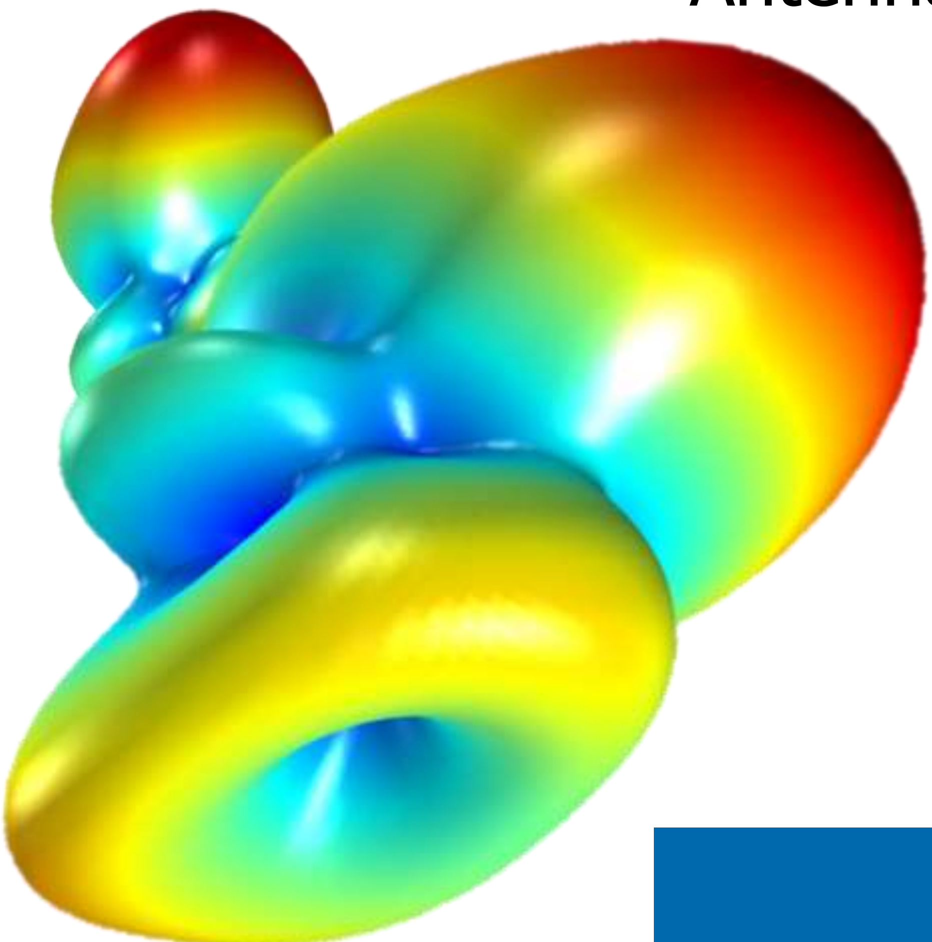
Impedance Matching of RFID Tag Antenna to Maximize Read Range & Design Optimization



CONTINUUMBLUE technology development

Tumbling Dice

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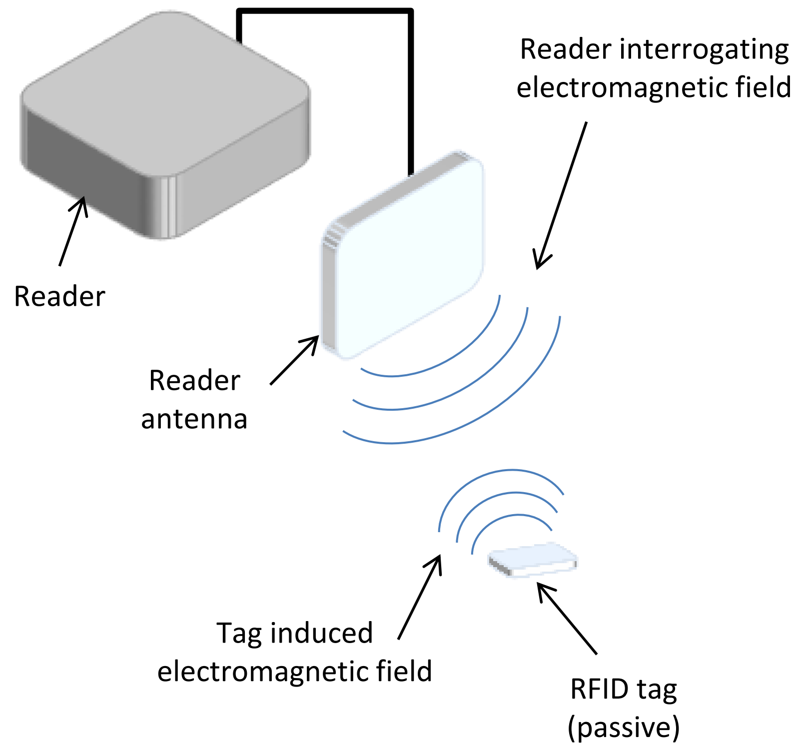
Overview



