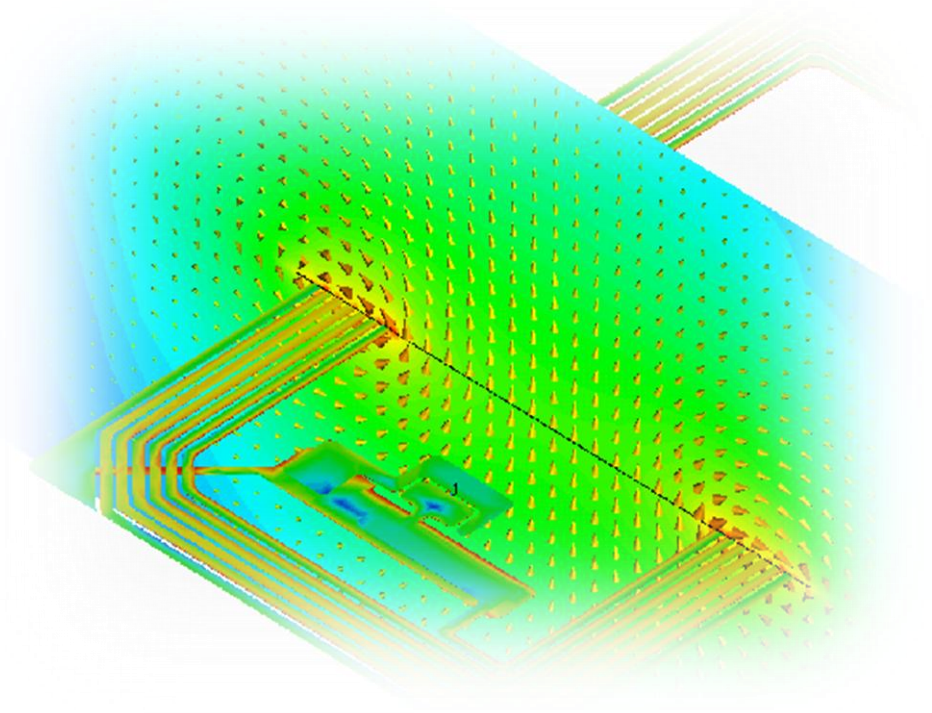
# RFID System Simulation



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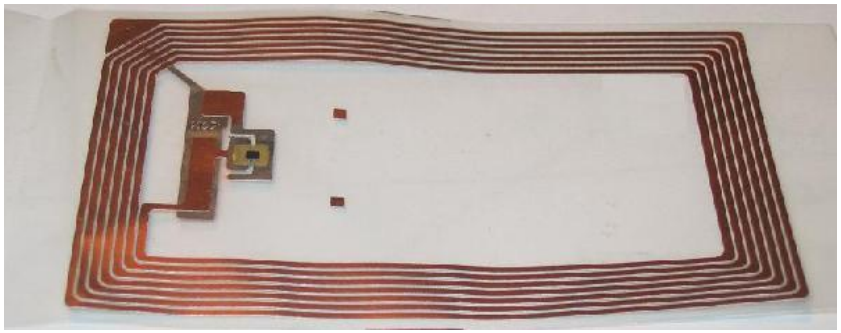
# Presentation Outline

- Overview
- RFID Design Process
- Where does EM simulation fit in, and how can it make the design process more efficient?
  - Tag design
  - System analysis
- What is required of an EM simulation tool?
  - Frontend
  - Solvers
  - Post-processing
- Some real-world examples

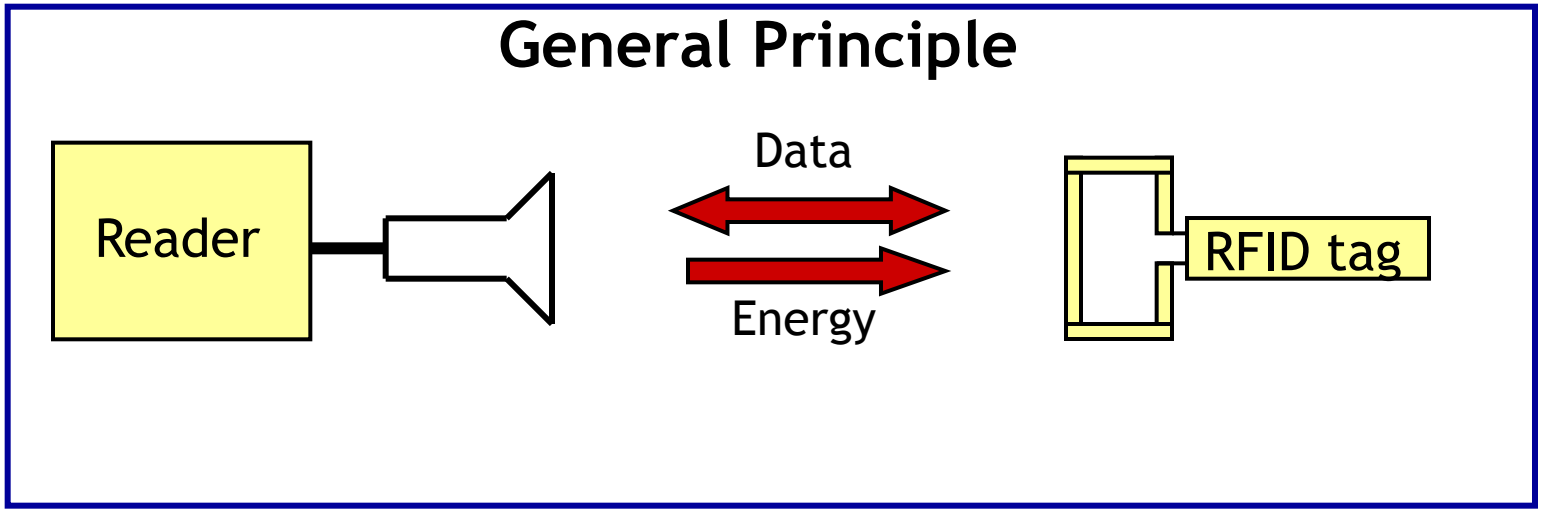


# Overview

## Radio Frequency IDentification

- Fundamental tool for Automatic Identification: authentication, ticketing, access control, supply management, parking, payment, vending, surveillance
- Advantages:
  - Contains more information than e.g. Barcodes
  - Can be read/write
  - Contactless ID (in contrast to phone or bank cards)
  - May become cheap mass product (e.g. in supermarkets)

# Overview




Typical characteristics of RFID:

- Tag is a passive device, energy is transmitted from reader
- Distance mm to 10m (typically ~20 cm)
- Contains silicon chip, can be read only or read/write
- Responds with modulated signal
- Mostly printed (planar) structures

# Overview

## Frequencies

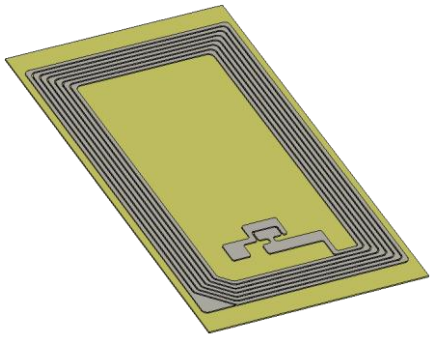
| | |
|---|---|
| 125/134 kHz | Animal identification, industrial applications, very robust, low data transmisstion (64 bit) |
| 7.4 - 8.8 MHz | Electronic Article Surveillance (EAS) |
| 13.56 MHz | "Smart Labels" widely used for product/article ID |
| | |
| 868 - 928 MHz | Logistics,... |
| 2.4 GHz | Vehicle identification, electronic toll collection |
| 5.8 GHz | electronic toll collection in Europe |
| | |

# RFID Tag Antenna Design Process

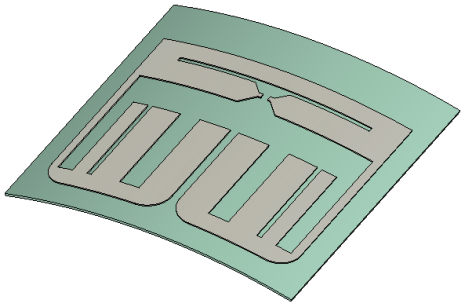
Application?
Tag requirements?

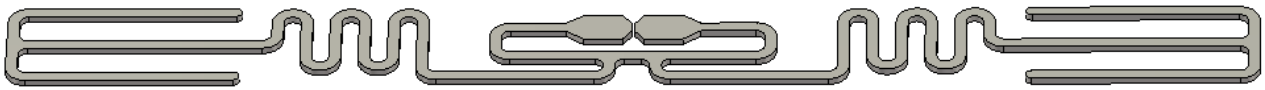
Construction materials?

ASIC Impedance?

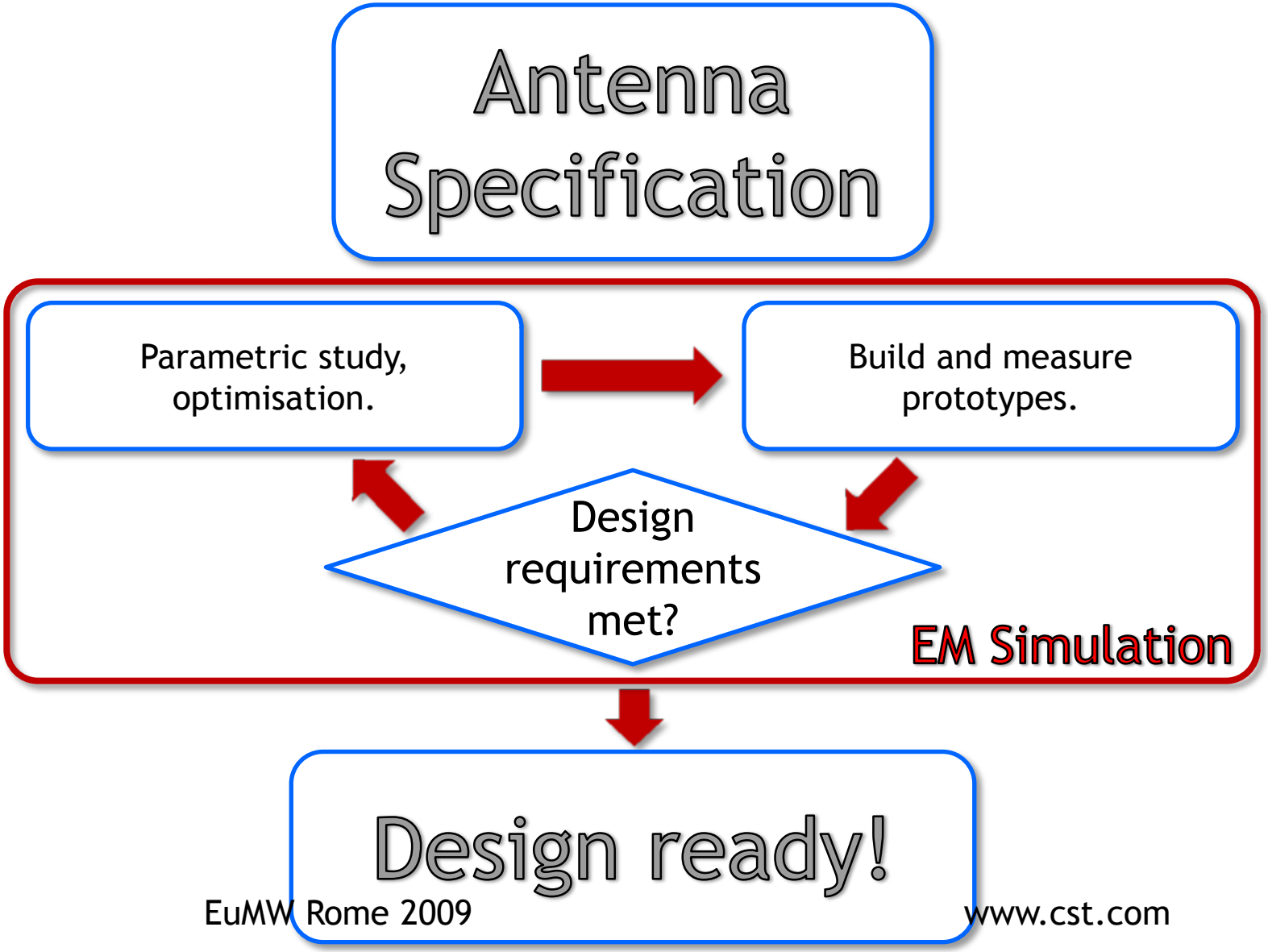


Antenna Specification





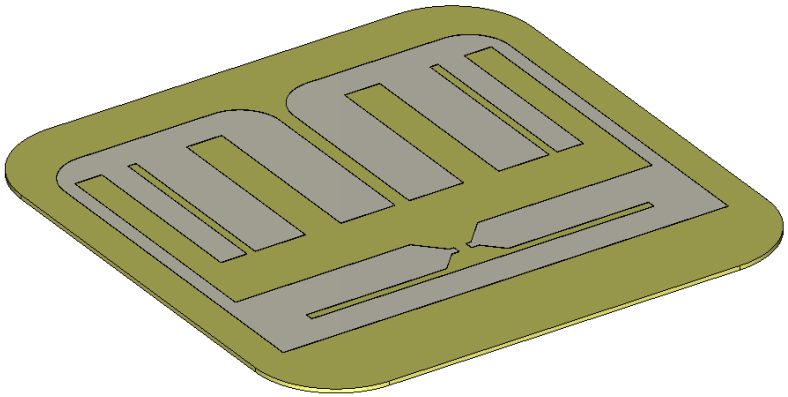
# RFID Tag Antenna Design Process



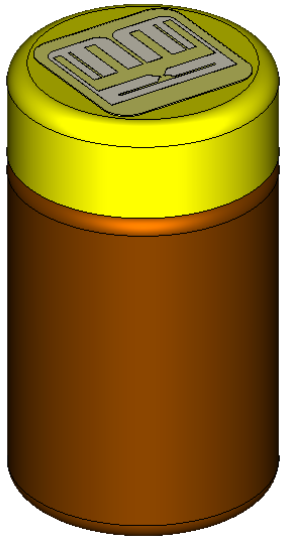
# Antenna to System

- The antenna design is only the first step. The antenna is positioned on an object and used in a system, and this introduces additional unknowns which may affect the tag's performance.

