THALES

HERIOT WATT UNIVERSITY

ALMA MATER STUDIORUM A.D. 1088

Cable for Wireless Power Transmission in Transportation Applications

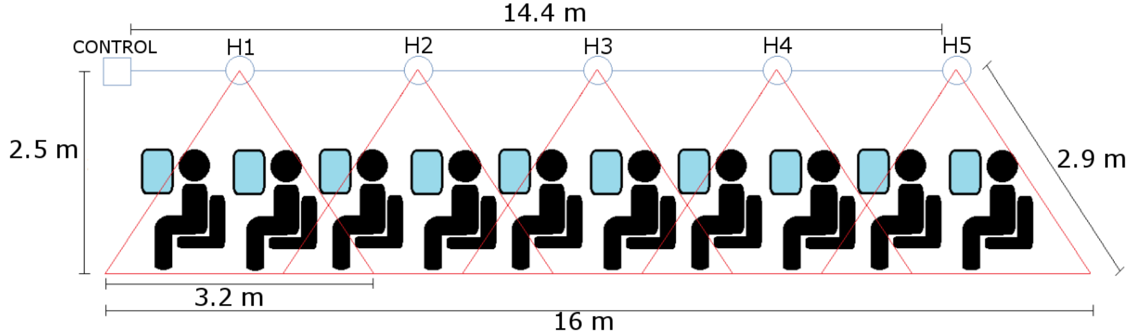
S. K. Podilchak, V. Buendía, G. Goussetis, A. Costanzo, P. Nicole

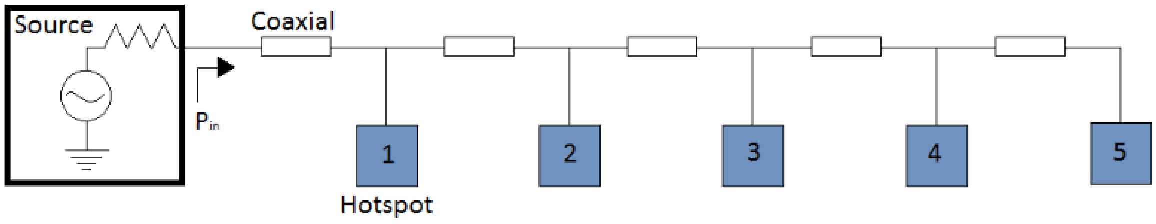
School of Engineering and Physical Sciences

Heriott-Watt University

Overview

- Introduction
- Component Design
- System Results
- Conclusions





Introduction

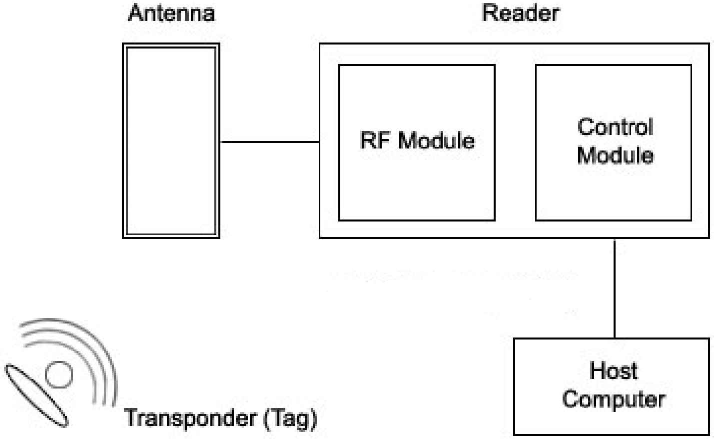
- Objective
  - Provide selective coverage throughout a corridor
  - Aeronautical applications (airplanes, subways, tunnels..)
  - Ensure the uniform power coverage at the tag
- Motivation
  - RFID tags working at microwaves frequencies
  - Evolve cable system towards wireless systems

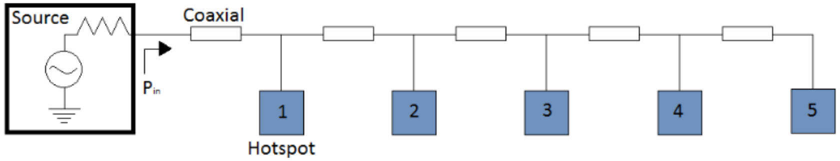
Why WPT and Communications

- 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





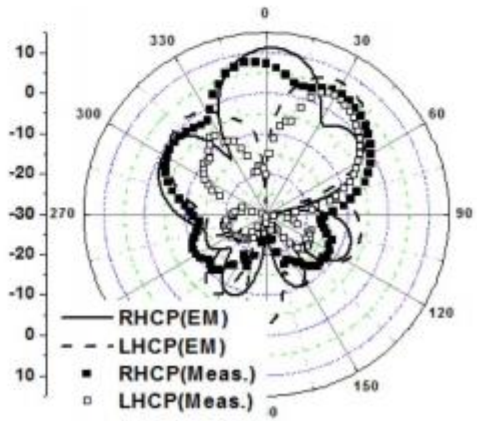
- Reader interrogates the tag through a EM wave
- Tag responds modulating backscattered signal with its unique ID
- The reader decodes the ID from the tag
- Detected information is provided to the host computer

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

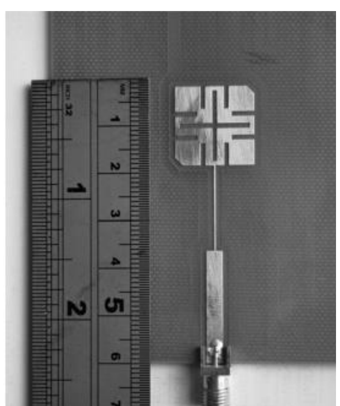
- Dual-Band circularly polarized Microstrip RFID Reader Antenna [1]
  - Using metamaterial branch-line coupler
  - Antenna Gain of 7.9 dBic
  - Ideal for UHF and ISM bands

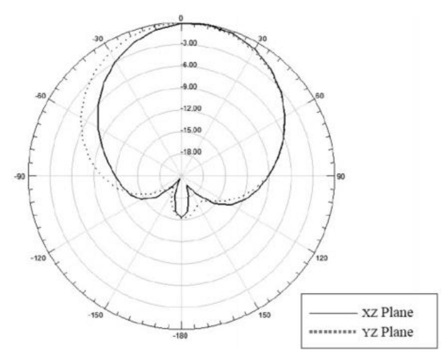


[1] Y. Jong, B. Lee, "Dual-Band Circularly Polarized Microstrip RFID Reader Antenna Using Metamaterial Branch-Line Coupler", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 60, NO. 2, FEBRUARY 2012

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)





[2] D.L. Nguyen, K.S Paulson, N.G. Riley, “Reduced-size circularly polarised square microstrip antenna for 2.45 GHz RFID applications”, IET Microw. Antennas Propag., 2012, Vol. 6, Iss. 1, pp. 94–99

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

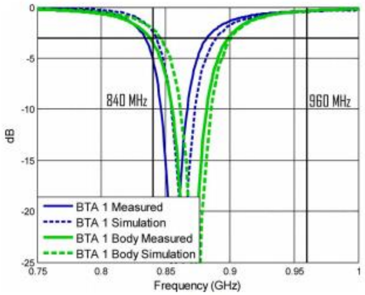
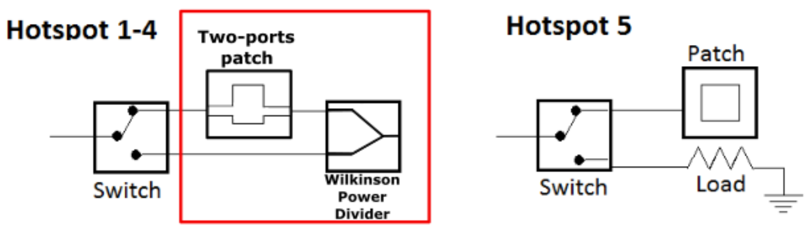


Fig. 5. Comparison of power reflection coefficient (measurements versus simulations) of BTA1 antenna for near-body and in free space (Air) conditions.