RFID System & Tags Overview

Model Details

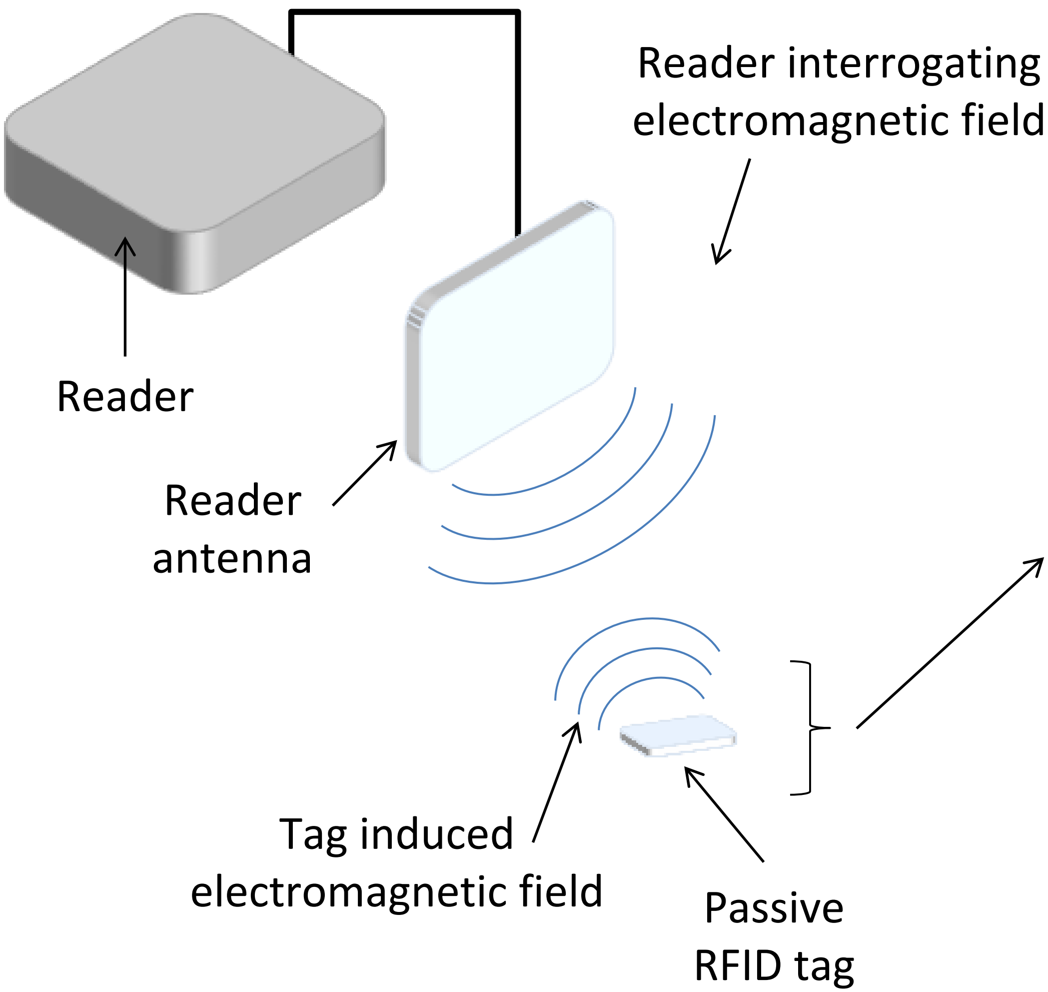
Validation Against available data

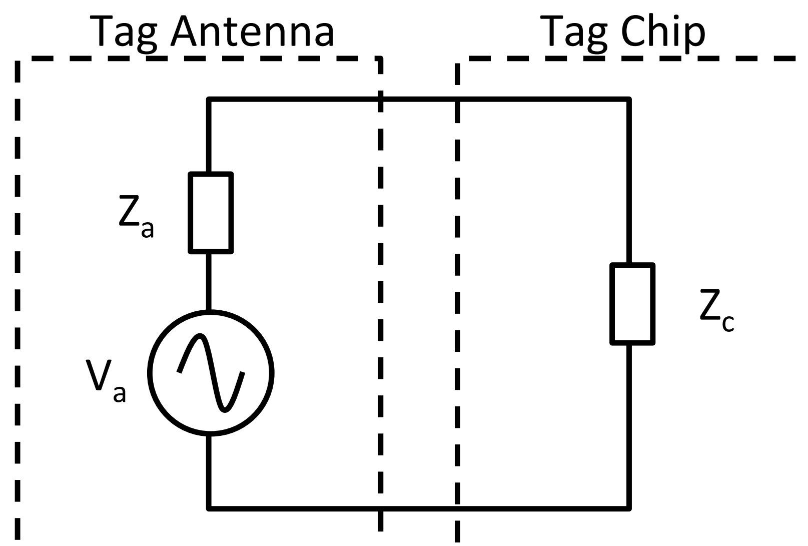
Optimization For example application

Manufacture & Future Testing Real world testing

RFID System & Tag Lumped Circuit

(i) Illustration of RFID System





(ii) Equivalent Circuit of RFID Tag

RFID Tag Read Range: Equations

- The power transmission coefficient (τ): relates the power absorbed by the chip (P_c) to the maximum power from the antenna (P_a)
- τ: describes the impedance match between chip and antenna.
  - As $\tau \to 1$ the better the match.
- P_a is obtained from Friis' free-space transmission equation, from which read range (r) for a particular RFID tag design & reader can be calculated.

Equations. Power Transmission Coefficient (τ), Friis Free-Space Transmission & Read Range (r)

$$P_c = P_a \tau$$

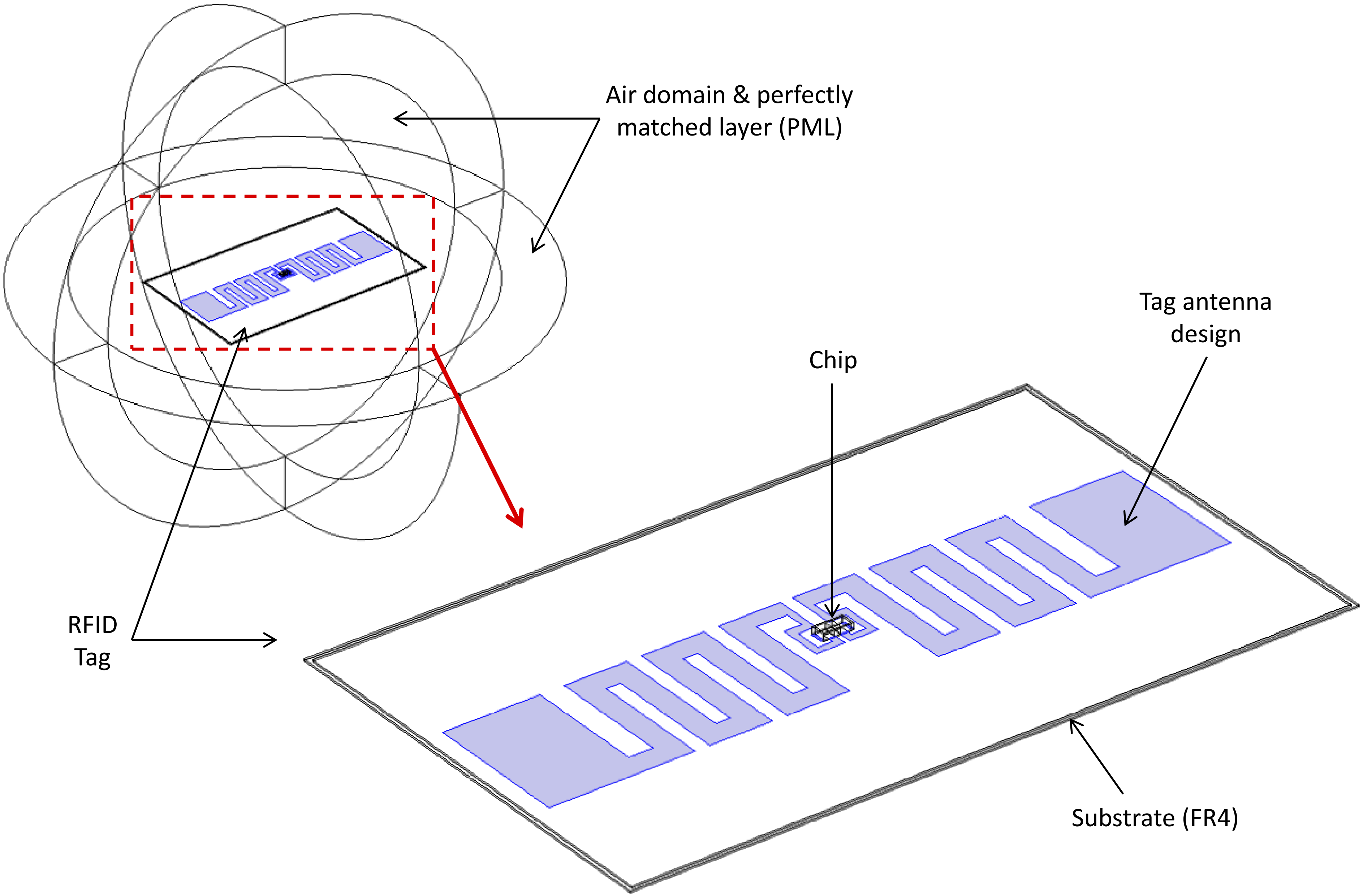
$$P_a = P_r G_r G_a \left(\frac{\lambda}{4\pi d}\right)^2$$