- Antenna unknowns:
  - geometry
  - material properties

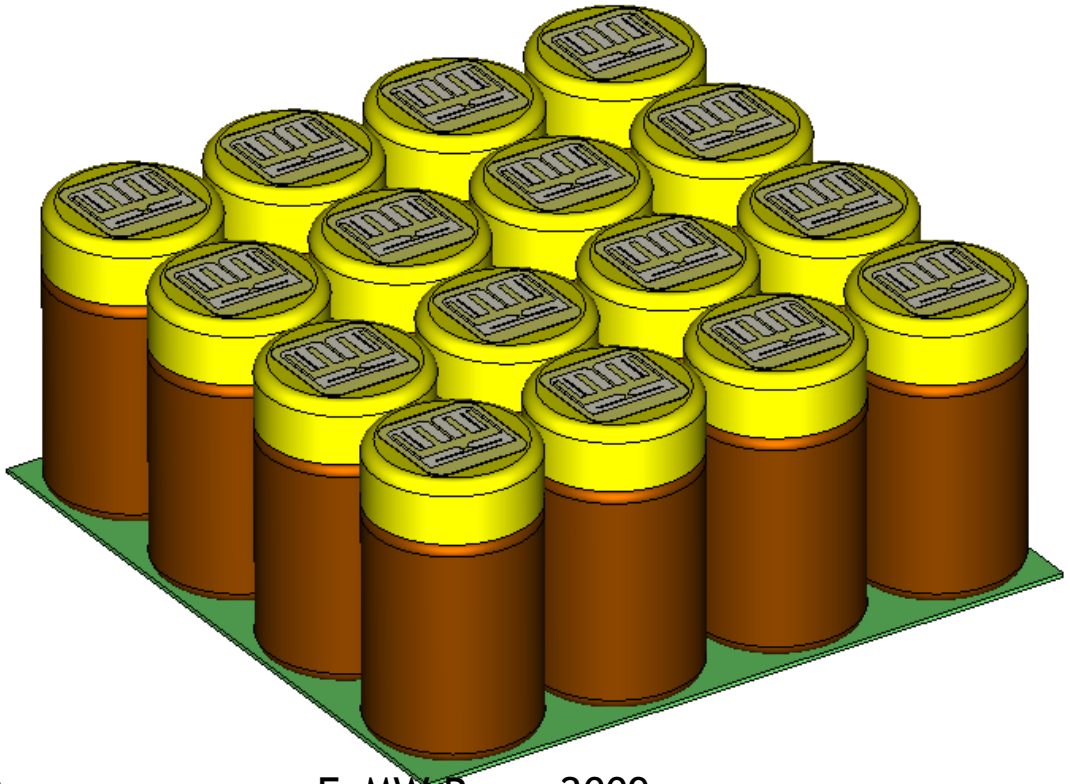


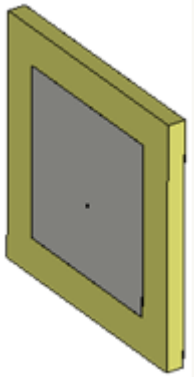
- Positioned antenna unknowns:
  - container geometry
  - container material properties



# Antenna to System

- Antenna in system unknowns:
  - position and orientation of tag relative to reader
  - effect of group on individual performance (e.g. shielding)





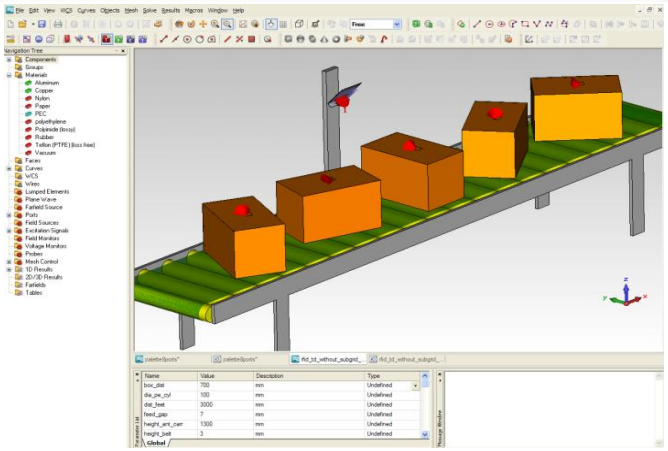
# Why EM Simulation?

- **RFID tags have to be fast to develop, cheap to manufacture, but are expected to function robustly despite construction tolerances, variations in material properties, on a variety of backgrounds, and *all that* in a system in a possibly complex environment.**
- **Using electromagnetic simulation, we can:**
  - robustly optimise the initial tag,
  - consider the effects of positioning the tag,
  - check that the whole system will work as envisaged.
- **The analysis of complex systems by traditional methods within an acceptable budget and time-frame is unfeasible.**
- **The only way to ensure that the tag will work not only on its own, but also in its intended environment, is by using EM simulation tools.**

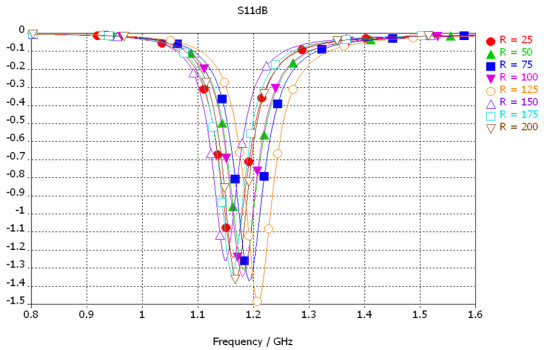
# EM Simulator Requirements

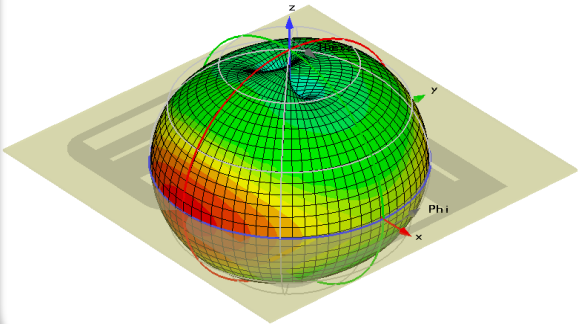
- General requirements of a modern EM simulation tool:

- intuitive user interface



- powerful post-processing

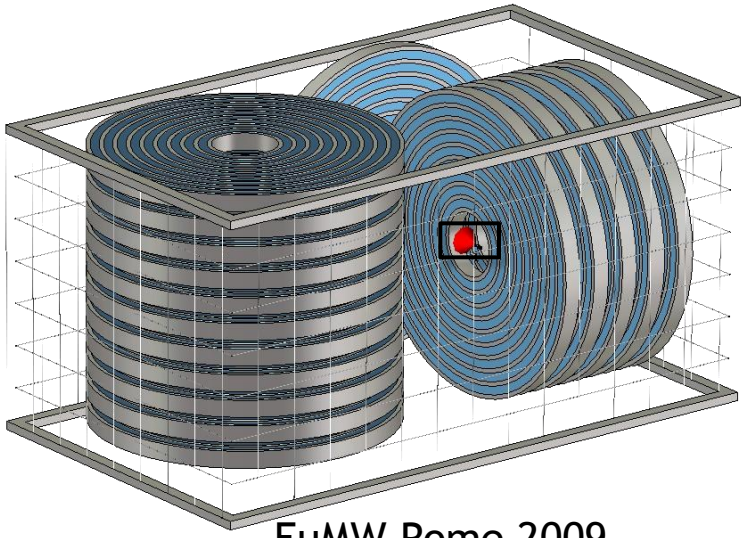


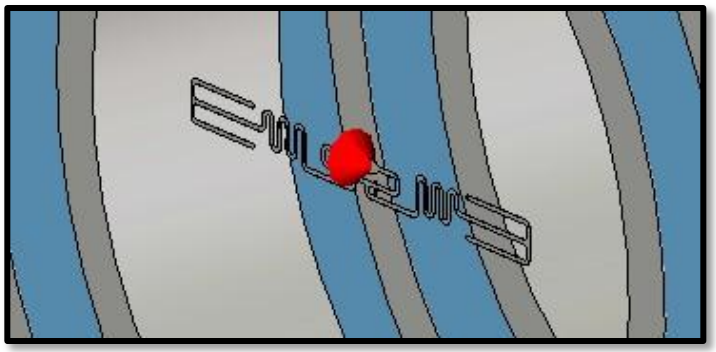




- efficient solvers

# User Interface Requirements

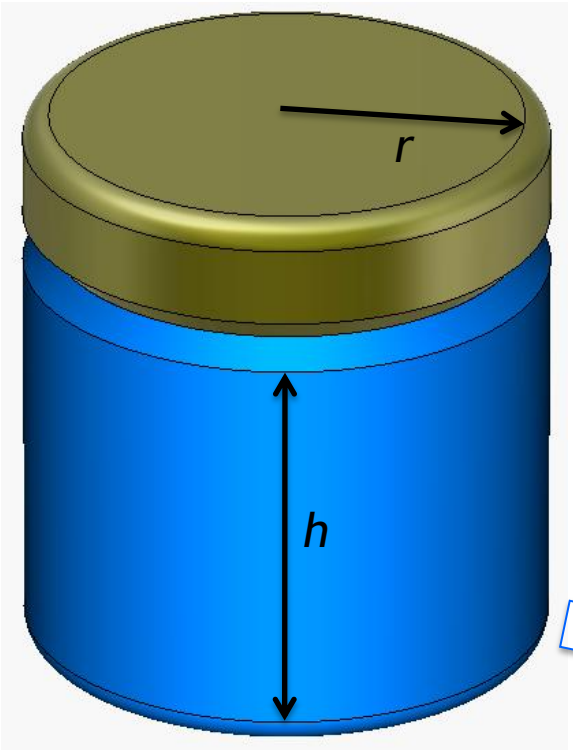
- **Intuitive CAD type graphical user interface**
- **Easy robust parametric construction**
- **Import from different formats**
  - integration, modification, parameterization
- **Advanced meshing algorithms**
- **Powerful macro programming and scripting**