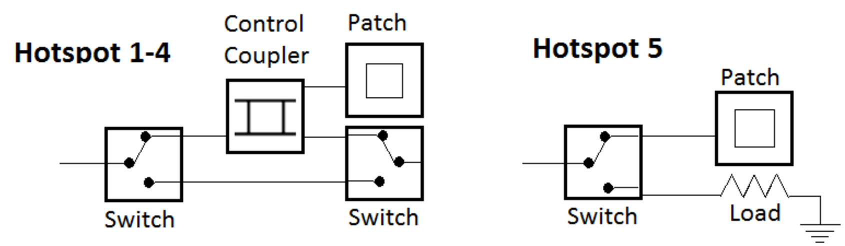
[3] A. Santiago, J. Costa, C. Fernandes, “Broadband UHF RFID Passive Tag Antenna for Near-Body Applications”, IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 12, 2013

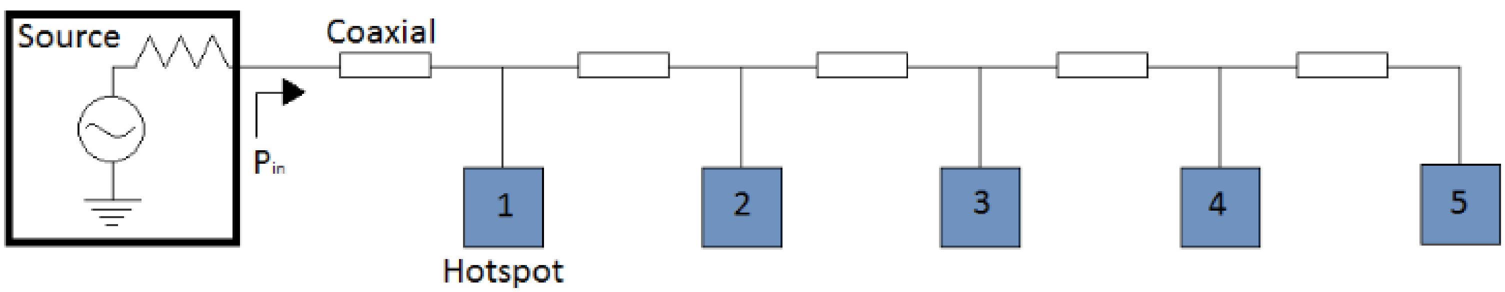
This Work: Possible Antenna Modules

Configuration #1



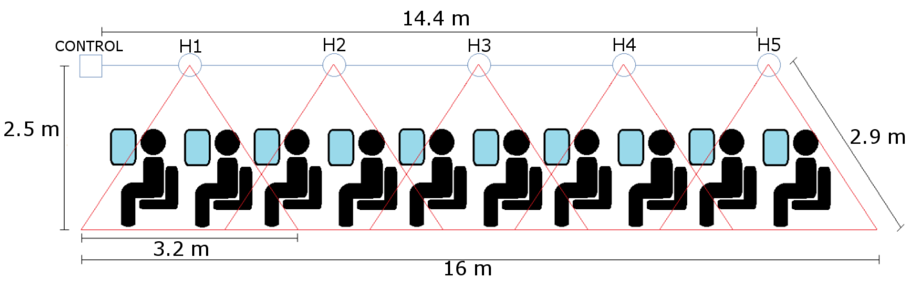
Configuration #2





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

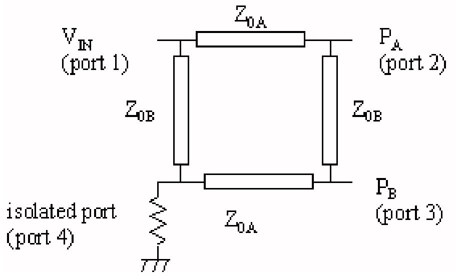


Hotspot Design

- 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



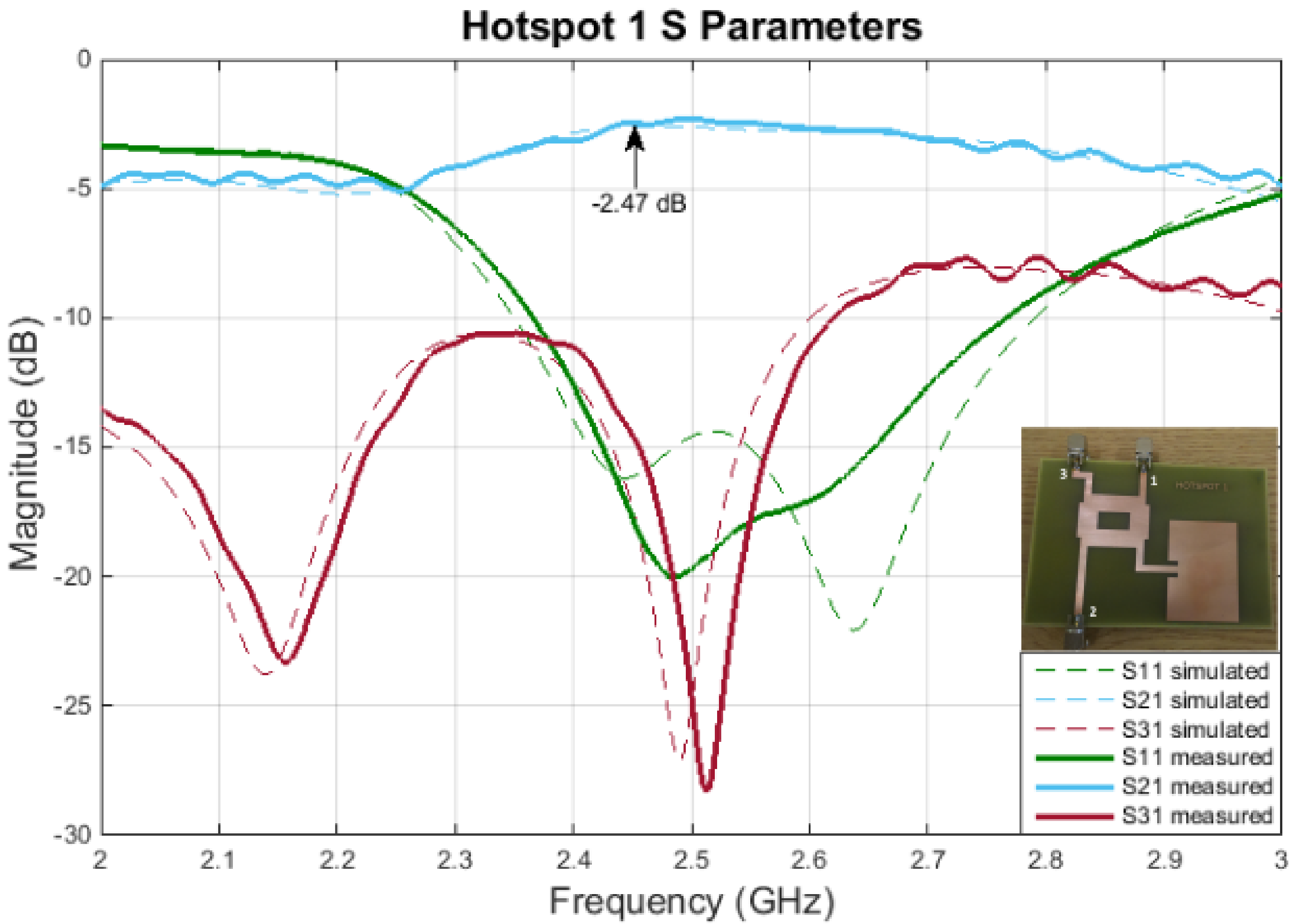
$$Z_{OA} = Z_O \cdot ((P_A/P_B)/(1 + (P_A/P_B)))^{0.5}$$
$$Z_{OB} = Z_O \cdot (P_A/P_B))^{0.5}$$