$$\tau = \frac{4 R_c R_a}{|Z_c + Z_a|^2}$$

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_r G_r G_a \tau}{P_{th}}}$$

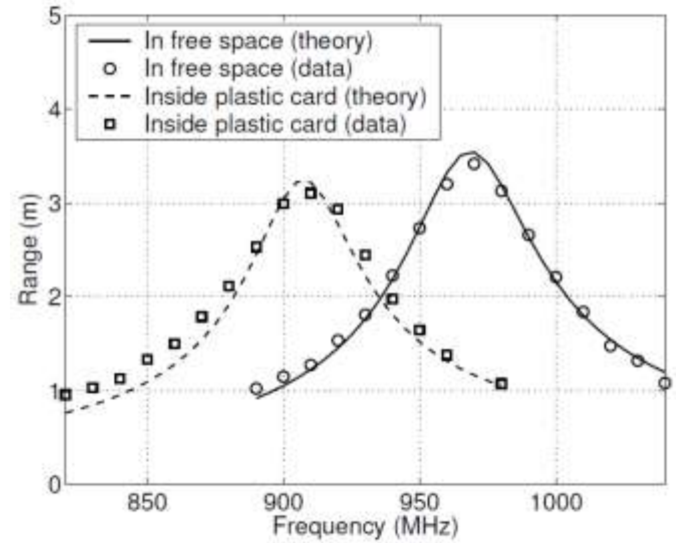
P_c : Power absorbed by chip
P_a : Maximum power from antenna
R_c : Chip resistance
R_a : Antenna resistance
Z_c : Chip impedance
Z_a : Antenna impedance
λ : Wavelength
P_r : Reader transmitted power
G_r : Reader antenna gain
G_a : Tag antenna gain
P_{th} : Chip minimum threshold power

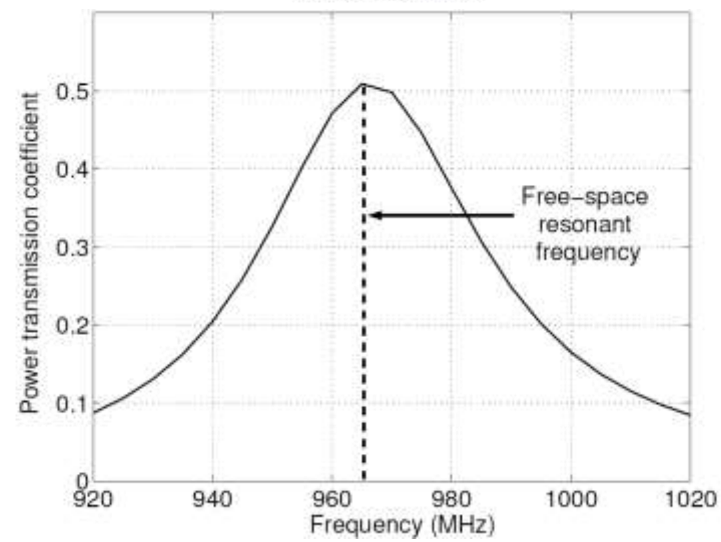
COMSOL Model



Validation: Literature (Rao et al. 2005[1])

Literature review of passive tag data [1-3], found that Rao et al. (2005) provided a good data set for comparison.





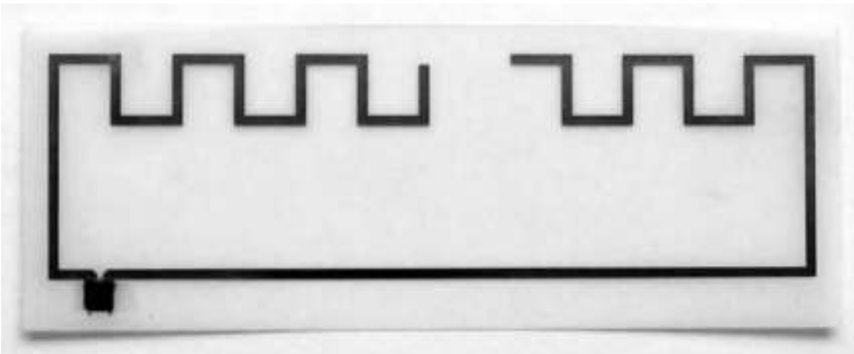
[1] Hsieh et al., Key Factors Affecting the Performance of RFID Tag Antennas, Current Trends and Challenges in RFID, Chapter 8, 151-170, InTech (2011)

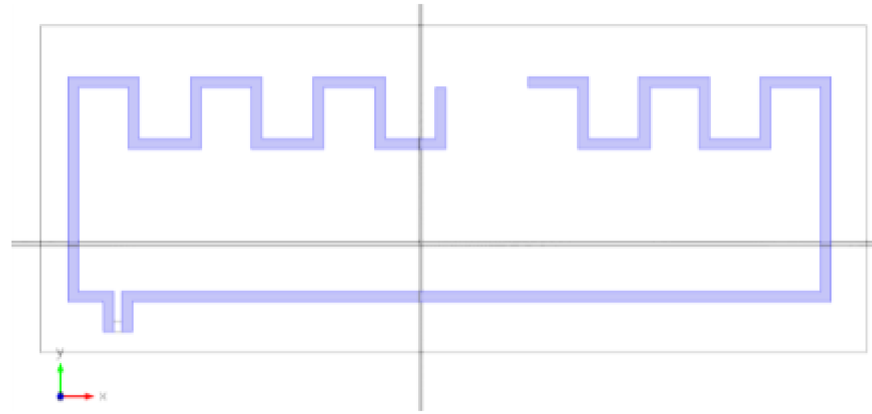
[2] N. D. Reynolds, Long range Ultra-High Frequency (UHF) Radio-frequency Identification (RFID) Antenna Desgin, MSc Thesis, Purdue University (2005)

[3] Rao et al., Impedance Matching Concepts in RFID Transponder Design, Fourth IEEE Workshop on Automatic Identification Advanced Technologies (2005)