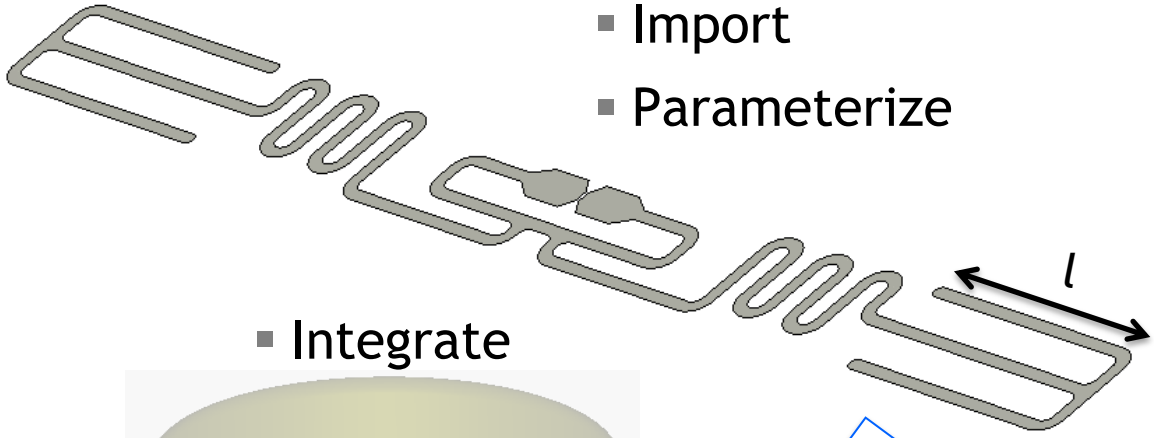


# Graphical User Interface

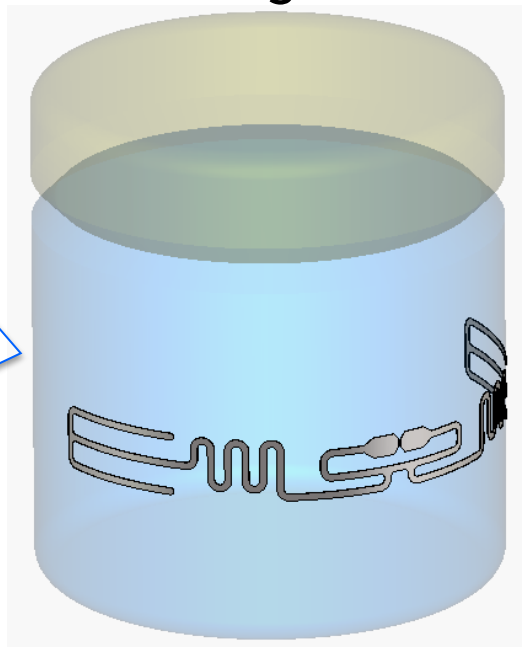
- Construct




- Import
- Parameterize



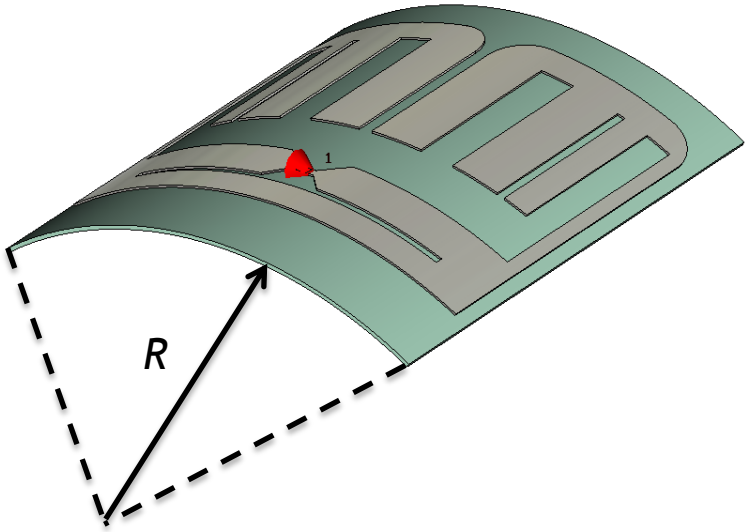

- Integrate

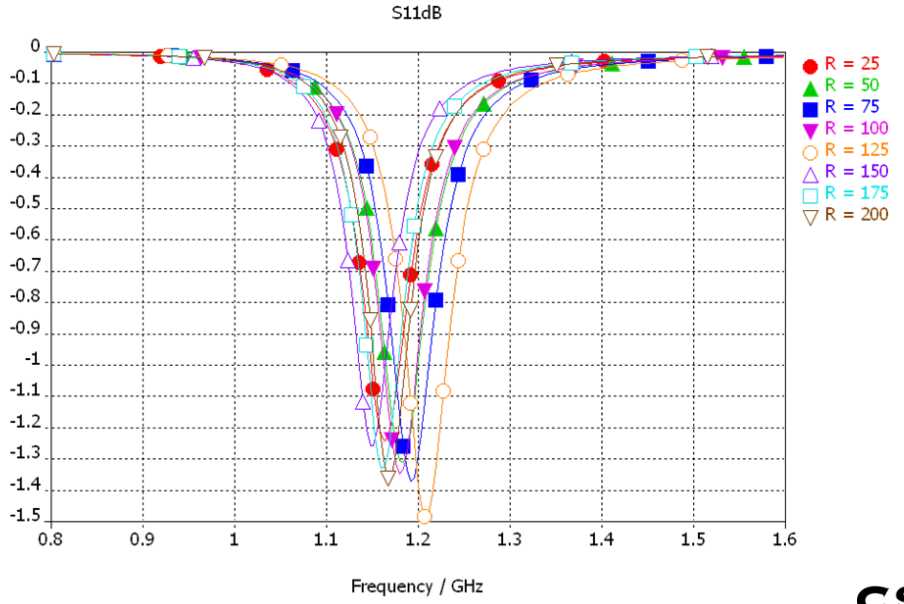


Autodesk Inventor
Mentor Graphics
Pro|ENGINEER
ZUKEN

# Parameterization

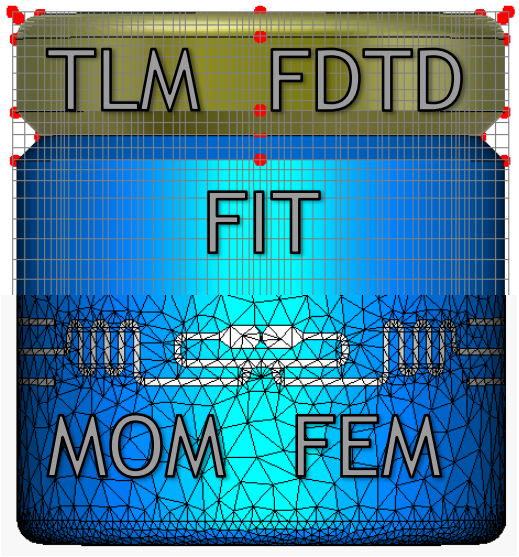
- Critical!
- Should be a fundamental part of construction.
- Should be easy to modify and parameterize imported structures.
- Allows parametric analysis and optimisation.

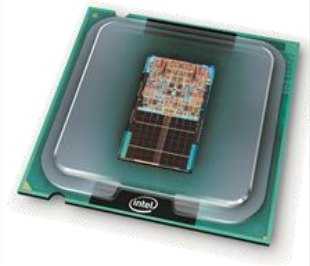


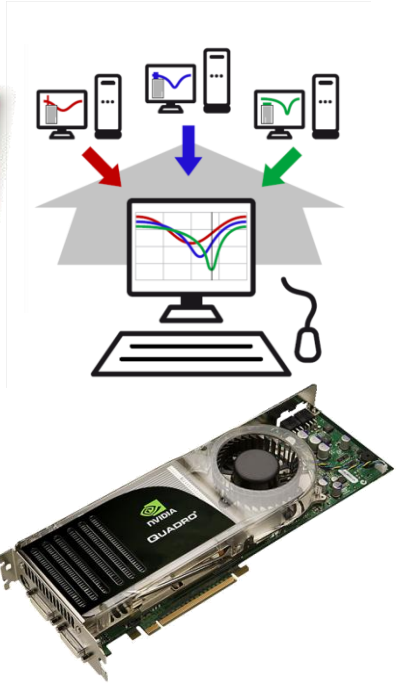



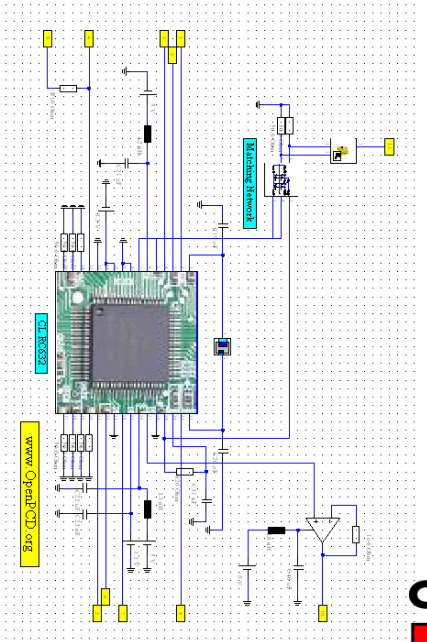
# Solver Requirements

- Choose the right solver for the job.
- Advanced algorithms efficiently using modern hardware give the best performance.
- Parametric sweeps and effective optimisers are essential.
- For systems: co-simulation of 3D EM model and attached circuit.



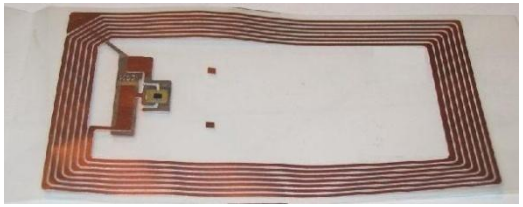





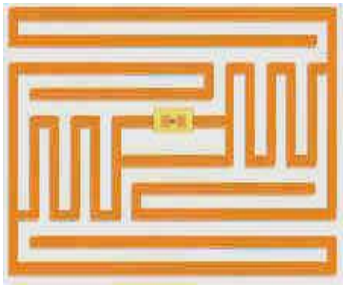



# Choose the Right Solver for the Job

- Inductive Coupling (125 kHz – 15 MHz)
  - Very small dimensions
  - Coupling only through magnetic field
  - Tag typically a planar coil
  - Best simulated in the Frequency Domain

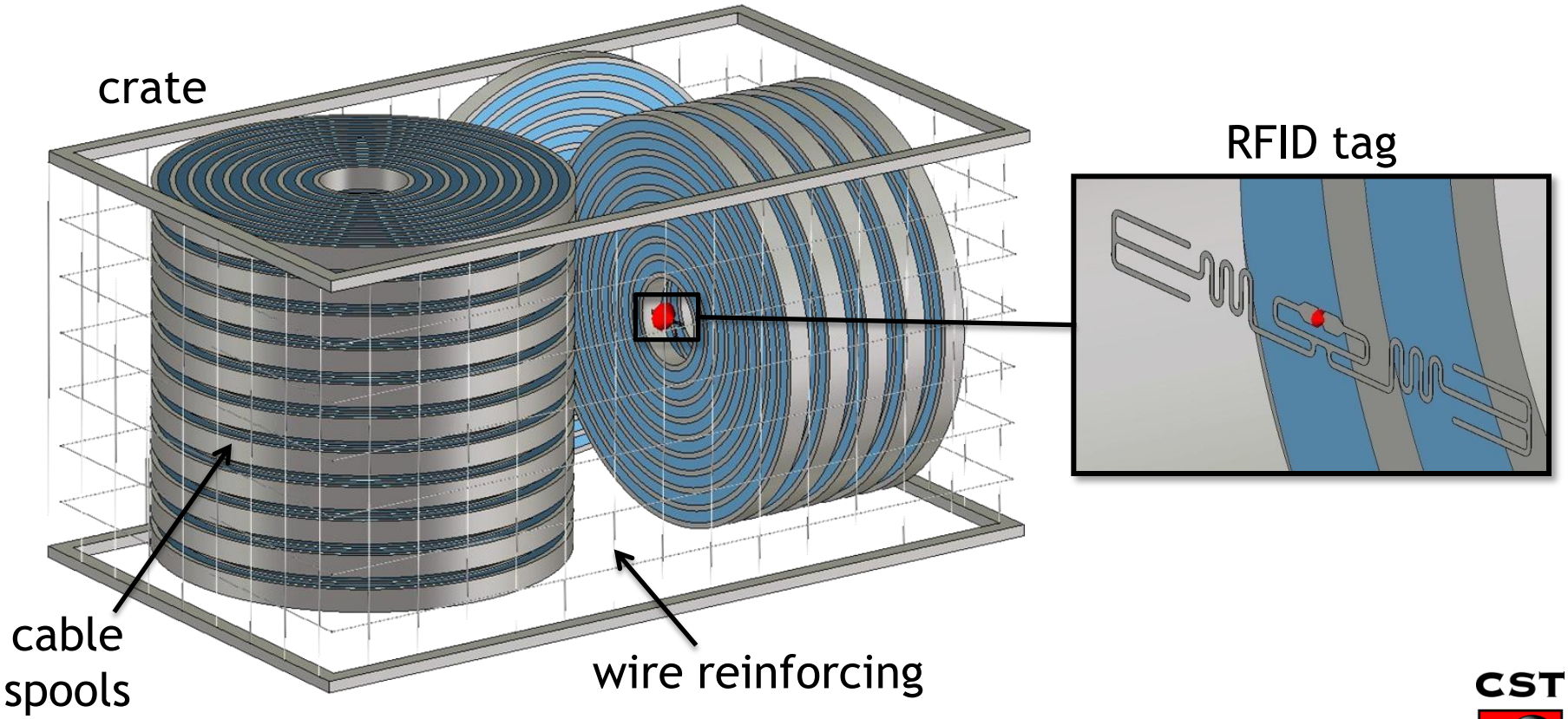


- Microwave Coupling (868 MHz – 5.8 GHz)
  - Typically a regular antenna
    (e.g. planar folded dipole)
  - Matching network important to keep antenna small
  - Best simulated in the Time Domain



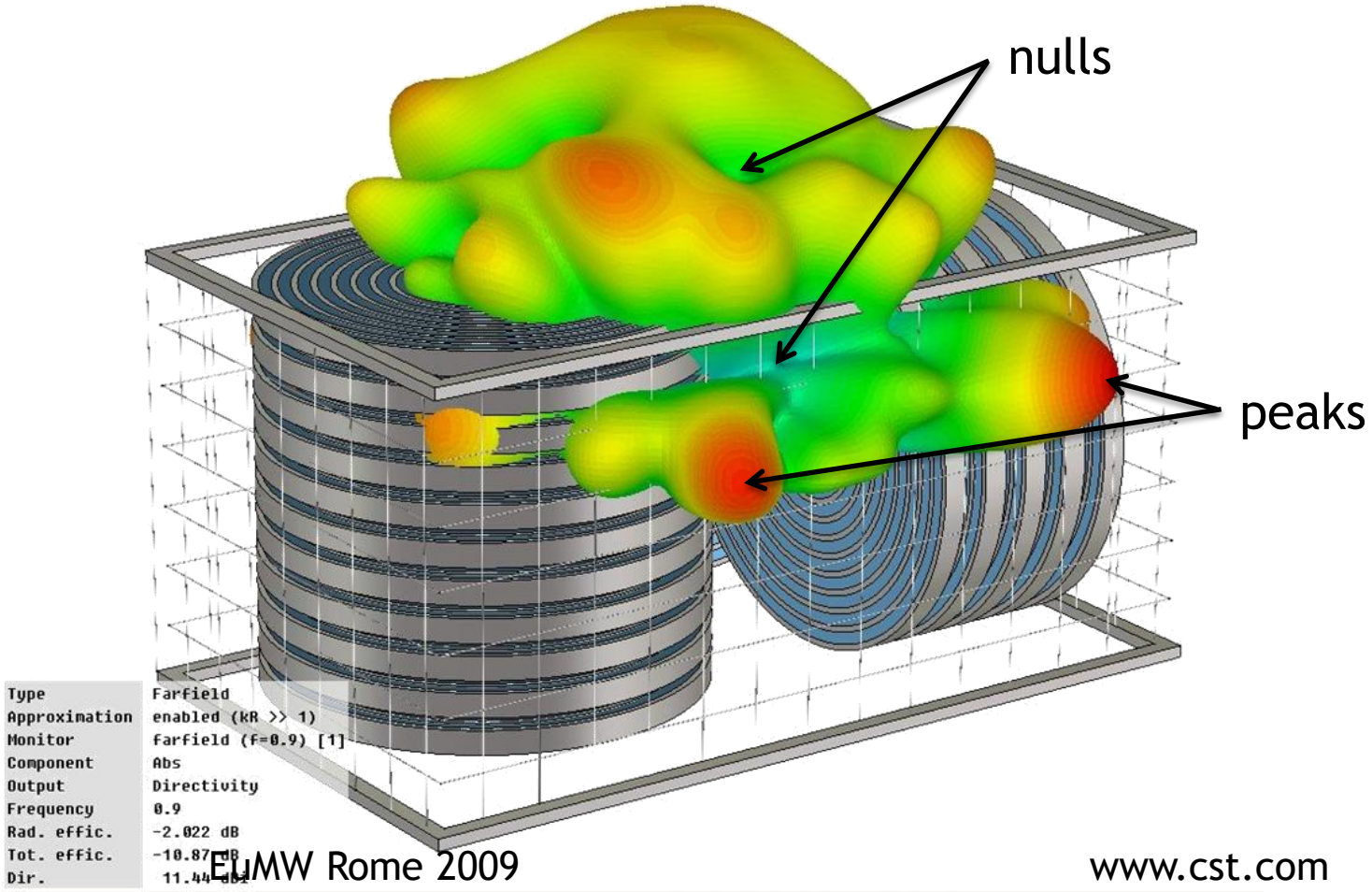
# Example: Complex Environment

- How well will the tag function when placed in a complex environment like a reinforced crate containing cable spools?