Hotspot Design (HS): Branch-Line Couplers

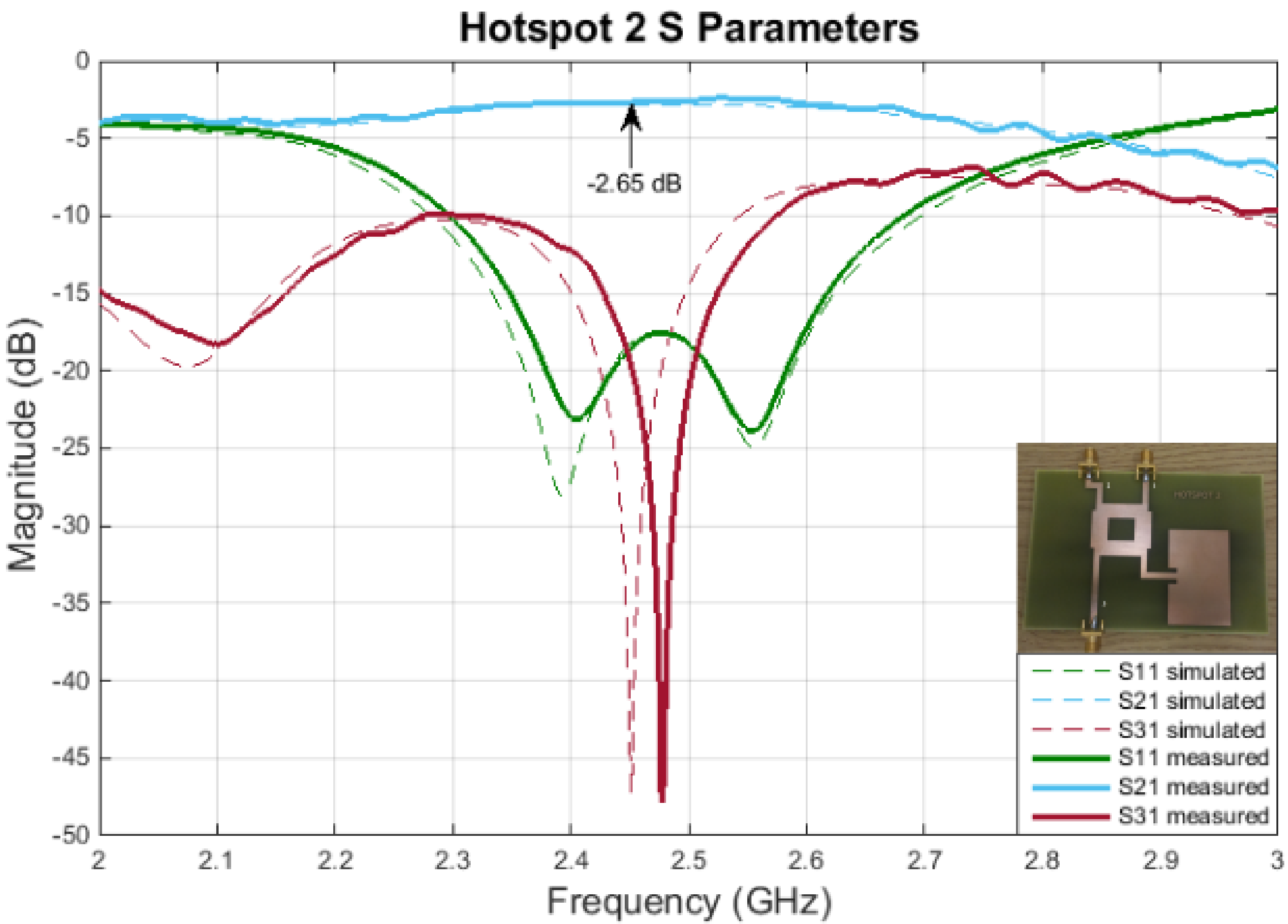
- Theoretical power levels:

HS	Power Diverted to the Antenna	Power Passing to the Next HS	Power Level on the Antenna (dB)	Power Level on the Output (dB)
1	20%	80%	-6.99	-0.99
2	25%	75%	-6.02	-1.24
3	33%	66.7%	-4.78	-1.76
4	50%	50%	-3.01	-3.01
5	100%	-	0	-