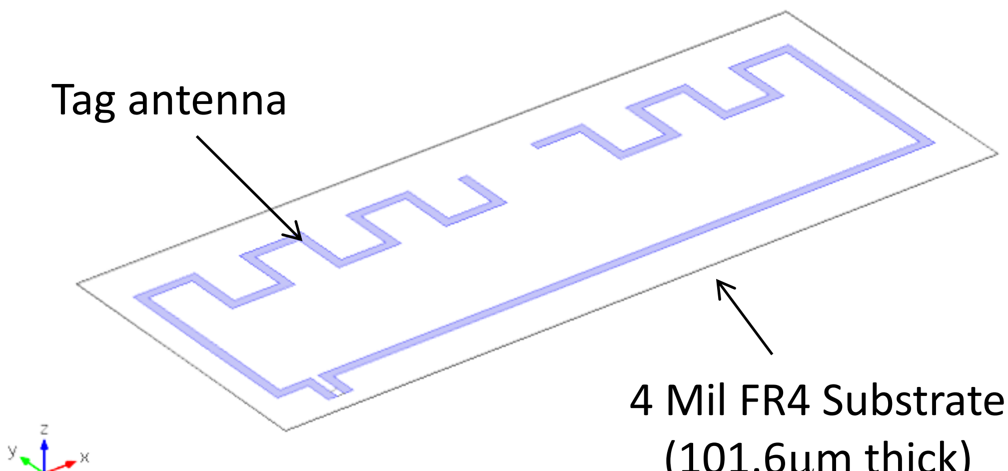
Validation: Equivalent COMSOL Model

Plan view



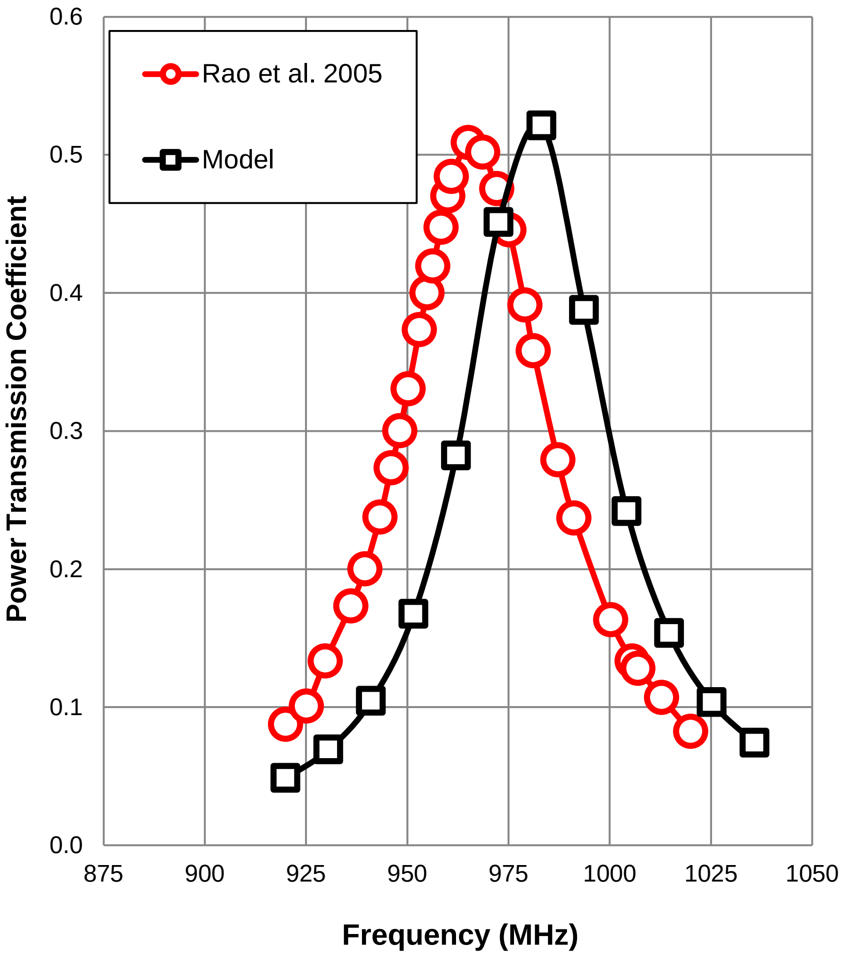


Isometric view

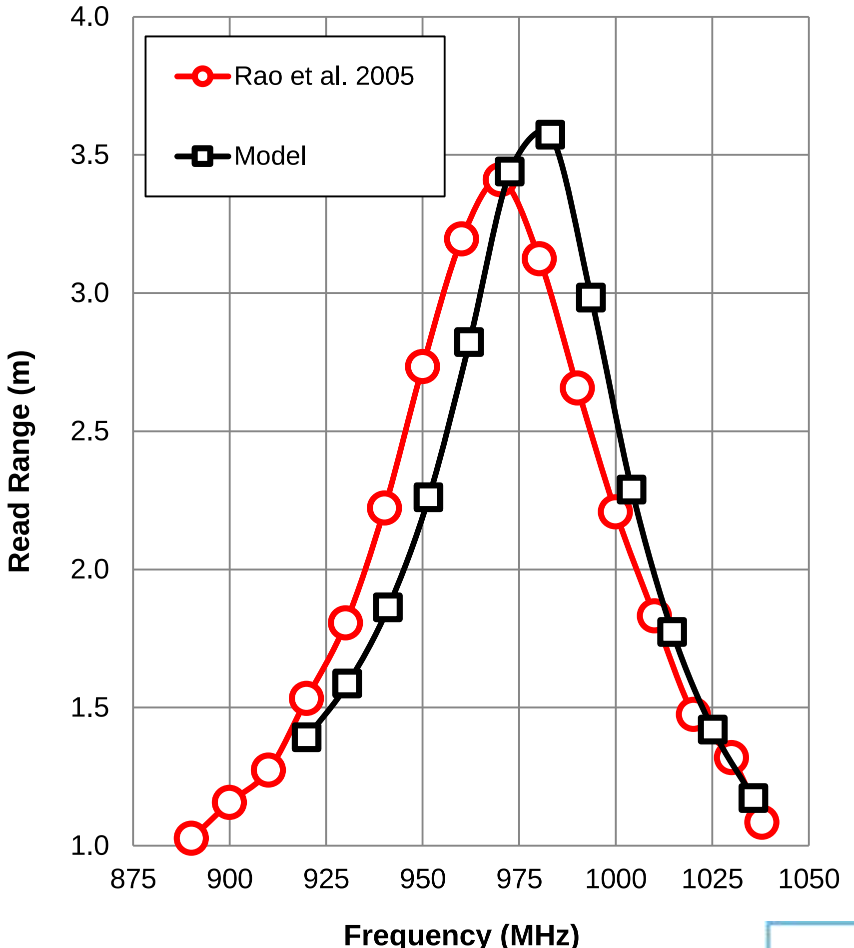


Validation: Comparison to Literature

(ii) Power Transmission Coefficient



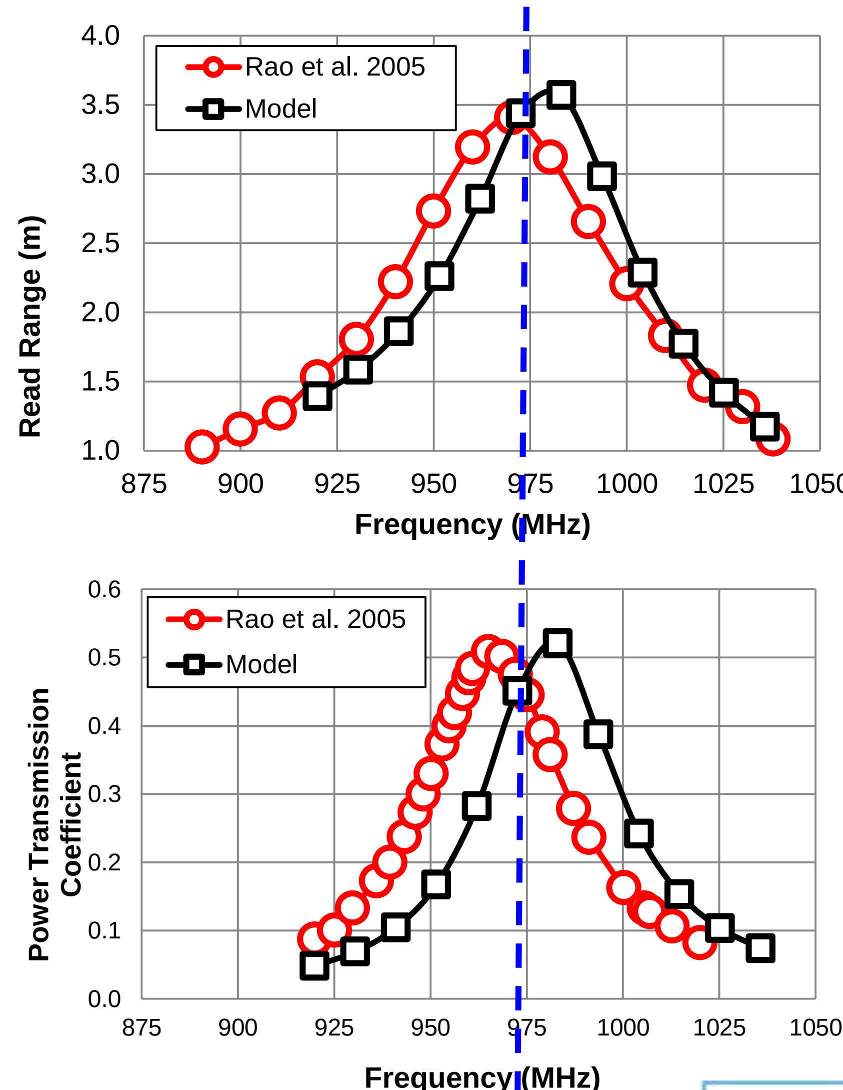
(i) Read Range Data



Validation: Conclusion

Differences could be due to:

- Error in in extracting geometric data from the antenna image
- Variations in the modelled substrate material properties & thickness vs actual sample
- Model used a constant chip impedance value ($Z_c = 15 - j\,420\Omega$), as given by Rao et al. (2005)
    - This will vary the power absorbed & frequency



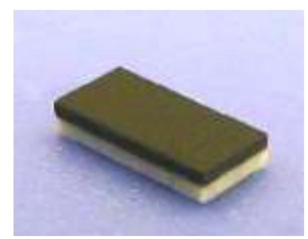
Chip Frequency at $Z_c = 15 - j\,420\Omega$ *?*

Optimization: Application

Example for an office card security system

- Had to use the following:
  - LRU1002 OBID® UHF long range reader (FEIG Electronic GmbH, Germany)[1]
  - OBID® i-scan® UHF reader antenna (FEIG Electronic GmbH, Germany)[2]
  - Murata Magicstrap® Chip (Murata Manufacturing Co., Ltd., Japan)[3].