# Example: Complex Environment

- The tag functions, but there are will be reception nulls from which it cannot be read. Using this information, we can decide on where to position the reader antenna.



# Simulation of a realistic multi-tag / reader environment

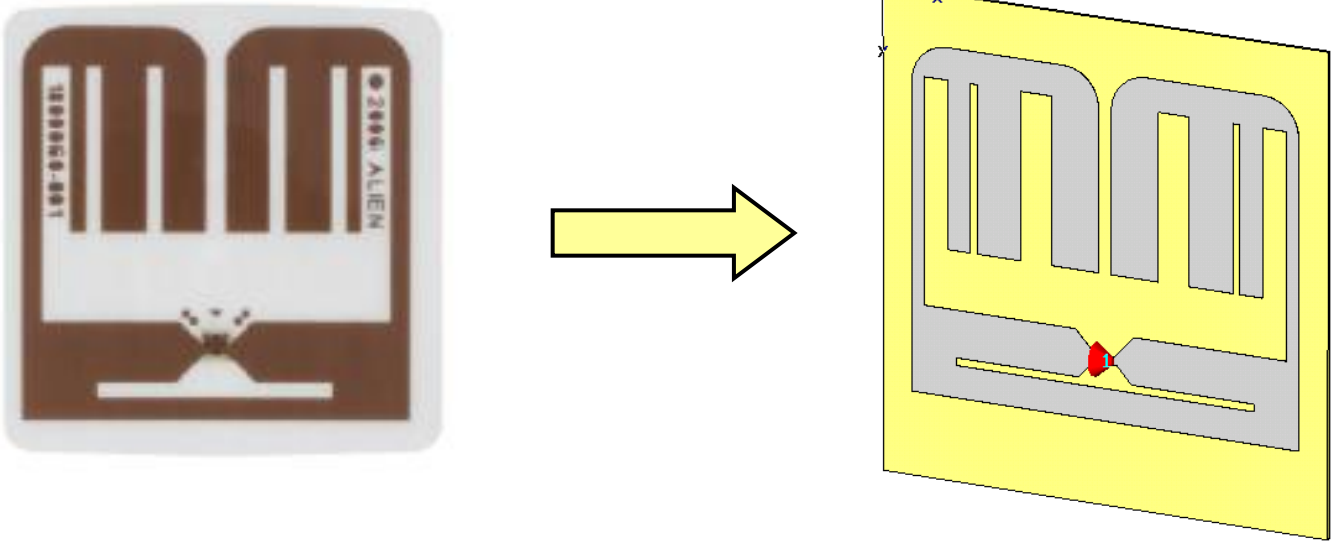
- Design of Tag and Reader
- Microwave coupling (900 MHz)
- 3D EM Simulation with CST‘s „Complete Technology“ using Time-Domain and Frequency Domain solvers
- Coupling to circuit analysis with CST DESIGN STUDIO™

# MicroWaveCoupling: TAG

## SMALL FORM FACTOR TAGS

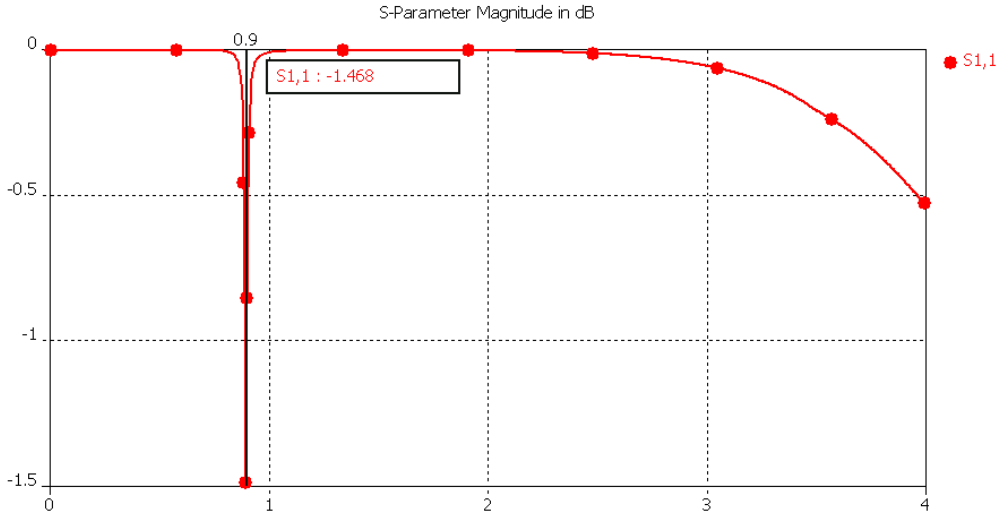
GEN 2 1X1

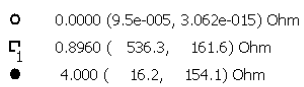
- Optimized for operation from 902 to 928 MHz
- Small form factor tag optimized for plastic packaging such as pharmaceutical pill bottles
- Near-field and far-field communication modes
- 25.4mm x 25.4mm

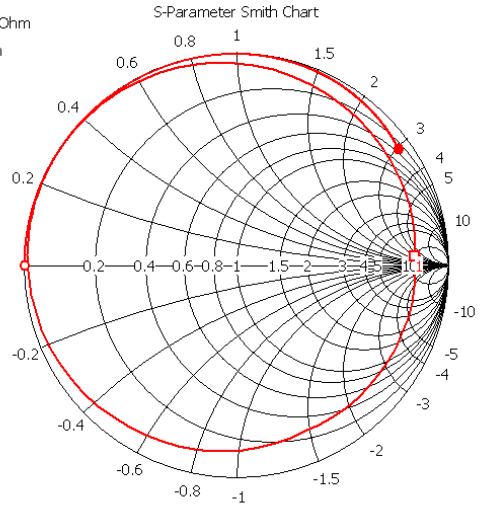



http://www.alientechnology.com/docs/Gen2_TagFam_datsht.pdf

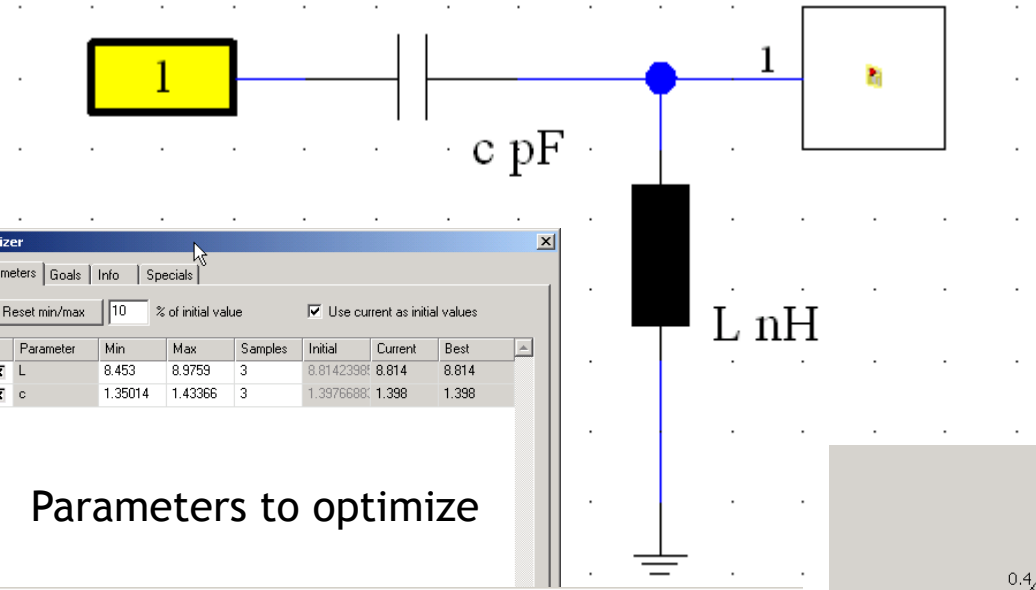
# S-Parameter
## $|S_{11}|$ in dB, unmatched



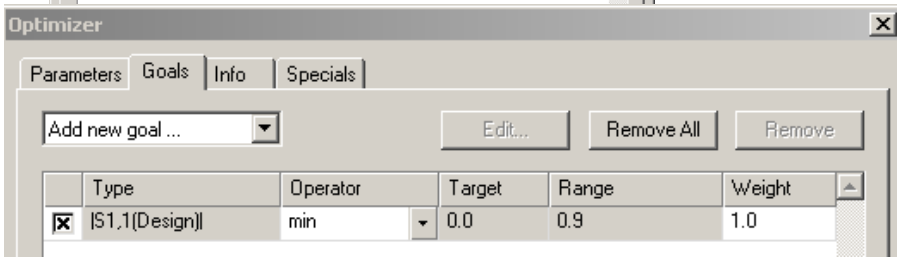
# Matching Network in DesignStudio™



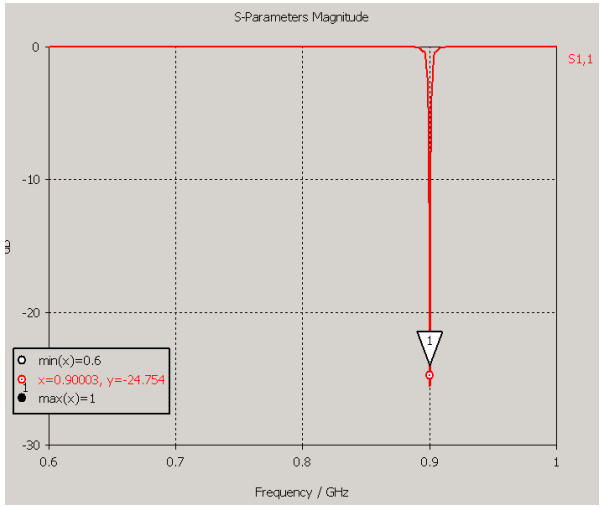


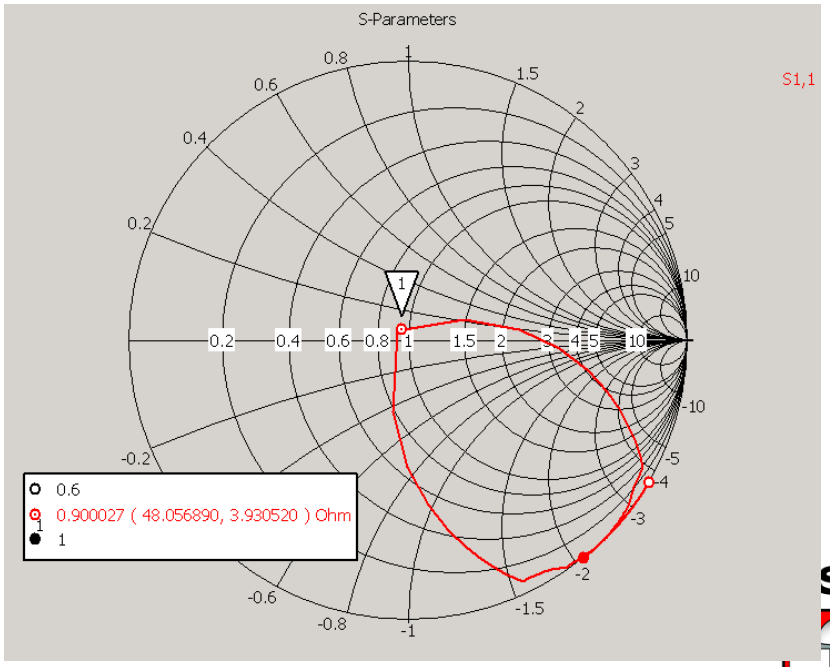


Parameters to optimize



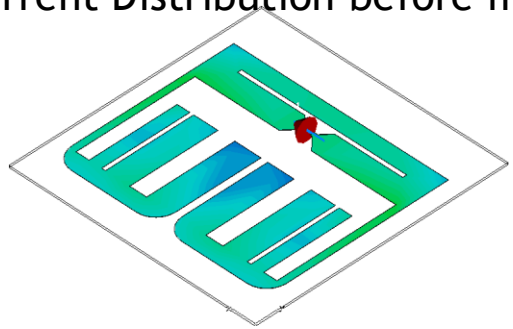

Goal definition



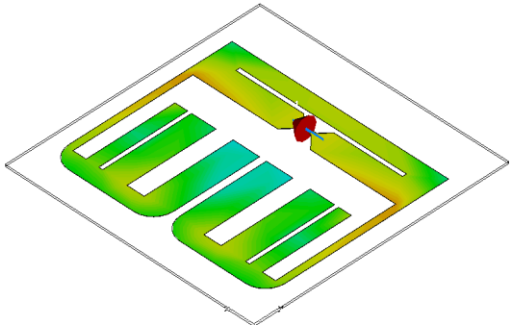



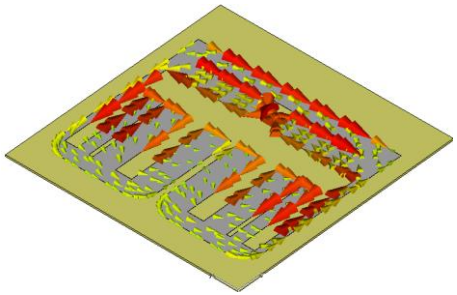
# Surface-Current and Farfield f=900 MHz

