Cable for Wireless Power Transmission in Transportation Applications

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Overview

• Introduction
• Component Design
• System Results
• Conclusions
Introduction

- Objective
  - Provide selective coverage throughout a corridor
  - Aeronautical applications (airplanes, subways, tunnels..)
  - Ensure the uniform power coverage at the tag

- Motivation
  - RFID tags working at microwaves frequencies
  - Evolve cable system towards wireless systems
Why WPT and Communications

• Wireless power transmission and communication by RFID principles

• Transmits the identity of objects

• Useful for so many fields (distribution, medicine, environment..)

• System based in the communication between a reader and a tag
Why WPT and Communications

- Reader interrogates the tag through an EM wave.
- Tag responds by modulating the backscattered signal with its unique ID.
- The reader decodes the ID from the tag.
- Detected information is provided to the host computer.
System Polarization

- Significant difference between circular and linear polarization in a RFID system

- Linear polarized (LP) reader antennas:
  - Known RFID tag orientation
  - Tag at the same plane and about the same height

- Circular polarized (CP) reader antennas:
  - Unknown or inconsistent tag orientation
  - No matter the location of the tag inside the read range
  - High losses
State Of The Art

• Dual-Band circularly polarized Microstrip RFID Reader Antenna [1]
  • Using metamaterial branch-line coupler
  • Antenna Gain of 7.9 dBi
  • Ideal for UHF and ISM bands

State Of The Art

- Size reduction of a circularly polarized square microstrip patch for RFID applications [2]
  - Reduction of 43.05% in patch length achieved
  - 67.56% in area compared to conventional design
  - Gain smaller than conventional one (6.6 dBi compared to 7 dBi)

State Of The Art

- Broadband passive tag for Near-field applications [3]
  - Minimizes the influence of human body, liquids or metals without sacrificing read range and universal UHF RFID band interoperability
  - Broadening reached with slots in the top of the metallization

This Work: Possible Antenna Modules

Configuration #1

Configuration #2
System Design

- Frequency: 2.45 GHz
- Total coverage of the system: 16 m x 2.5 m
- Smart cable length: 14.4 m
- Patch coverage: 3.2 m
- Substrate:
  - FR-4
  - Height: 1.6 mm
Hotspot Design

- Inset fed patch antennas for all hotspots
- Switches to control power flow instead of Wilkinson power dividers
- Branch line couplers as feeders
  - Low losses
  - Easy control of the power split ratio
- Improved system efficiency with Configuration #2.
Hotspot Design: Branch-Line Couplers

- Power entering input port is divided between the two output ports
- Minimal power is coupled to the isolated port
- Unequal Split Ratio
  - Varying the impedance of each pair of arms

\[
Z_{OA} = Z_0 \cdot \left(\frac{P_A}{P_B} / (1 + (P_A/P_B))\right)^{0.5}
\]
\[
Z_{OB} = Z_0 \cdot (P_A/P_B)^{0.5}
\]
Hotspot Design (HS): Branch-Line Couplers

• Theoretical power levels:

<table>
<thead>
<tr>
<th>HS</th>
<th>Power Diverted to the Antenna</th>
<th>Power Passing to the Next HS</th>
<th>Power Level on the Antenna (dB)</th>
<th>Power Level on the Output (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20%</td>
<td>80%</td>
<td>-6.99</td>
<td>-0.99</td>
</tr>
<tr>
<td>2</td>
<td>25%</td>
<td>75%</td>
<td>-6.02</td>
<td>-1.24</td>
</tr>
<tr>
<td>3</td>
<td>33%</td>
<td>66.7%</td>
<td>-4.78</td>
<td>-1.76</td>
</tr>
<tr>
<td>4</td>
<td>50%</td>
<td>50%</td>
<td>-3.01</td>
<td>-3.01</td>
</tr>
<tr>
<td>5</td>
<td>100%</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
Hotspot Design: Branch-Line Couplers
Hotspot Design: Branch-Line Couplers
Hotspot Design: Branch-Line Couplers

![Hotspot 3 S Parameters](image)

- Frequency (GHz)
- Magnitude (dB)
- S11 simulated
- S21 simulated
- S31 simulated
- S11 measured
- S21 measured
- S31 measured

-3.32 dB
Hotspot Design: Branch-Line Couplers

![Graph showing S-parameters with frequency and magnitude axes. The graph includes lines for S11 simulated, S21 simulated, S31 simulated, S11 measured, S21 measured, and S31 measured. There is a peak at 2.4 GHz with a magnitude of -4.49 dB.](image-url)
Hotspot Design: MEMS Switches