OBID® UHF Antennas & Reader

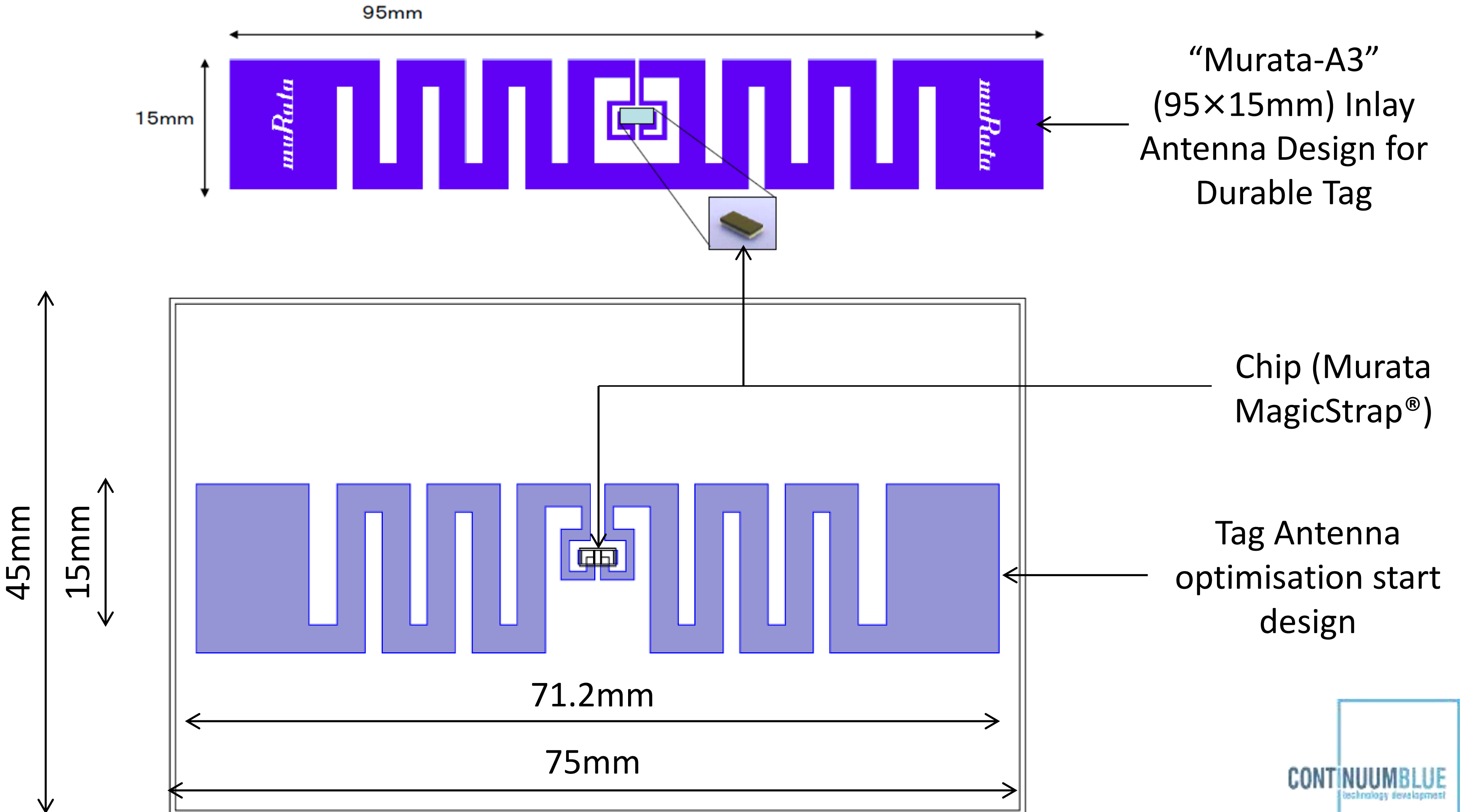


Murata Magicstrap®

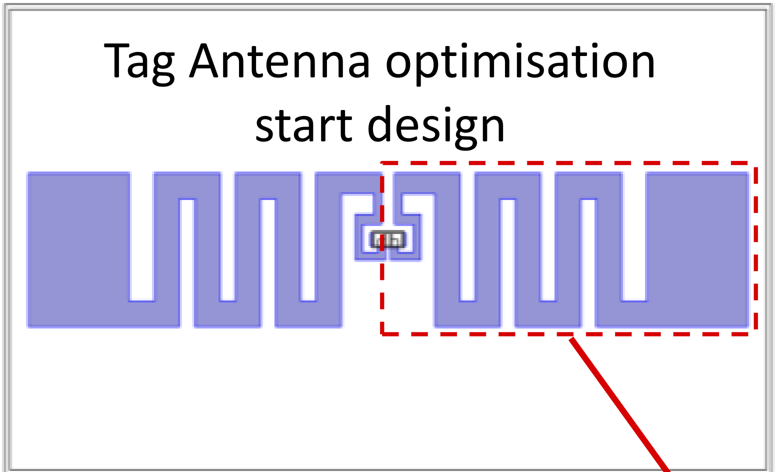
[1] OBID® UHF Long Range Reader LRU1002 Product Data Sheet, FEIG Electronic GmbH, Lange Strasse 4, D-35781 Weilburg, Hessen, Germany, www.feig.de
[2] OBID i-scan® UHF Antenna series Product Data Sheet, FEIG Electronic GmbH, Lange Strasse 4, D-35781 Weilburg, Hessen, Germany, www.feig.de
[3] Murata Magicstrap® Technical Data Sheet, Murata Manufacturing Co., Ltd., Kyoto, Japan, www.murata.com

Optimization: Starting Design

- Initial starting antenna design (71.2×45mm)
- chosen based on an existing “Murata-A3” (95×15mm) antenna

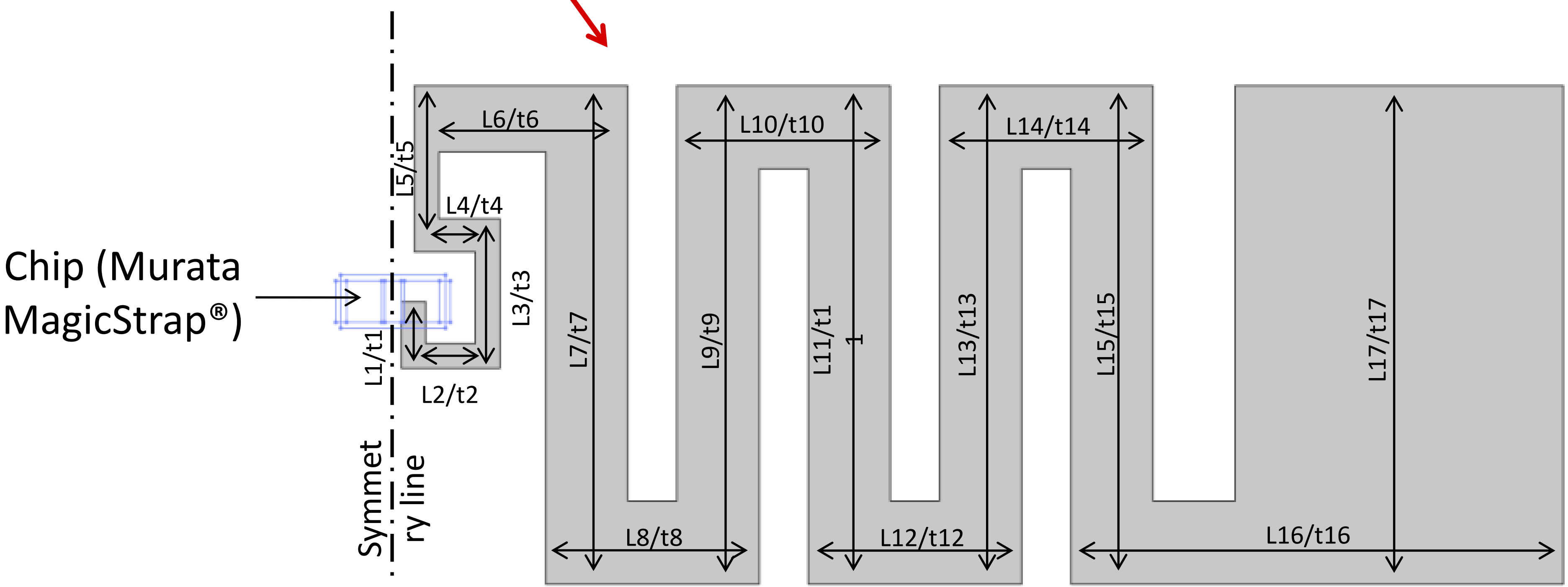


Optimization: Geometric Variables



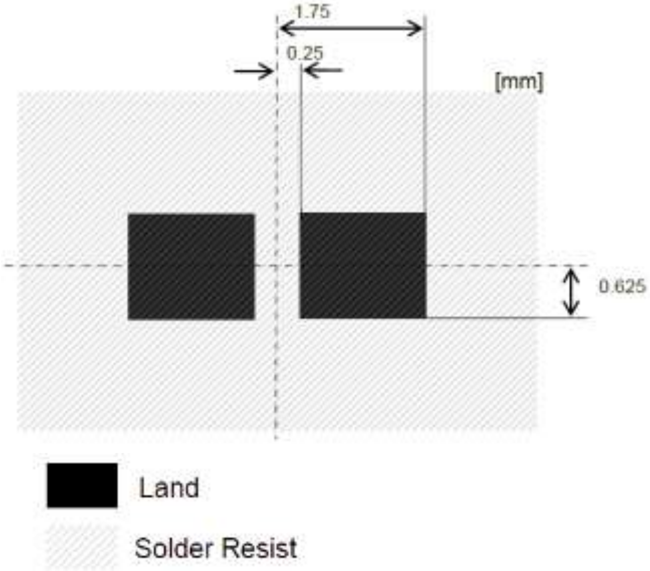
<u>34 geometric variables</u>

- Lengths: *l*1 to *l*17
- Widths: *t*1 to *t*17



Optimization: Constraints

- Within 75×45mm footprint
- Within tolerances of manufacture (Newbury Electronics Ltd., Berkshire UK)[1].
- Fixed chip mounting pattern
  - based on requirements for Murata Magicstrap®
- *l*1 to *l*17
  - +ve or –ve values
  - Maximum to ½ footprint length = 37.5mm
  - Minimum to 125μm (minimum manufacture)
- *t*1 to *t*17
  - +ve values
  - Maximum to ½ footprint width = 22.5mm
  - Minimum to 125μm (minimum manufacture)



Murata's Recommended Mounting Pattern at Antenna Side for Reflow Soldering

[1] Newbury Electronics Ltd. (Berkshire UK), www.newburyelectronics.co.uk.