Current Distribution before matching

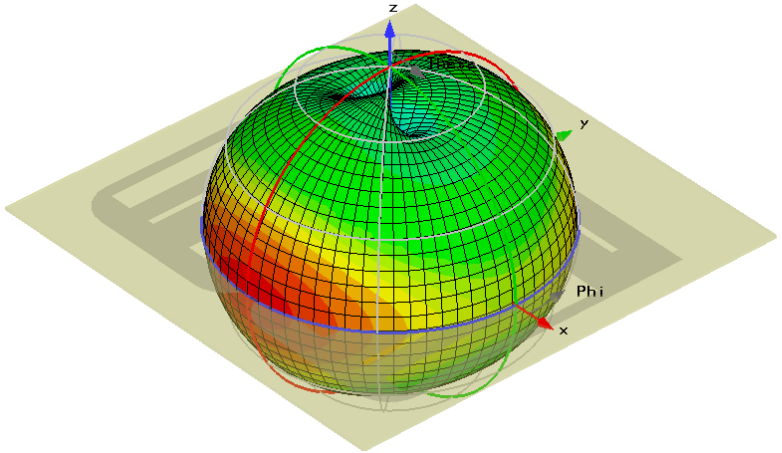


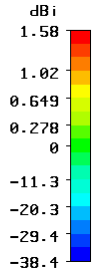
Current Distribution after matching

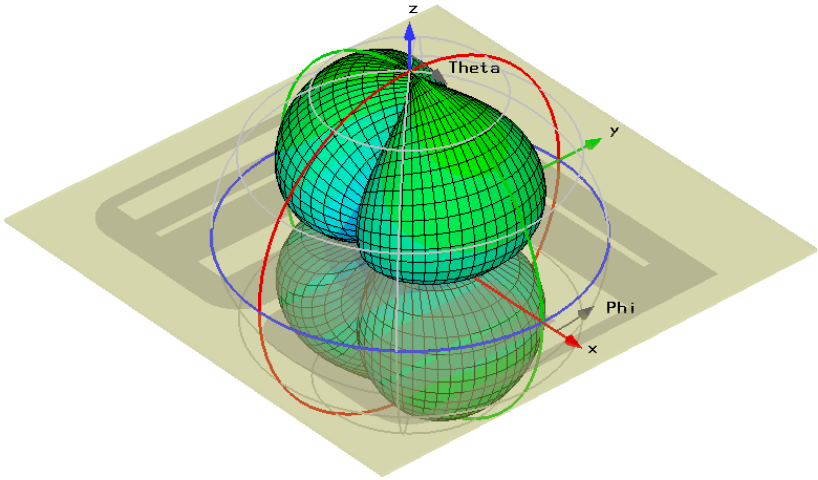


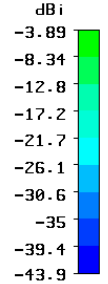


phi-component



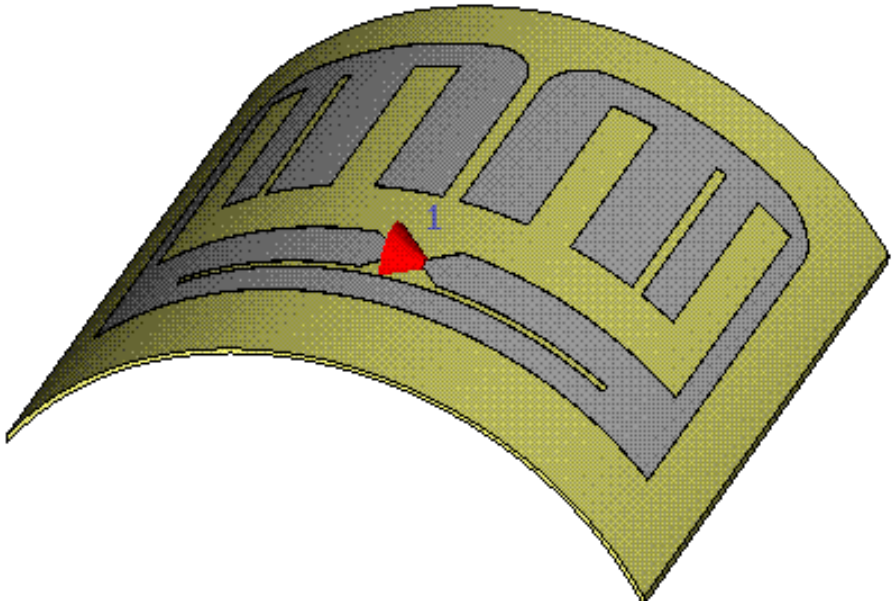



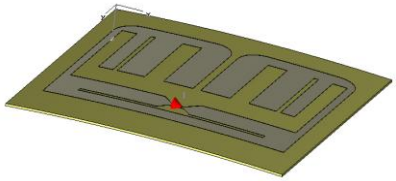



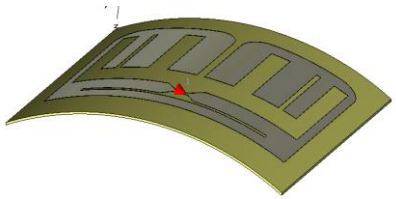

theta-component

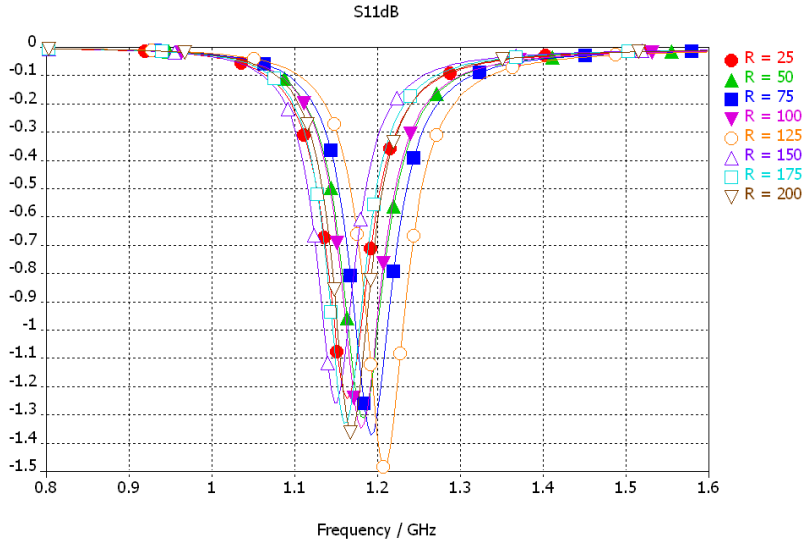
# Parameter Study of a warped Tag




The impact on S-Parameters and farfields are investigated for warped tags. The conformal radius is varied in a range of 25 – 200 mm