Hotspot Design: Branch-Line Couplers



Hotspot Design: Branch-Line Couplers



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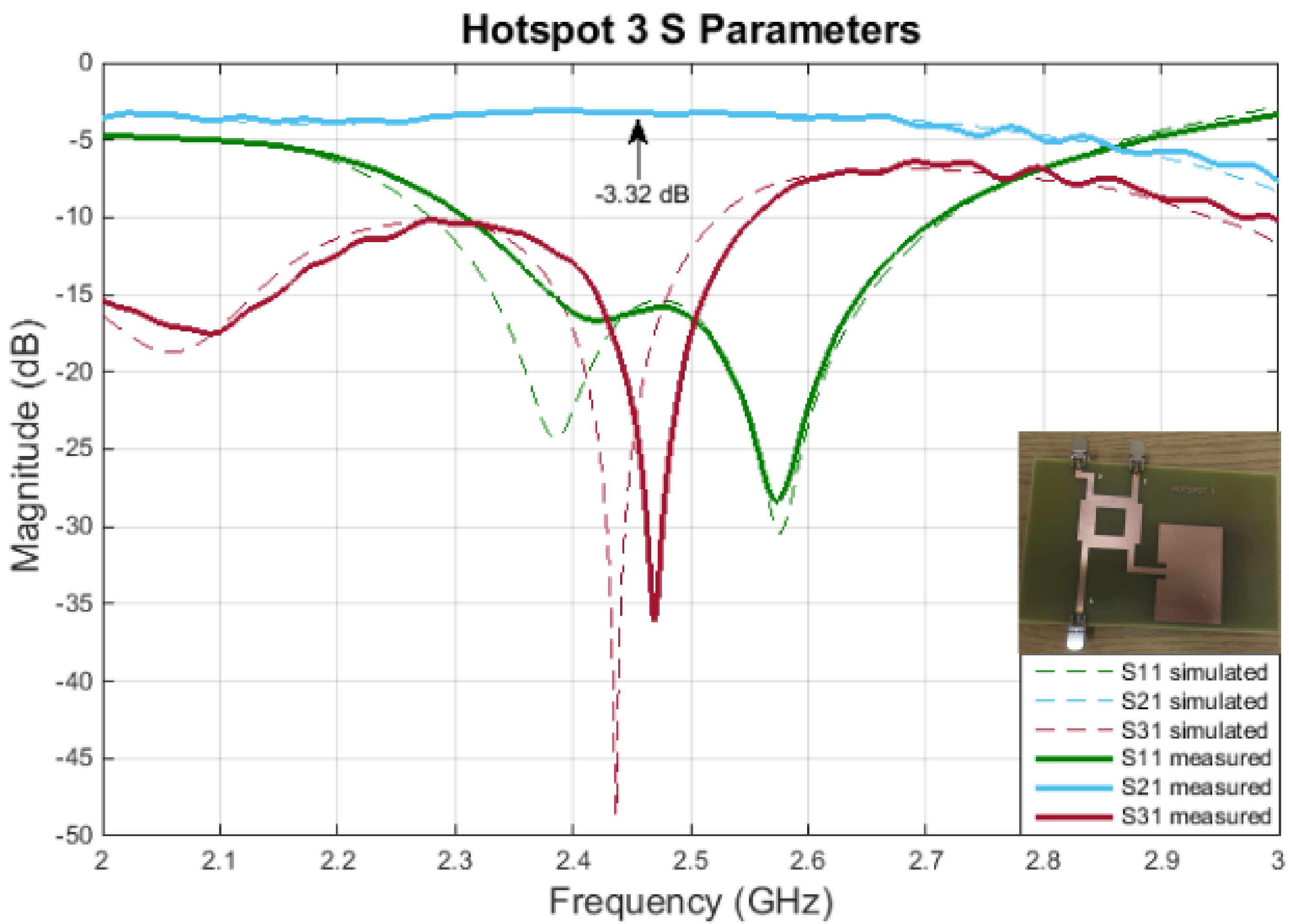
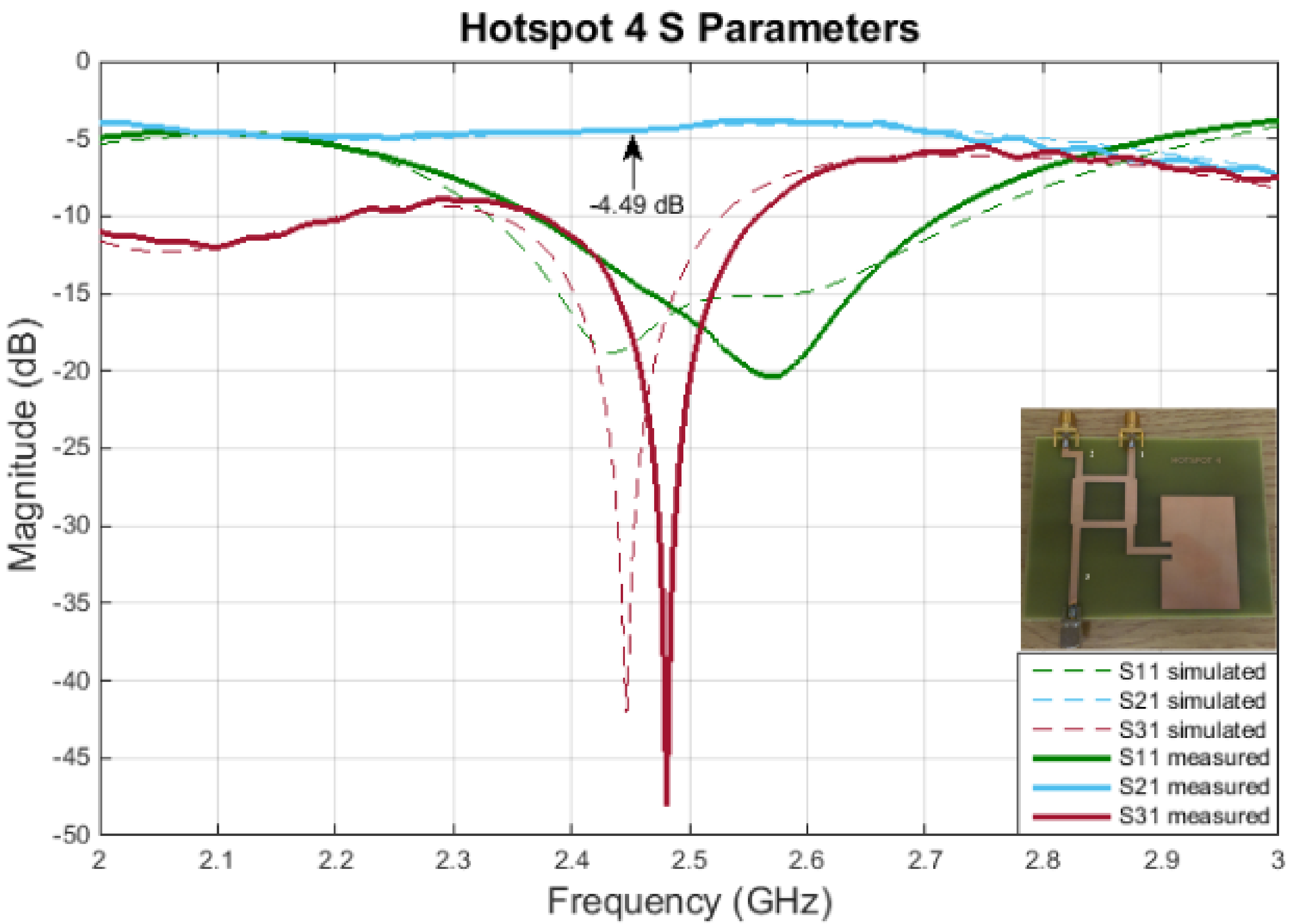