Optimization: Objective Function & Inputs

Objective Function:

- Maximize Power Transmission Coefficient (τ)

Reader System Inputs:

- Chip frequency: 866.5 MHz
- Chip Impedance: 15-45j Ω
- Tag Substrate: 250µm FR4
- Reader Power: 1W (mid range value)
- Reader Antenna: ID ISC.ANT.U.270/270
- Reader Antenna Gain: 9dBi

Optimization: Solvers & Solutions

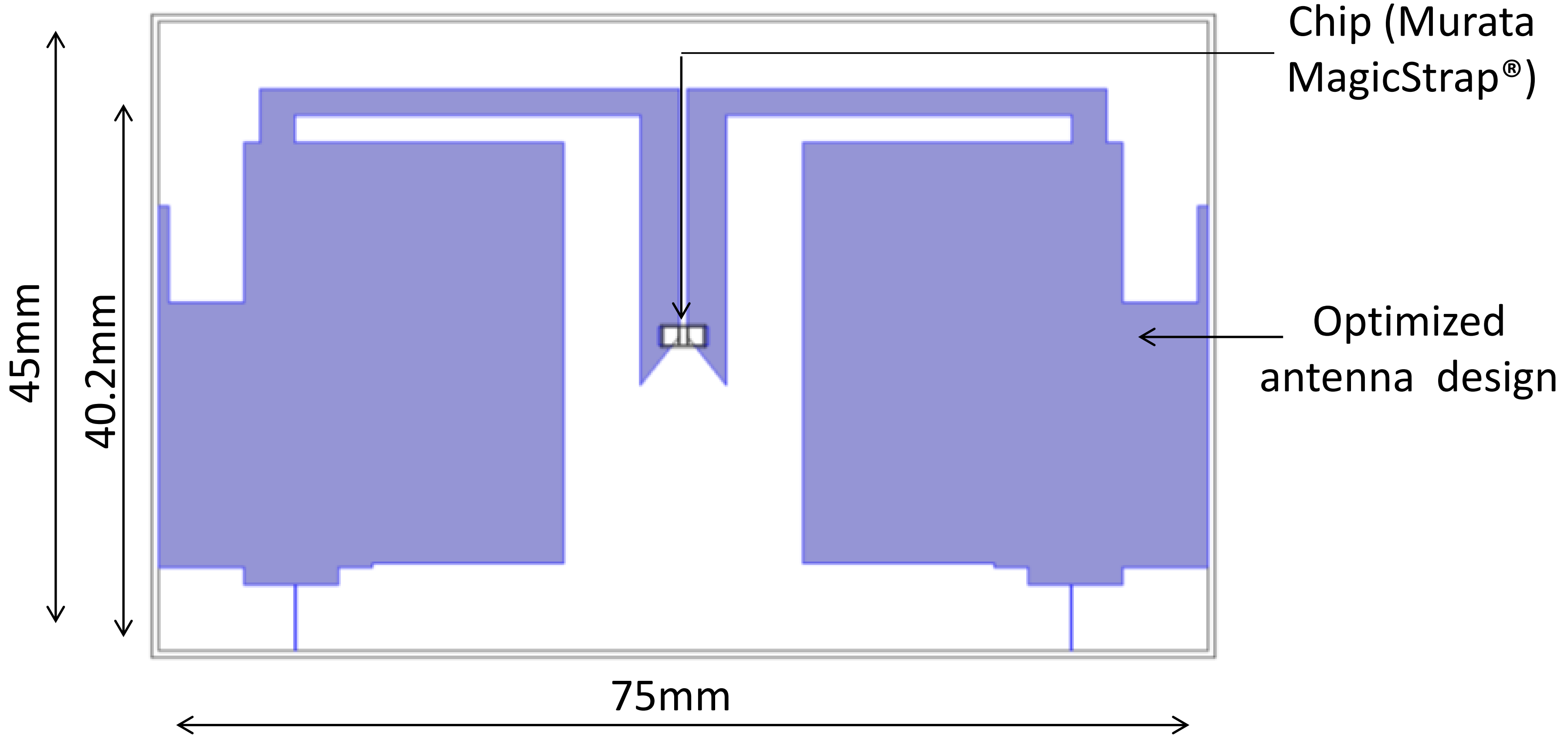
- Two gradient-free optimisation methods looked at:
  - Bound optimization by quadratic approximation (BOBYQA)
  - Monte Carlo
- Chose as objective function does not need to be differentiable with respect to variables
- Definition of the problem & geometric relations will be discontinuous

Stage #	Optimisation Solver	Design Start Point	Run time	Objective Value (τ)
1	BOBYQA	Initial design	2h 13m	0.498
2	Monte Carlo	Solution from Stage 1	36h 28m	0.644
3	BOBYQA	Solution from Stage 2	3h 42m	0.675
Initial (start) antenna design objective value				0.303

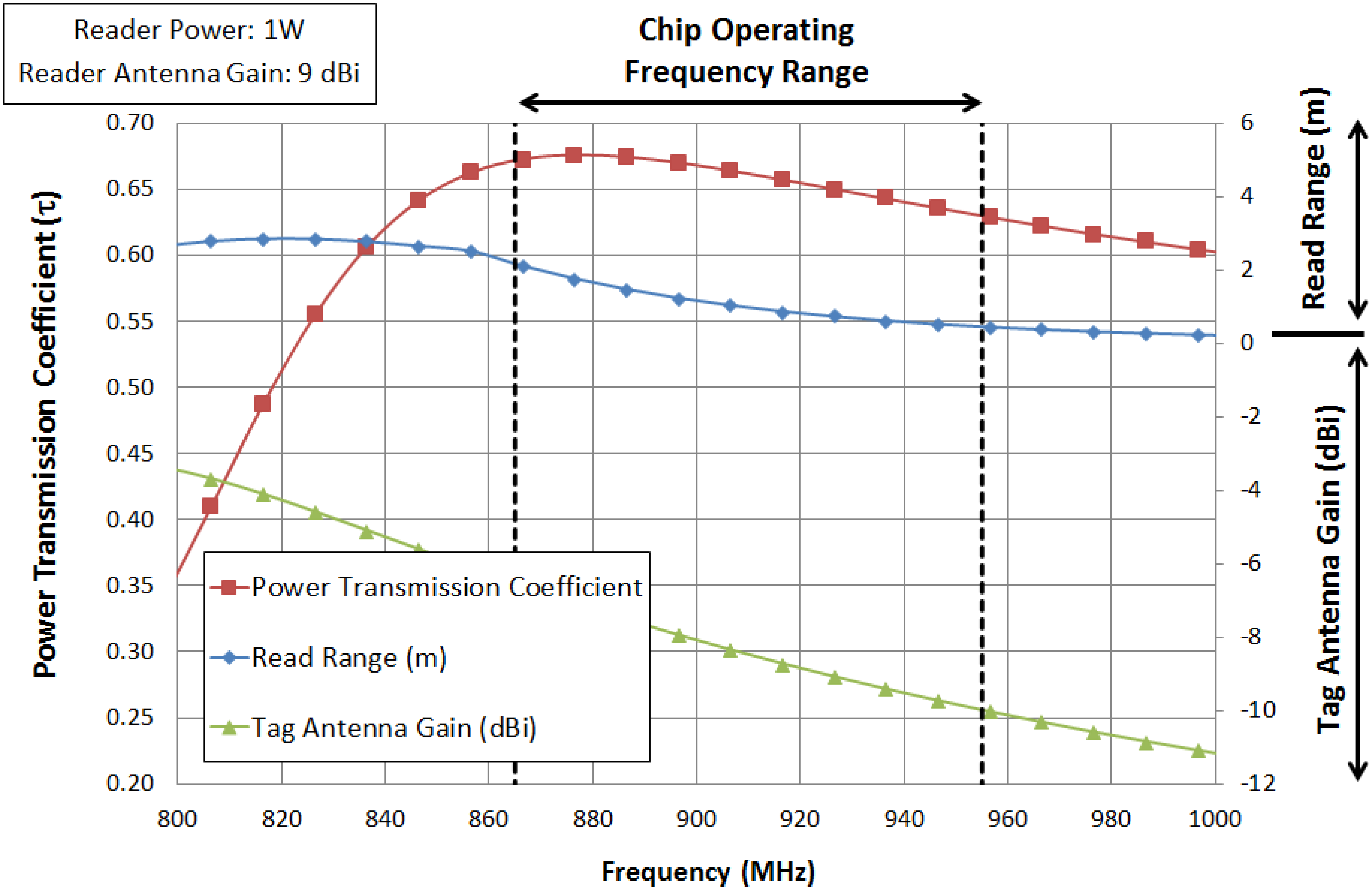
Optimisation runs and changes in Power Transmission Coefficient (τ)