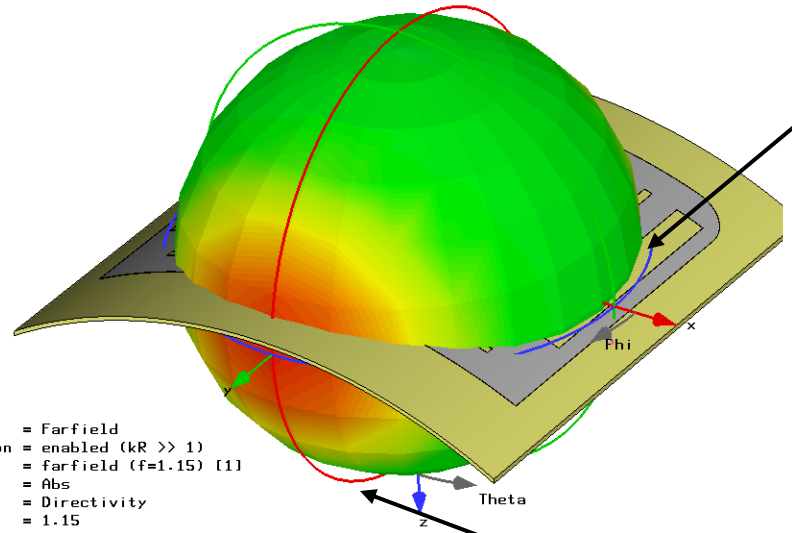




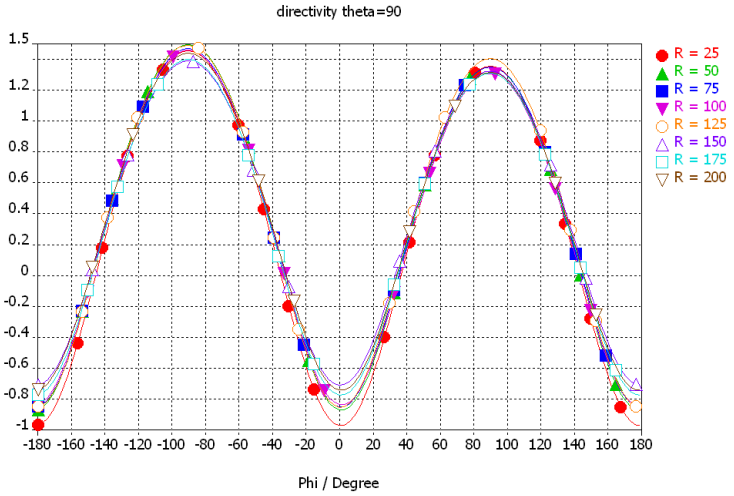


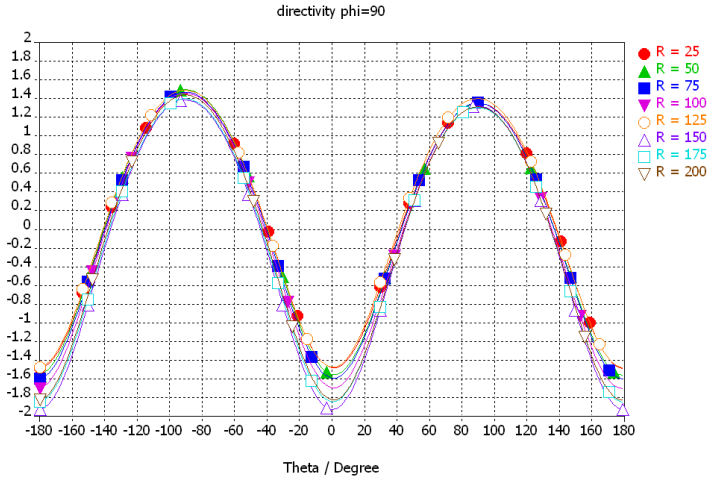
# Parameter Study of a warped Tag

Farfield at 1.15 GHz



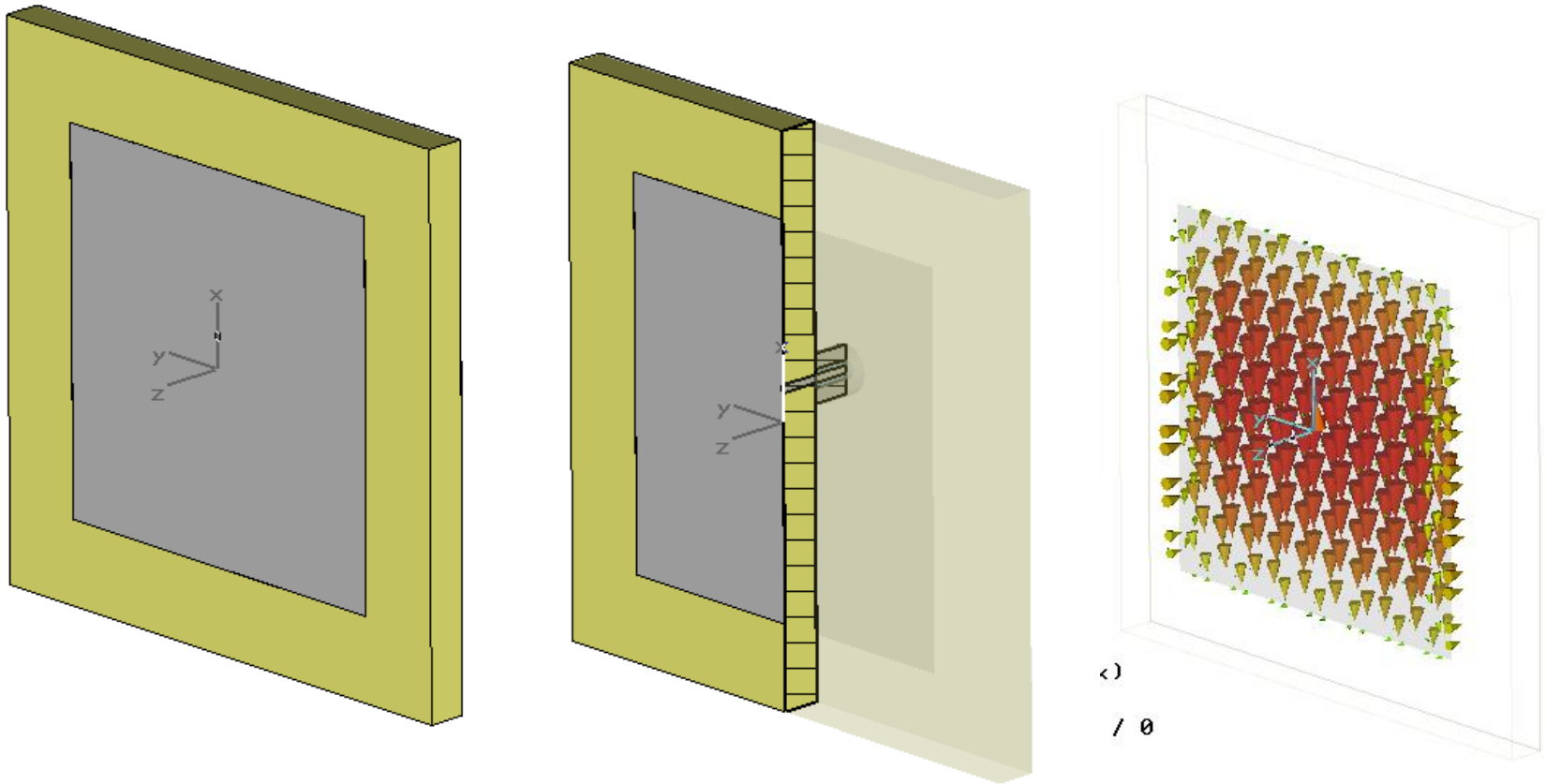

```
Type          = Farfield
Approximation = enabled (kR >> 1)
Monitor       = farfield (f=1.15) [1]
Component     = Abs
Output        = Directivity
Frequency     = 1.15
Rad. effic.   = 0.2567
Tot. effic.   = 0.1617
Dir.          =  1.529 dBi
```



# Geometry of the Reader

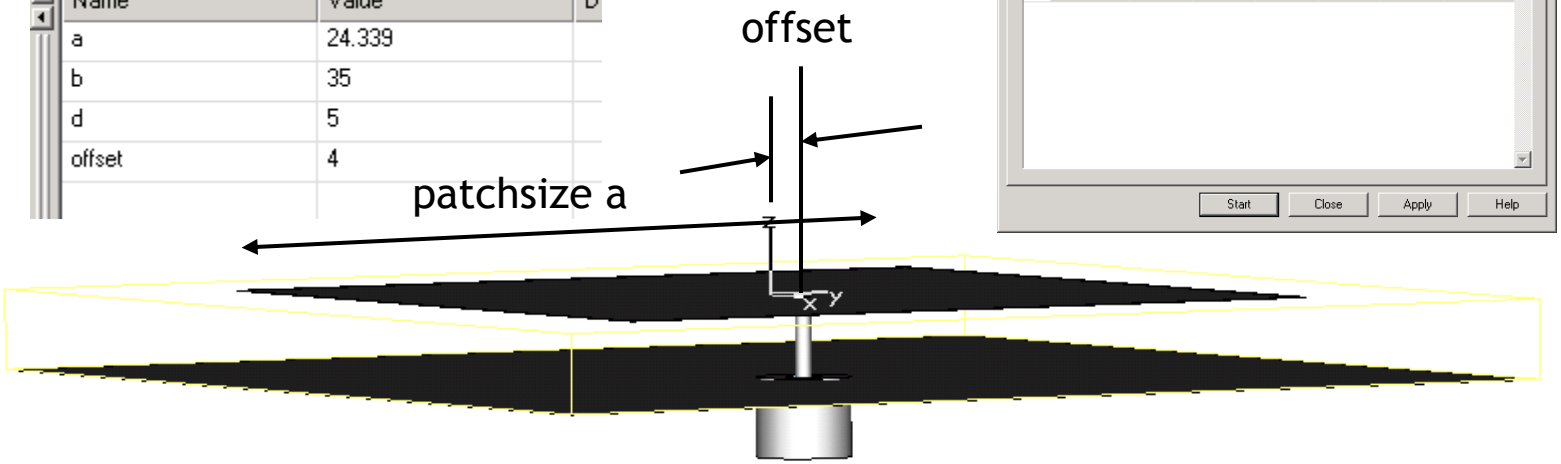
A simple, vertically polarized patch-type reader antenna was used as reader antenna. The feed is designed as a simple coax-connector line.



# Reader: Optimization

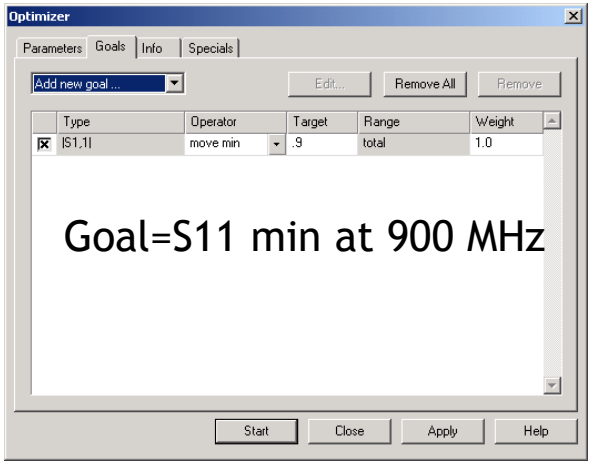
Parametric model setup

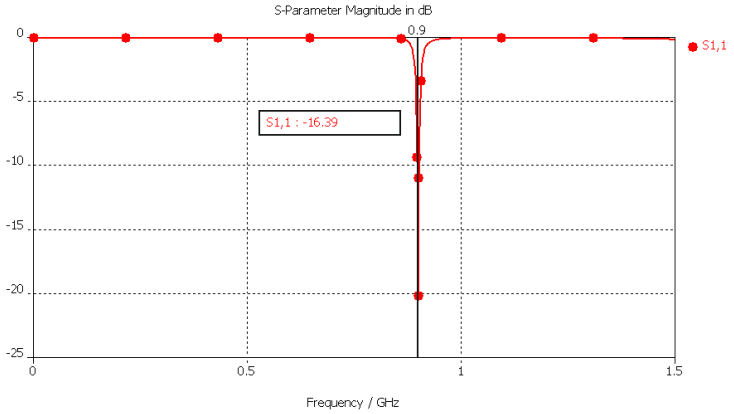
| Name | Value | D |
|---|---|---|
| a | 24.339 | |
| b | 35 | |
| d | 5 | |
| offset | 4 | |





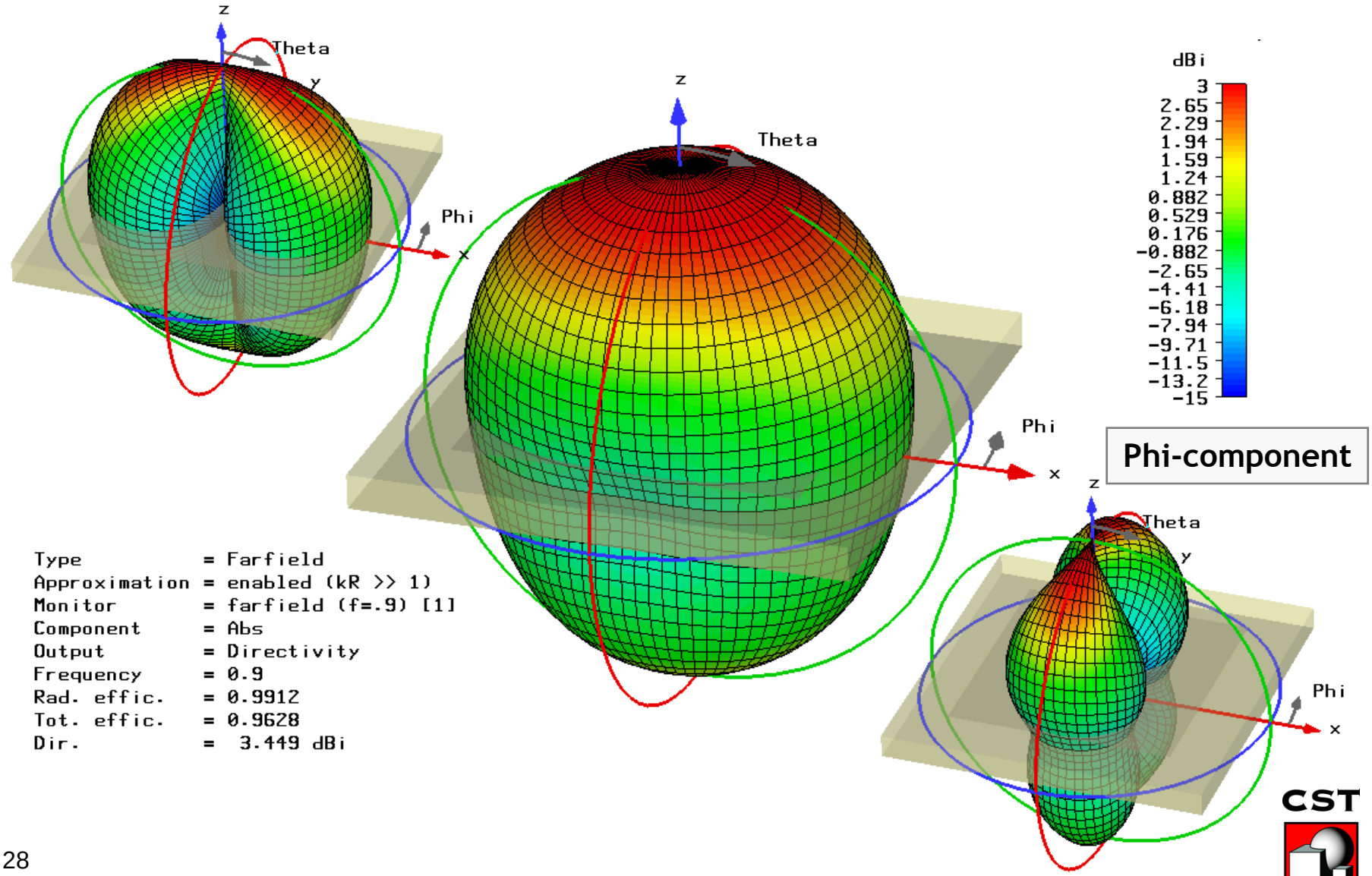




# Reader: Directivity
## f=900 MHz

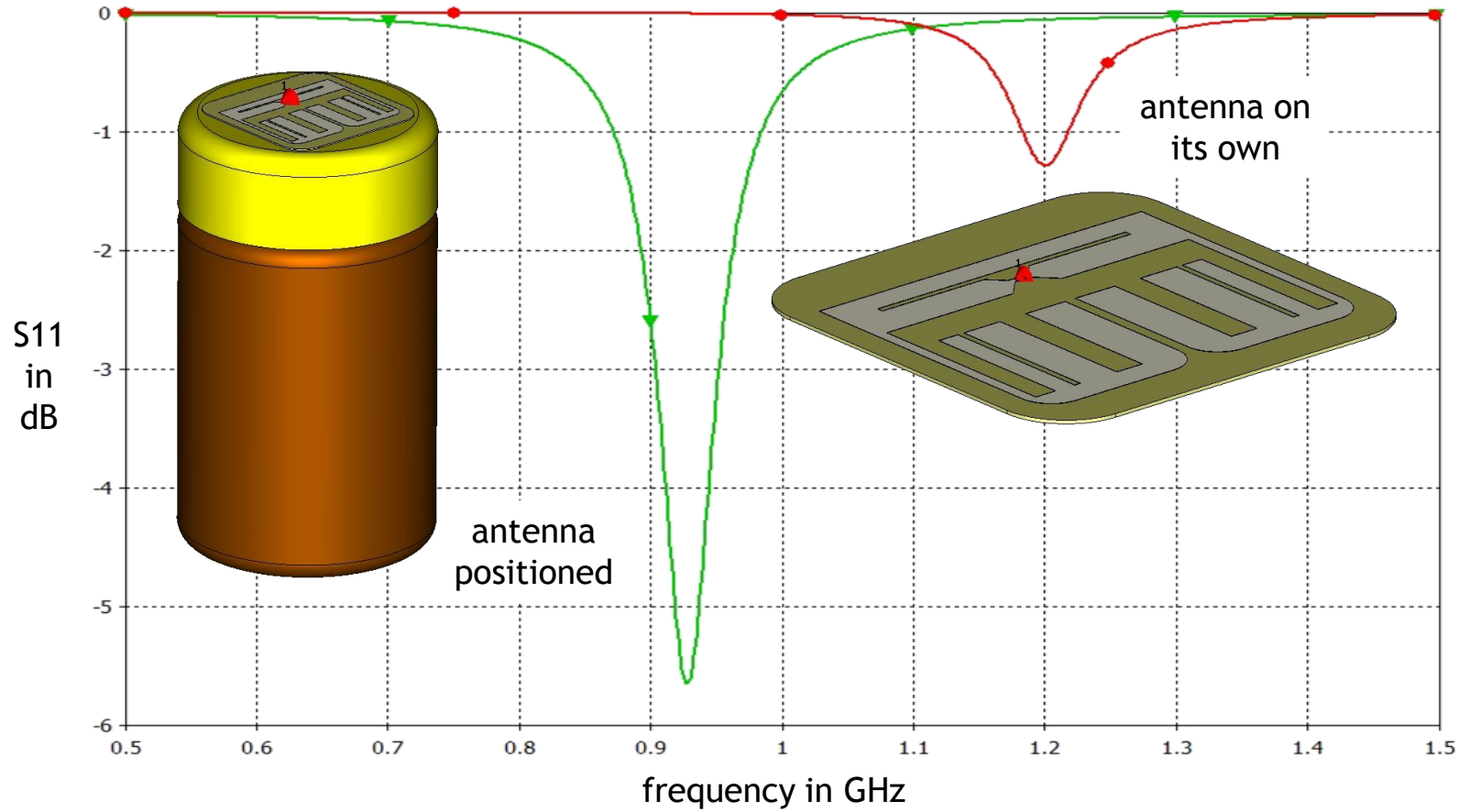
Theta-component




```
Type           = Farfield
Approximation  = enabled (kR >> 1)
Monitor        = farfield (f=.9) [1]
Component      = Abs
Output         = Directivity
Frequency      = 0.9
Rad. effic.    = 0.9912
Tot. effic.    = 0.9628
Dir.           =  3.449 dBi
```