Hotspot Design: Branch-Line Couplers



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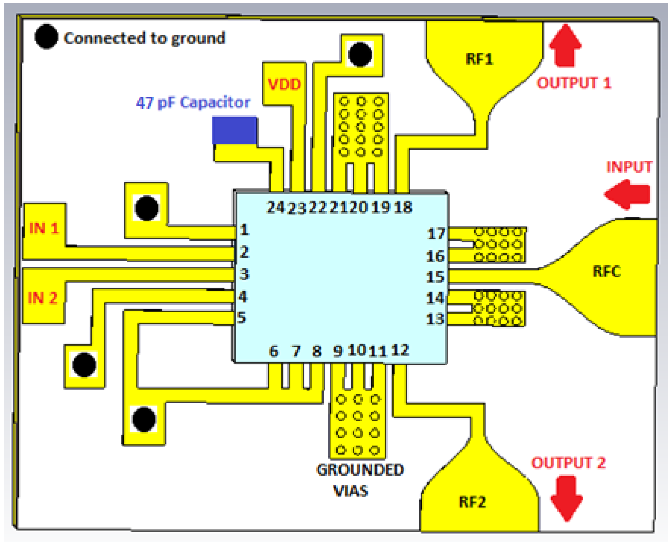
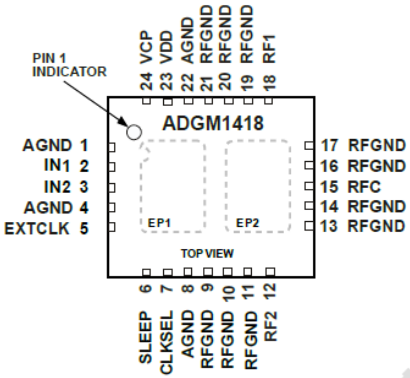
Hotspot Design: MEMS Switches

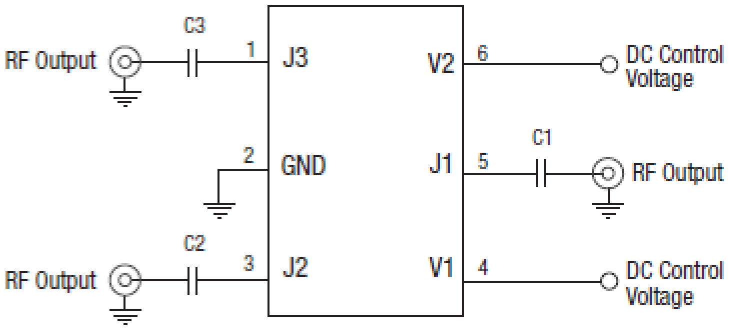




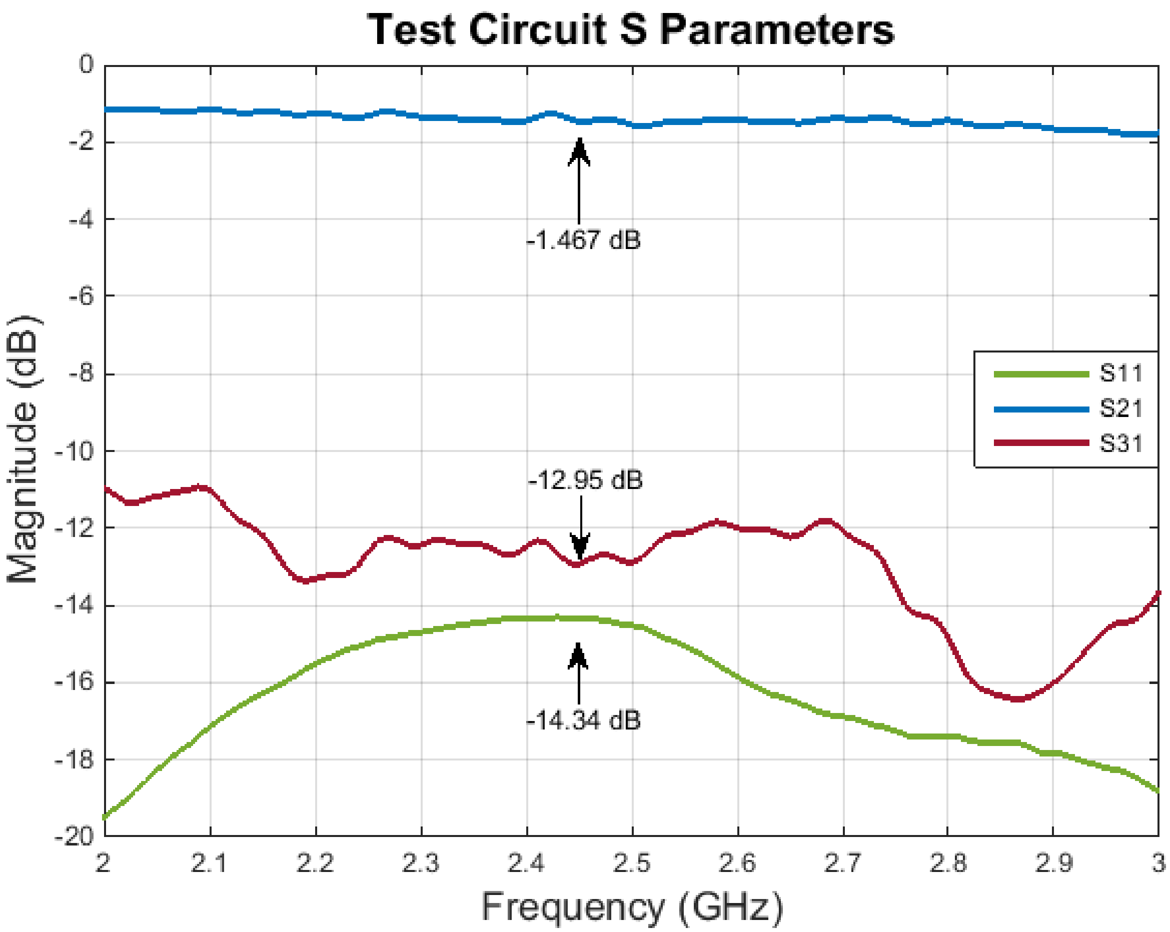
- Analog Devices
- 0.28 IL
- Complicated design
- Lack of equipment (in-house) for building and soldering