- Initially BOBYQA solver was used, however solutions were localized & highly dependent on the initial start design
- The Monte Carlo method was favored, as this looked at the complete design space and introduced random variations in the design variables assessed.
- drawback for this method is the time taken to find global solution
- Ended with a BOBYQA to improve local solution

Optimization: Antenna Design Solution



Optimization: Frequency Operational Range



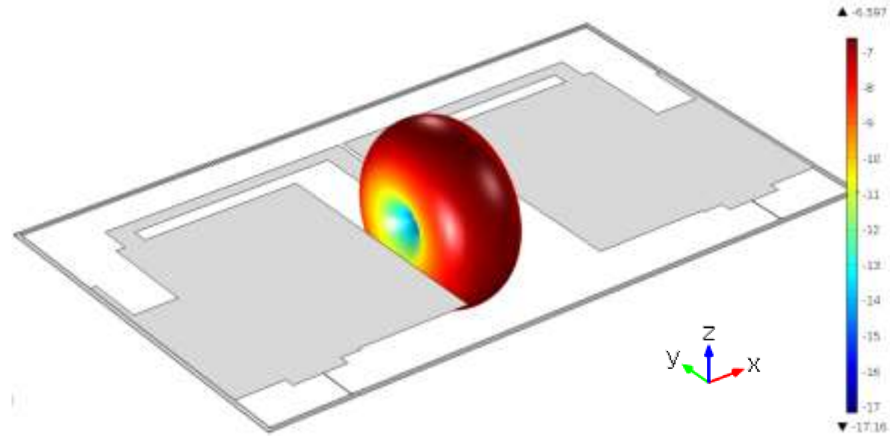
Optimization: Reader Setting Variations

Read ranges for different reader settings

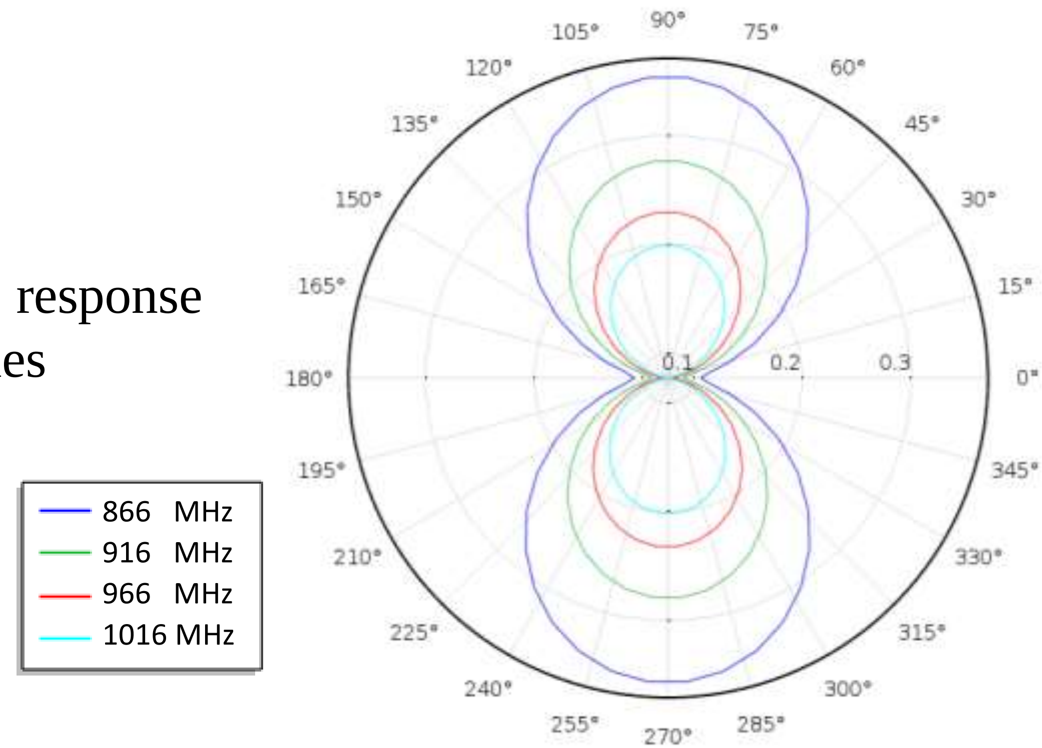
Description	Units	Reader System			
Reader Power	W	1	2	1	2
Reader Antenna Gain	dBi	9	9	11	11
Read Range	m	2.38	3.36	2.99	4.23

Optimization: Far-Field Pattern

Simple omnidirectional far-field pattern response of optimized antenna design at 866.5MHz



Polar plot of far-field response for different frequencies



Conclusion

- An RFID tag model was developed & validated against data available in literature
- The model was found to marginally over-estimate the tag's response. Possibly due to:
  - Variations in geometric & material properties compared to the physical samples
  - COMSOL Model used a constant chip impedance value (Z_c = 15 − j 420Ω), as provided by Rao et al. (2005).

Z_c This will vary the power absorbed & frequency

- The model was used to find an optimal tag antenna design, where geometric & manufacturing constraints were implemented
- A solution for another application is currently being manufactured & will be tested

References

1. Hsieh et al., Key Factors Affecting the Performance of RFID Tag Antennas, Current Trends and Challenges in RFID, Chapter 8, 151-170, InTech (2011)
2. N. D. Reynolds, Long range Ultra-High Frequnecy (UHF) Radio-frequency Identification (RFID) Antenna Desgin, MSc Thesis, Purdue University (2005)
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4. Murata Magicstrap® Technical Data Sheet, Murata Manufacturing Co., Ltd., Kyoto, Japan, www.murata.com
5. OBID® UHF Long Range Reader LRU1002 Product Data Sheet, FEIG Electronic GmbH, Lange Strasse 4, D-35781 Weilburg, Hessen, Germany, www.feig.de
6. OBID i-scan® UHF Antenna series Product Data Sheet, FEIG Electronic GmbH, Lange Strasse 4, D-35781 Weilburg, Hessen, Germany, www.feig.de
7. Newbury Electronics Ltd. (Berkshire UK), www.newburyelectronics.co.uk.

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