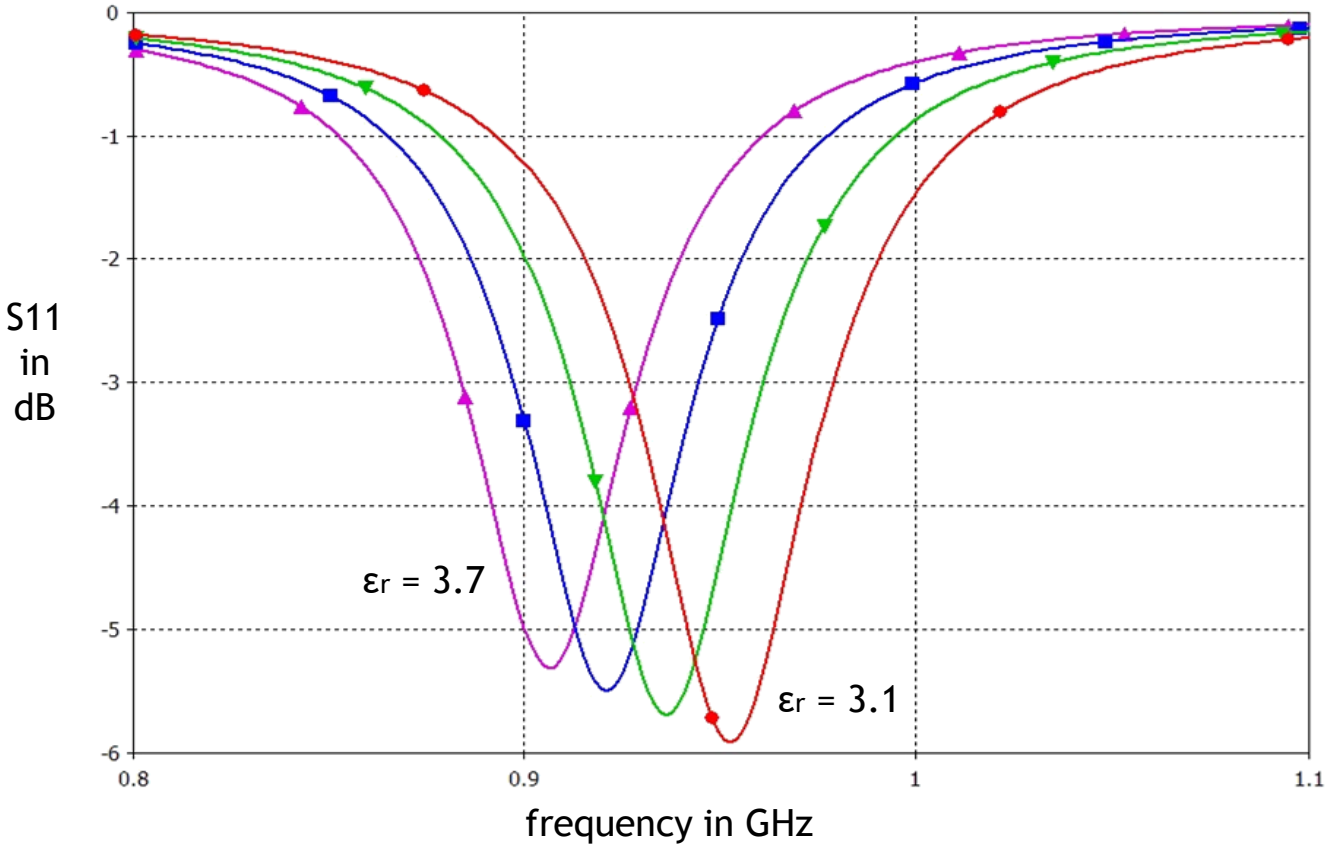
# Example: Effect of Placing Tag

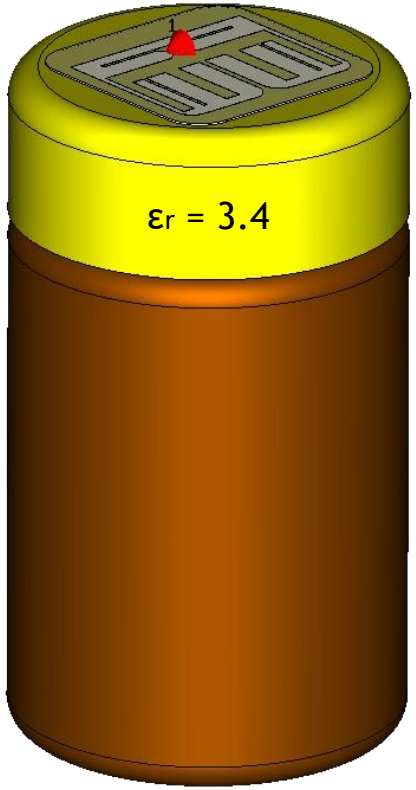
- Placing a tag on an object can have a dramatic effect on its properties, and this must be taken into account during its design.



# Example: Tag Optimisation

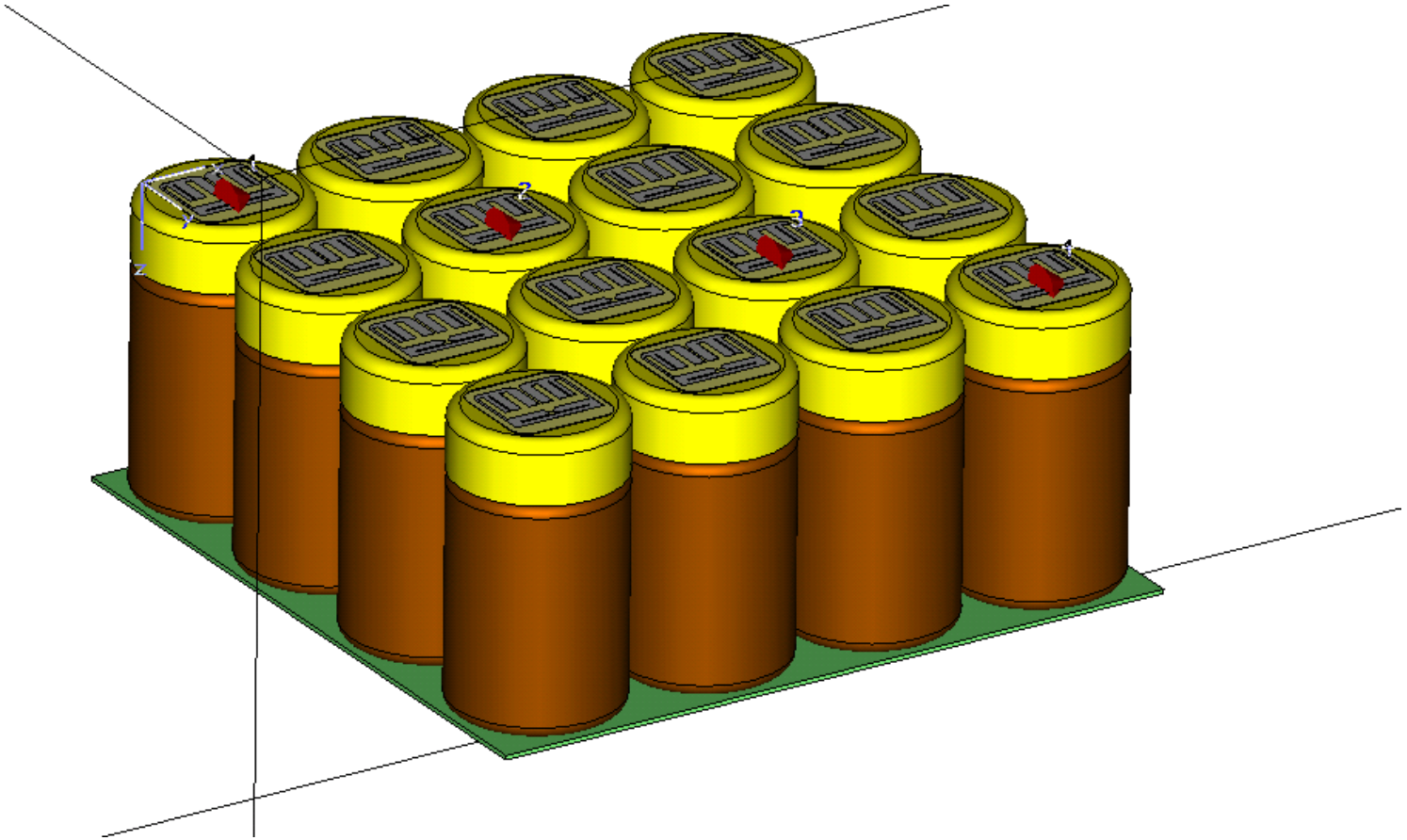
- Will the tag work despite changes in the material properties of the object on which it is placed? A parameter sweep of the permittivity may answer this question.



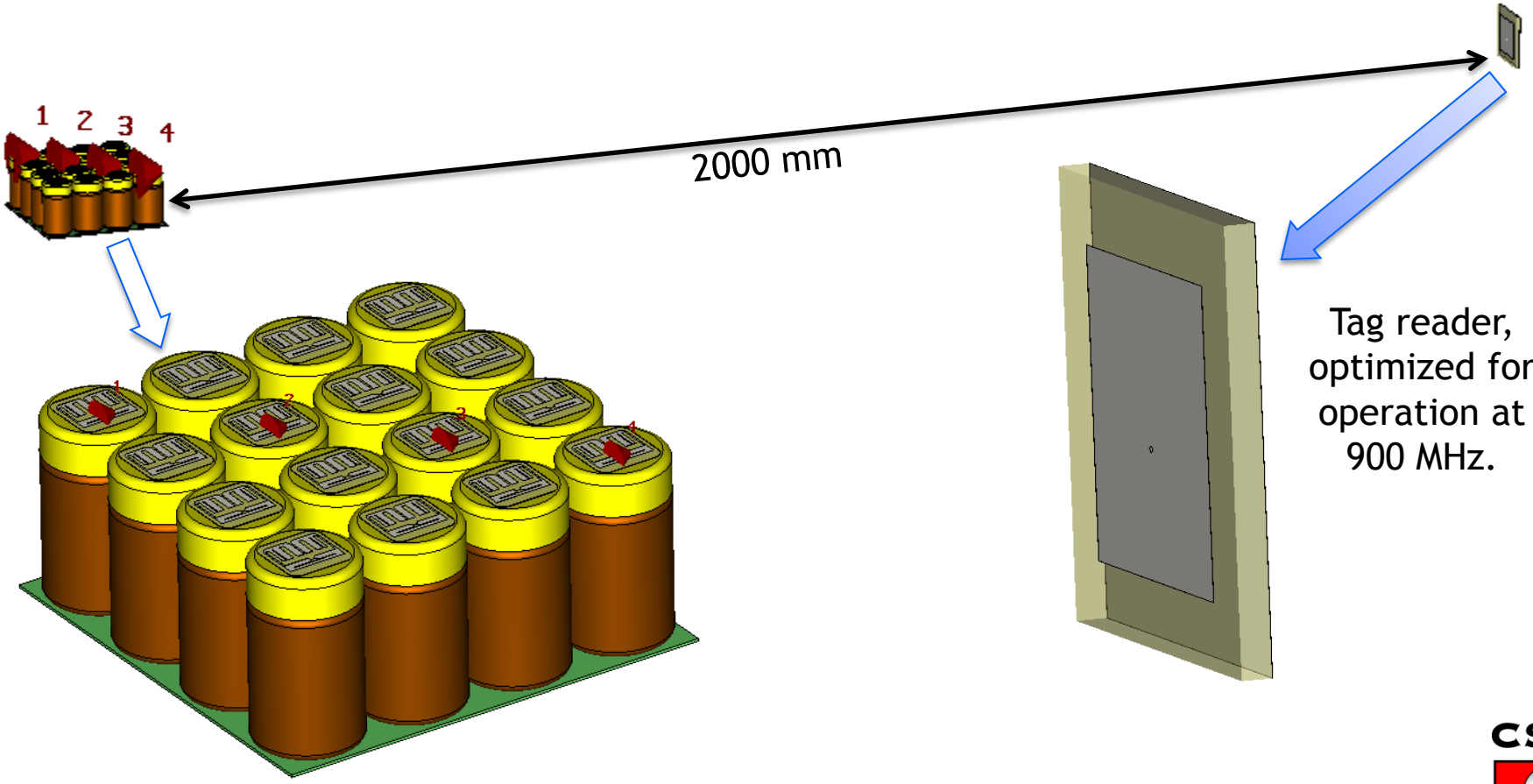
# Tags on medical pill-boxes

For a more realistic scenario, an ensemble of tags were placed on the lids of a set of pill-boxes