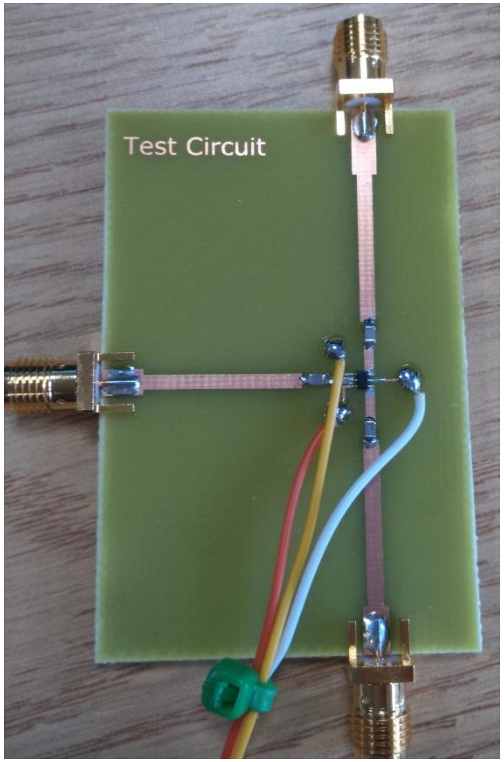
Hotspot Design: Switches

- SKYA21001
- 20 MHz to 3 GHz
- 0.4 dB IL
- Ease of design

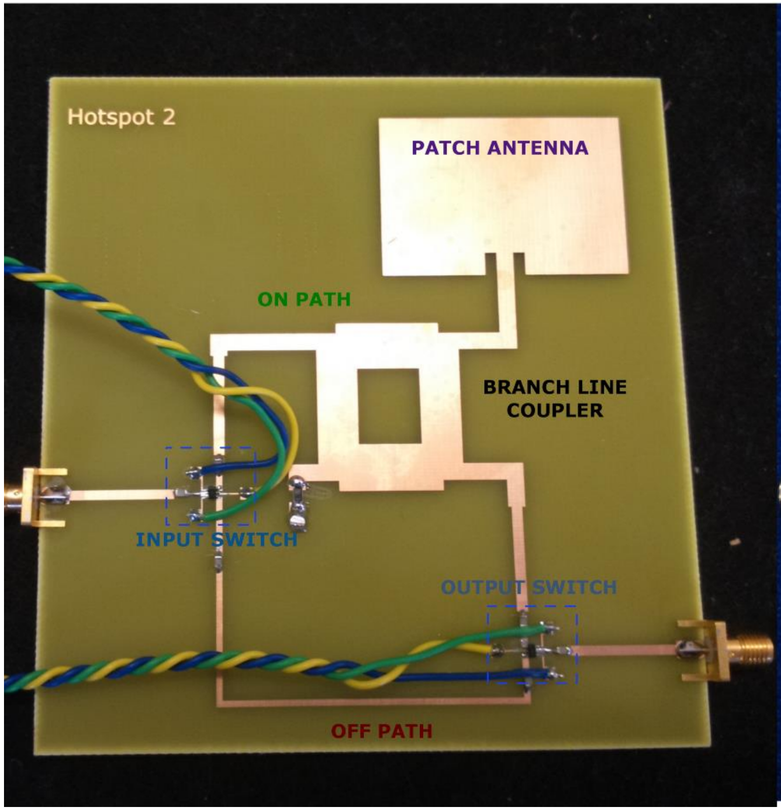


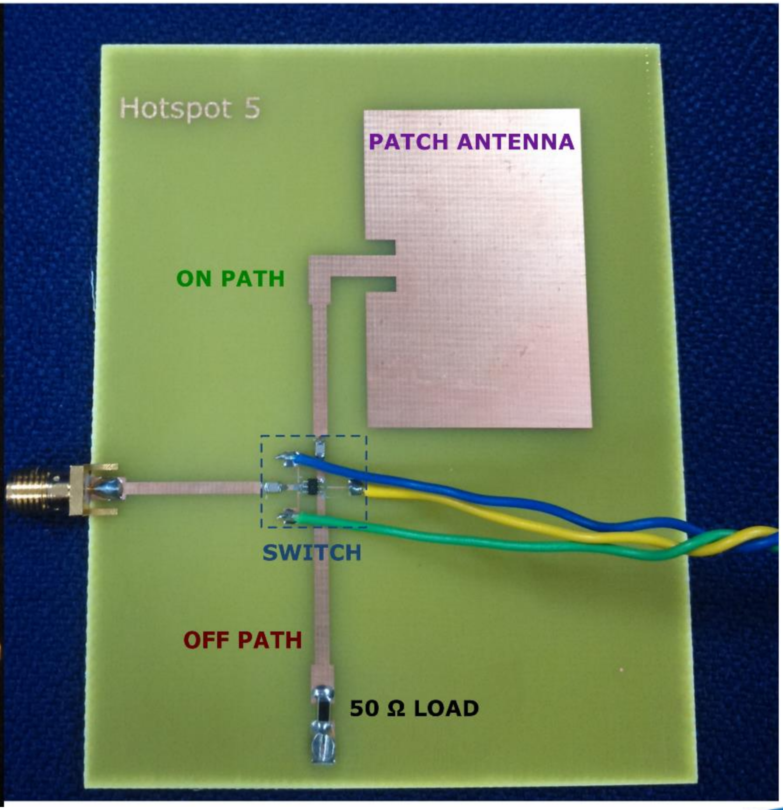
Hotspot Design: Switches



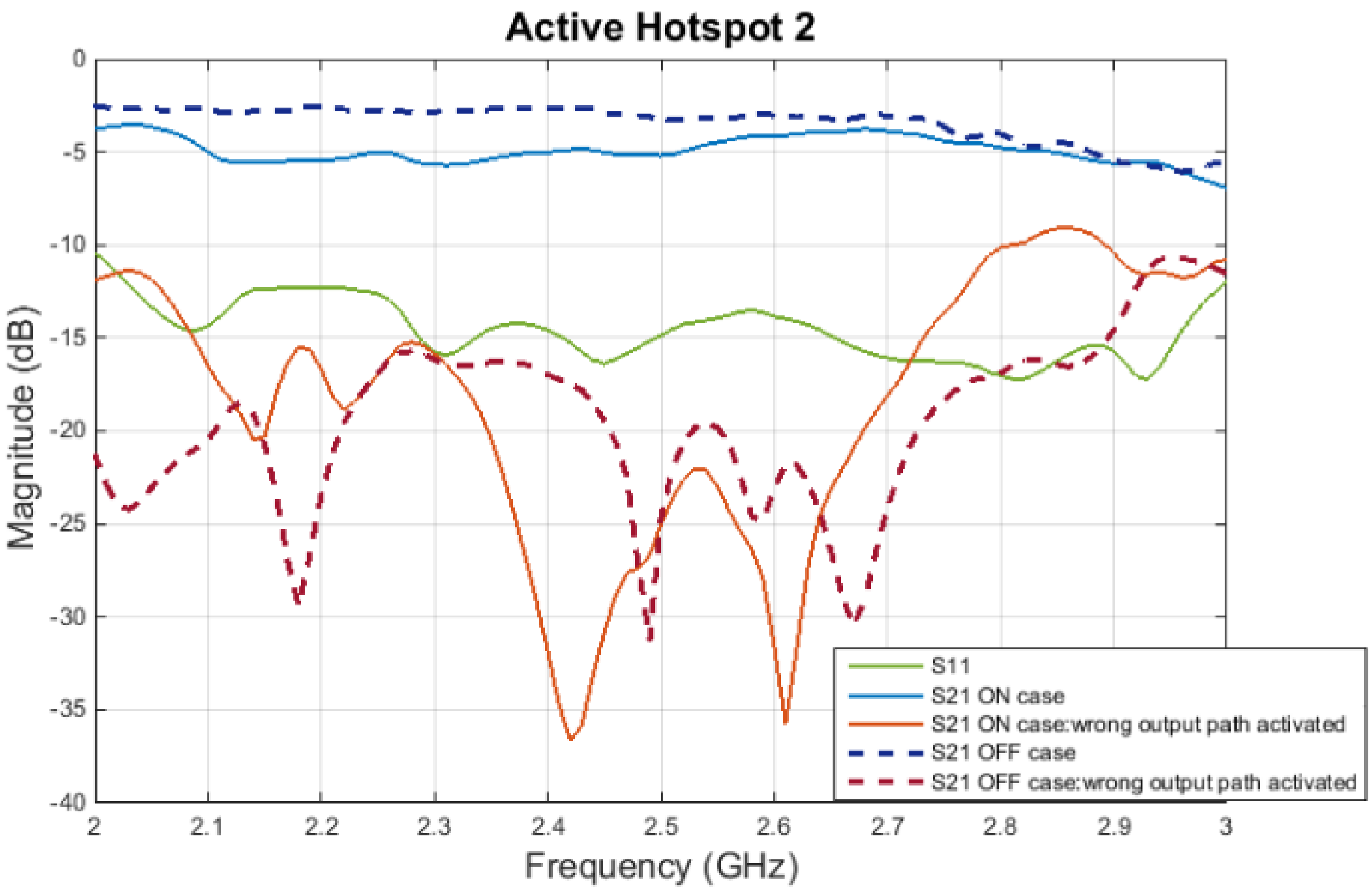


Hotspot Design: Final Prototypes

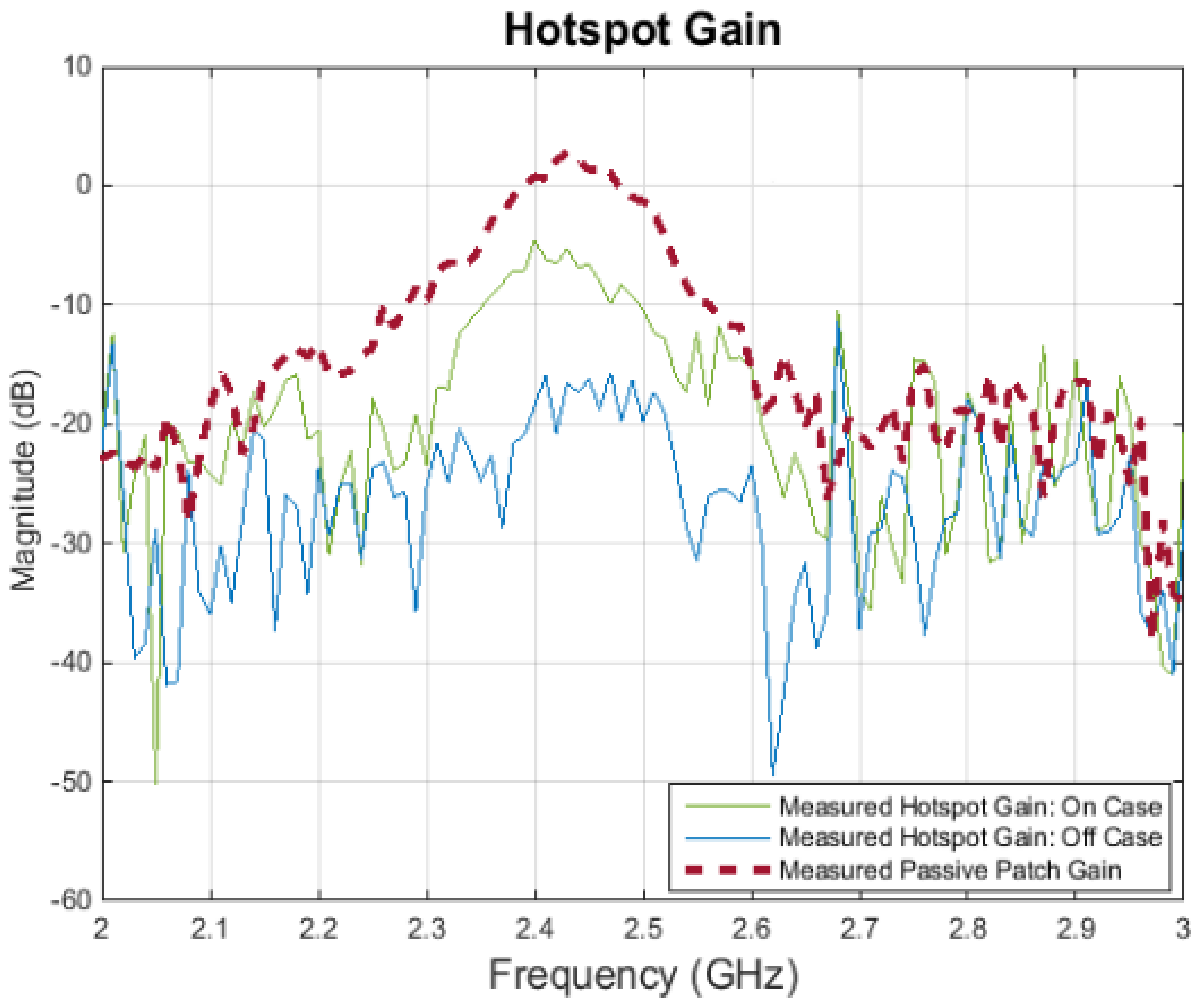




System Results: Hotspot 2



