>
<td>Easy</td>
<td>Medium</td>
<td>Complicate</td>
</tr>
<tr>
<td><strong>Ranked</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Planar Spiral

Archimedean Spiral

Self-Complementary when
\( \delta = \pi / 2 \)

\[ s = w = \frac{r_1 - r_0}{4N} \]

\[ a = \frac{s + w}{\pi} = \frac{2\nu}{\pi} \]

First Arm

\[ r_1 = r_0 (1 + a\phi) \]
\[ r_2 = r_0 (1 + a(\phi - \delta)) \]

Second Arm

\[ r_3 = r_0 (1 + a(\phi - \pi)) \]
\[ r_4 = r_0 (1 + a(\phi - \pi - \delta)) \]

How Radiation happen

\[ L_{QP'} = \pi r = \lambda / 2 \]

Under Antiphase feeding at points A and B
Radiation happen when

\[ 2\pi r = \lambda \]
Circular Polarized Radiation

Circumference = \lambda

|I_x| \approx |I_y| \& I_x \perp I_y

I_x, I_y 90° phase different

RHCP Rule

RHCP OR LHCP depend on Rotation sense

Arafat
Jan 2008

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Spiral Antenna System

Consist from 3 Units

- Feeding circuit (Balun)
- Archimedean Spiral PCB
- Absorber loaded Cavity
Feeding Circuit (Balun)

Balun will provide
- Balanced feeding
- Impedance transformation

Baluns type
- Linear Tapered Balun
- Infinite Balun
- Marchand balun
Balun Simulation and Measurement

Measurement and Simulation results for Single balun

Measurement and Simulation results for B2B balun
**Measurement Verification**

2 inner connectors soldered to balance side of Balun

50 Ohm broadband match lead

**Symmetry**

\[ S_{11} = S_{22}, S_{21} = S_{12} \quad \text{Symmetry} \]

\[ a_1 = -a_2 \quad \text{Balanced feed} \]

\[ \Gamma = S_{11} - S_{21} \]

\[ Z_{in} = 2Z_0 \frac{1 + \Gamma}{1 - \Gamma} = 100 \frac{1 + S_{11} - S_{21}}{1 - S_{11} + S_{21}} \]
Antenna Parameters and Simulation

1: Spiral rate of growth (a)

Improved in AR for tight spiral growth of rate (small value of a)

2: Conductor spacing (w)

Self-Complementary or No Self-Complementary control the impedance of antenna

3: Feed structure

\[ r_0 = w \] will provide flat resistance and close to zero reactance

4: Spiral diameter

\[ D_{\text{max}} > \lambda / \pi \]

Activate High order modes
Pattern distortion

\[ D_{\text{max}} < \lambda / \pi \]

Reduced Gain
Increased AR
3D Far-Field pattern Simulation

RHCP far field radiation pattern (Simulation)
Current Distribution Simulation

800 MHz

Current Density Distribution (Simulation)

Active Region Concept
Antenna Measurement

Return losses better than 15 dB

Antenna impedance using two ports measurement.

<table>
<thead>
<tr>
<th></th>
<th>SP5</th>
<th>SP6</th>
<th>SP7</th>
<th>SP8 LHCP</th>
<th>SP9 RHCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of turns</td>
<td>22</td>
<td>22</td>
<td>56</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Spiral rate (μm)</td>
<td>658</td>
<td>510</td>
<td>260</td>
<td>510</td>
<td></td>
</tr>
<tr>
<td>Arm width (μm)</td>
<td>1000</td>
<td>800</td>
<td>410</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Outer Radius (cm)</td>
<td>9.1</td>
<td>7.1</td>
<td>9.1</td>
<td>9.1</td>
<td></td>
</tr>
</tbody>
</table>
Cavity

• Unloaded cavity
  • When high gain need
  • Narrow bandwidth

• Absorber loaded cavity
  • Gain reduction not critical
  • Wide bandwidth

• Cavity Dimension
  • Depth $\lambda/4$ at lower frequency
  • Diameter 1.05 spiral diameter

• Absorber material

\[
\mu_r = \mu'_r - j \mu''_r = \varepsilon_r = \varepsilon'_r - j \varepsilon''_r
\]

\[
Z = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \sqrt{\frac{\mu_r}{\varepsilon_r}} = 377 \sqrt{\frac{\mu_r}{\varepsilon_r}} = 377 \Omega
\]
Antenna Measurement In Anechoic Chamber

Gain Measurement
- Gain Transfer method

L/H/W = 12/5.5/8 m

From 0.4 up to 64 GHz

Polarization Measurement
- Polarization Pattern Method

1
H
2
V
Sp5 and Sp7 Measurement Results

Axial Ratio

Gain

Sp5

Gain [dB]

Sp7

Gain [dB]

Gain \{\phi, \theta = 90^\circ\}
Measurement with Cavity

Empty & loaded Cavity

Diff. Absorber length
Measurement with Resistance Termination

Termination improved
Low Frequency range

Axial Ratio With and Without Impedance Termination
Far-Field Measurement For Final Version

\[ G \left\{ \phi, \theta = 90^\circ \right\} \]

- **RHCP**
- **LHCP**

Azimuth [deg]

Gain [dBi]
Cross-Polarization better than 20dB

Omnidirectional pattern in the spiral plane
3D Far-Field Radiation Pattern Measurement

RHCP far field radiation pattern (Measurement)
Conclusion

- RHCP antenna worked (0.6 < f/GHz < 13)
- Two arms Archimedean spiral antenna was shown many desirable characteristic.
- Microstrip tapered balun provides a balance feeding and impedance transformation
- An unidirectional pattern achieved using absorber loaded cavity.
- The numerical results were confirmed by measurements.
- As a result the developed antenna worked well for OTA measurement test.
Future Work

- Reduce the spiral size using slow wave techniques or absorber painting at the open end of spiral.
- Improve and reduce balun size.
- Decrease the cavity depth by thinner absorber loading.
- Benefit of the new MetaFerrite material for reducing the antenna size.
Thank You for Your Attention