- Analog Devices
- 0.28 IL
- Complicated design
- Lack of equipment (in-house) for building and soldering
Hotspot Design: Switches

- SKYA21001
- 20 MHz to 3 GHz
- 0.4 dB IL
- Ease of design
Hotspot Design: Switches
Hotspot Design: Final Prototypes
System Results: Hotspot 2
System Results: Hotspot 2

[Graph showing Hotspot Gain with frequency on the x-axis and magnitude on the y-axis, comparing measured hotspot gain with and without case, and passive patch gain.]
## Comparison of all Results for Hotspot 2

| Element               | |S21| Expected | |S21| Measured | Losses Measured |
|-----------------------|-----------------|-----------------|-----------------|
| Branch-Line           | -2.74 dB        | Not fabricated  | Not fabricated  |
| Passive Hotspot       | - 2.74 dB       | - 2.82 dB       | 1.58 dB         |
| Test Circuit          | - 1.26 dB       | -1.47 dB (Port 2 ON)/ -1.57 dB (Port 3 ON) | 0.21 dB(Port 2 ON)/ 0.31 dB(Port 3 ON) |
| Final Prototype       | - 5.26 dB (On case)/ - 2.36 dB (Off case) | -5.03 dB (On case)/ -2.8 dB (Off case) | 3.79 dB (On case)/ 2.8 dB (Off case) |
Power Budget Analysis

- Design for uniform power coverage
- First antennas must absorb a smaller fraction of power
- Free space loss at max. distance: -49.47 dB
- Worst case scenarios:
  - Only last element radiates
  - All elements are radiating
### System Analysis: Worst Case 1 (No Switches)

<table>
<thead>
<tr>
<th>Hotspot</th>
<th>Power Absorbed Configuration #1 (mw/dBm)</th>
<th>Power On System* Configuration #1 (mw/dBm)</th>
<th>Power Absorbed Configuration #2 (mw/dBm)</th>
<th>Power On System* Configuration #2 (mw/dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In</td>
<td>-</td>
<td>1000/30</td>
<td>-</td>
<td>1000/30</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>417.15/26.20</td>
<td>-</td>
<td>568.9/27.55</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>161.65/22.08</td>
<td>-</td>
<td>303.4/24.82</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>62.64/17.96</td>
<td>-</td>
<td>162.2/22.1</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>24.27/13.85</td>
<td>-</td>
<td>91.62/19.62</td>
</tr>
<tr>
<td>5</td>
<td>19.73/12.95</td>
<td>-</td>
<td>74.47/18.72</td>
<td>-</td>
</tr>
</tbody>
</table>

*After the hotspot (taking into account hotspot and coaxial losses).*
Power Budget Analysis – Worst Case 1

- Configuration #1 using Wilkinson PDs
- Power transferred to last antenna: 12.95 dBm
- Power radiated by last antenna: ~ 6.47 dBm
- Considering a tag with 0 dB Gain

Power received: -40 dBm
Power Budget Analysis – Worst Case 1

- Configuration #2 using branch line couplers
- Power transferred to last antenna: 18.72 dBm
- Power radiated by last antenna: ~ 9.36 dBm
- Considering a tag with 0 dB Gain

Power received: -37.35 dBm

😊
Power Budget Analysis – Worst Case 2

- Configuration #1 using Wilkinson PDs
- Power transferred to last antenna: 6 dBm
- Power radiated by last antenna: ~ 3 dBm
- Considering a tag with 0 dB Gain

Power received: -43.72 dBm
Power Budget Analysis – Worst Case 2

- Configuration #2 using branch line couplers
- Power transferred to last antenna: 14.42 dBm
- Power radiated by last antenna: ~ 7.21 dBm
- Considering a tag with 0 dB Gain

\[ \text{Power received: } -39.51 \text{ dBm} \]
Power Budget Analysis
Active Configuration #2 (Switches)

• Worst case 1 - only the last element radiates
  • Power transferred to the antenna: 14.02 dBm
  • Power radiated: 7.01 dBm
  • Power received: -42.46 dBm

• Worst case 2 - all elements radiate
  • Power transferred to the antenna: 3.03 dBm
  • Power radiated: 1.5 dBm
  • Power received: -47.97 dBm
Power Budget Analysis
Active Configuration #2 (Switches)

Only the last element radiates
Power Budget Analysis
Active Configuration #2 (Switches)

All elements radiate
Conclusions

- The design of each hotspot is essential for the efficient operation of the system.

- The minimum amount of power radiated in each hotspot must ensure adequate coverage along the floor.

- Necessary optimization for decreasing the losses inside the hotspot.

- Good application for the RFID and WPT applications.
Aknowledgement

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Thank you, any questions?