System Results: Hotspot 2



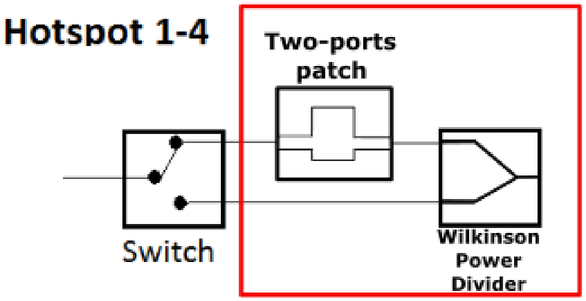
Comparison of all Results for Hotspot 2

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)

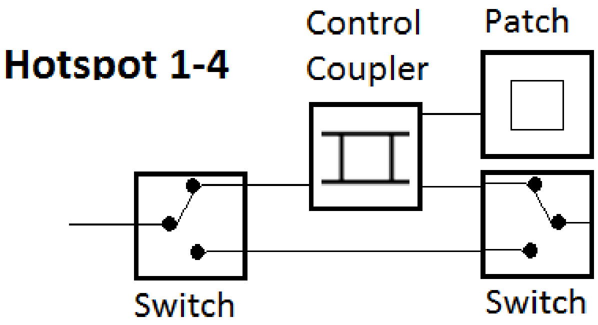
Power Budget Analysis

- 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 element are radiating

Configuration #1



Configuration #2



System Analysis:
Worst Case 1 (No Switches)

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

*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

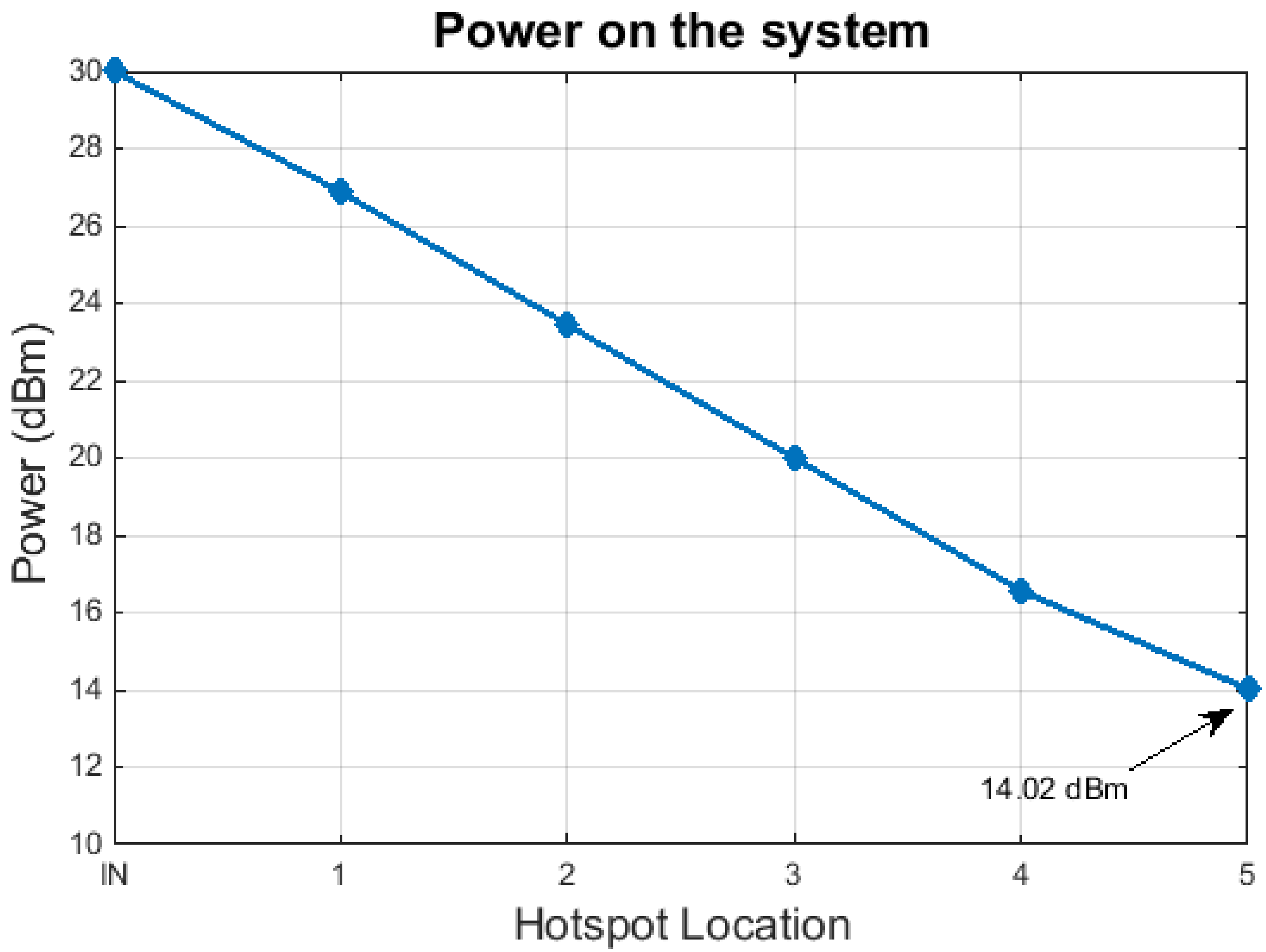
Power received: -39.51 dBm ☺

Power Budget Analysis
Active Configuration #2 (Switches)

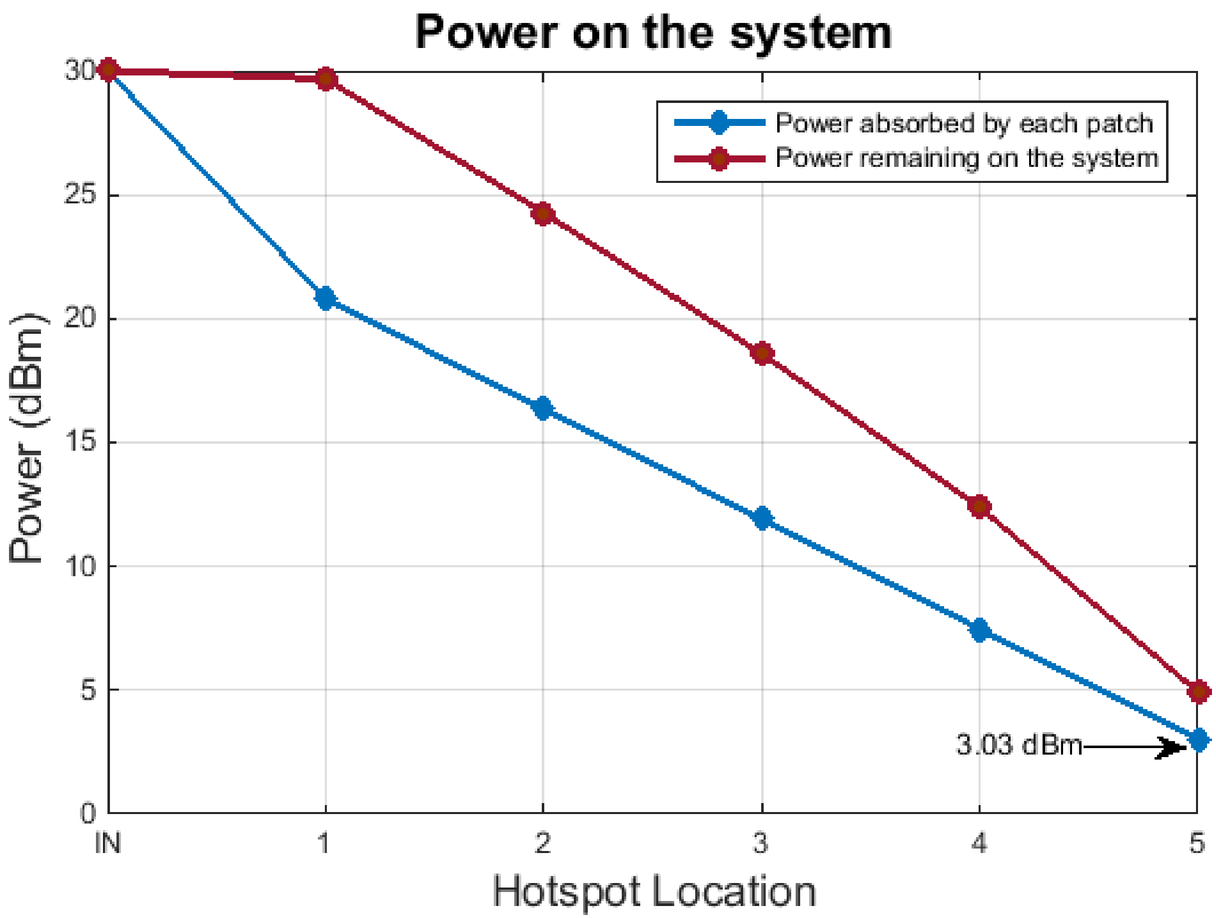
- Worst case 1 - only the last element radiates
  - Power transferred to the antenna: 14.02 dBm
  - Power radiated: 7.01 dBm
  - Power received: -42.46 dBm
- Worst case 2 - all elements radiate
  - Power transferred to the antenna: 3.03 dBm
  - Power radiated: 1.5 dBm
  - Power received: -47.97 dBm

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.

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Aknowledgement

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Thank you, any questions?