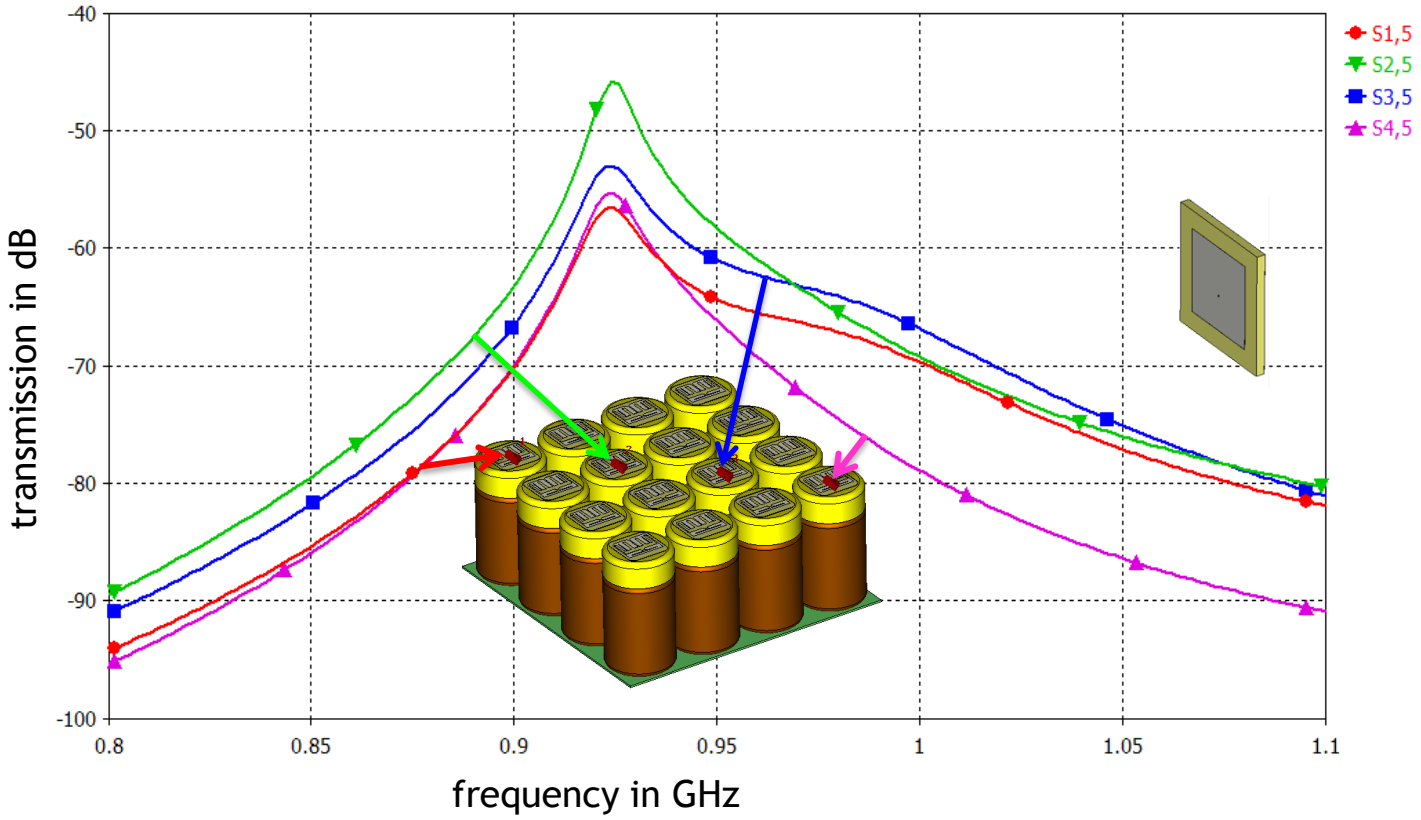
# Example: System Simulation

- How is the read range affected if the tag is placed among a group of other tags? Will the transmission to each still be sufficient?



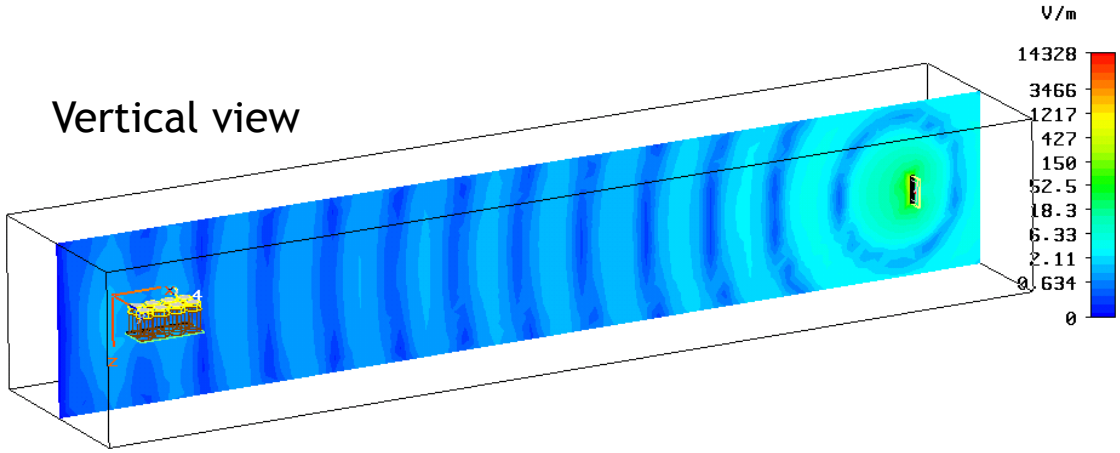
# Example: System Simulation

- Shielding effects become apparent for the tags that are further removed from the reader. We can evaluate whether transmission is still acceptable at this range.



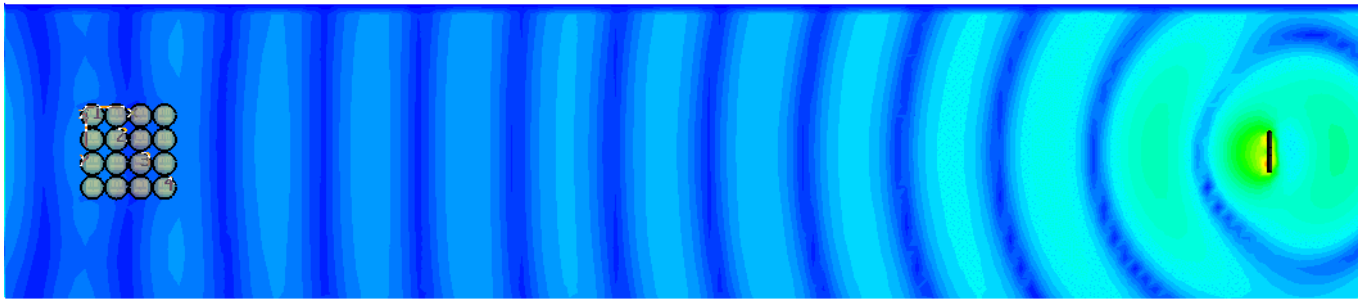
# E-Field > e-field (f=900) MHz

Vertical view




```
Type         = E-Field (peak)
Monitor      = e-field (f=.9) [5]
Component    = Abs
Plane at y   = 75.7
Frequency    = 0.9
Phase        = 67.5 degrees
Maximum-2d   = 12624.8 V/m at 2080.7 / 75.7 / 45.72
```

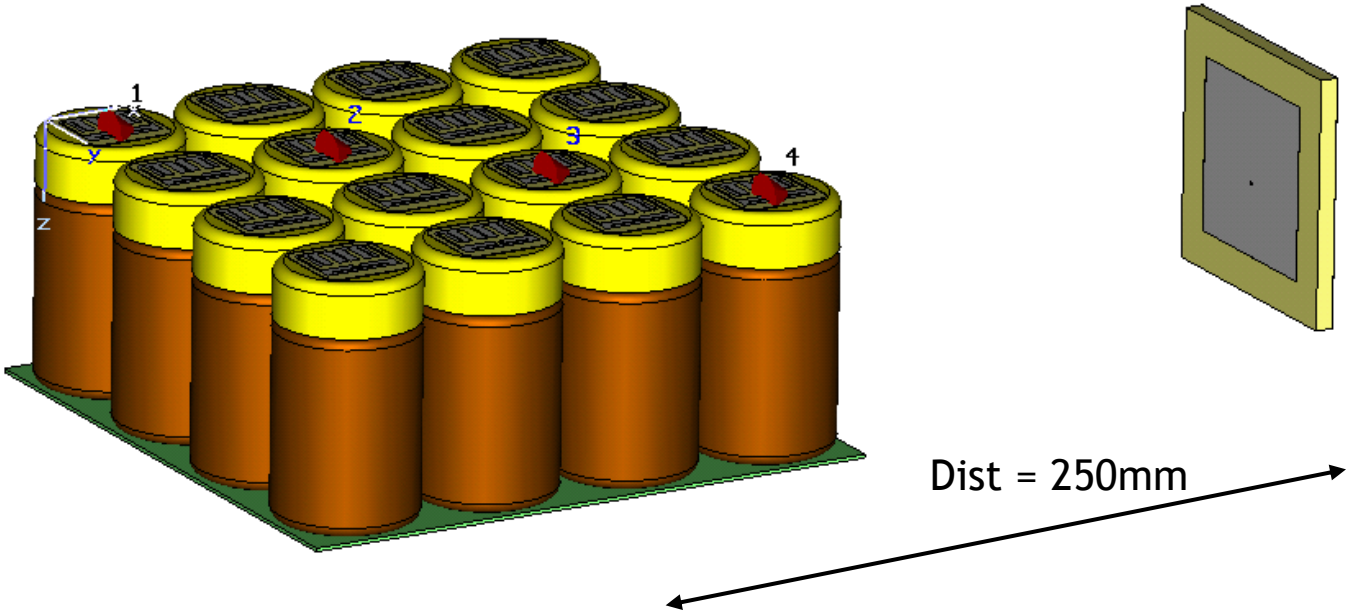
Animated top view



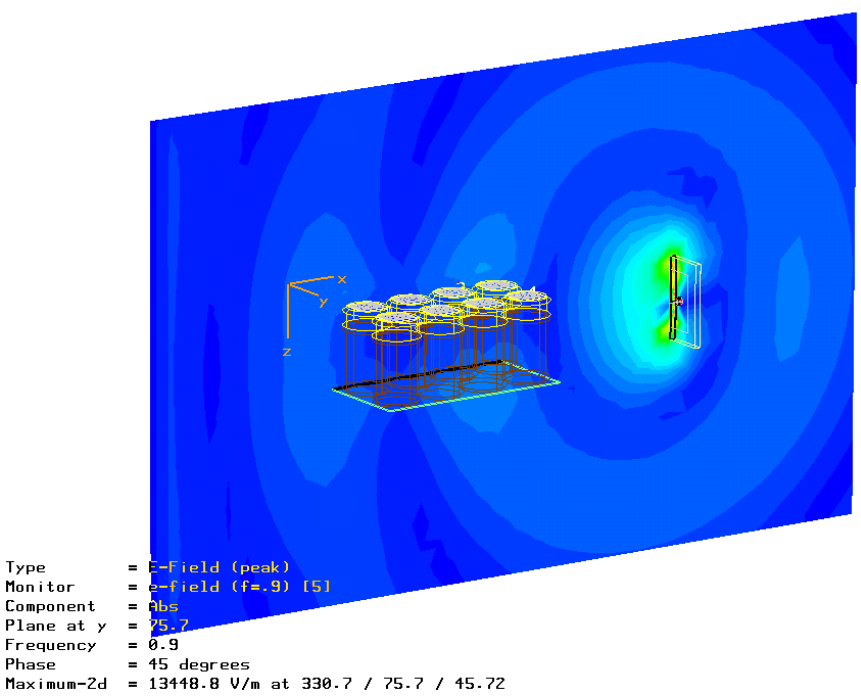
CST - Computer Simulation Technology

# Simulation of tags and reader

Broadband S-parameters are computed for a modified distance between Reader and Tag reduced to 250 mm. The reader is fed by an AM-signal, the deformed signal waveforms at the tag-ports can be observed

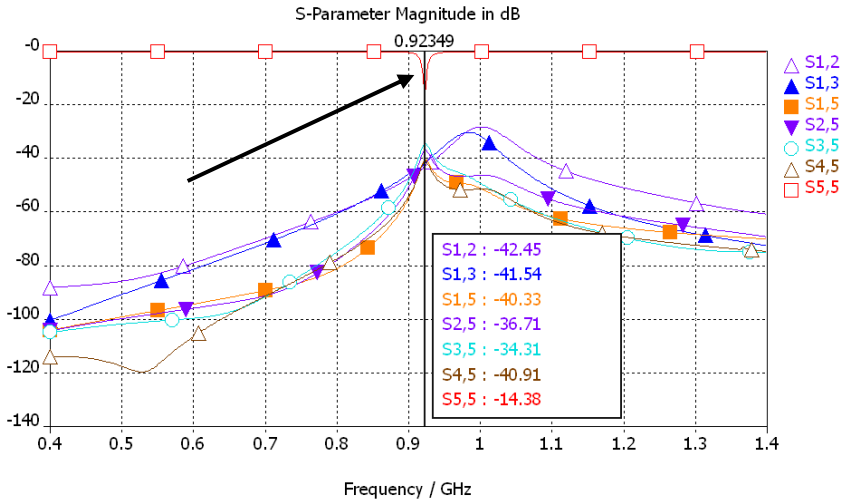


# Simulation of tags and reader




E-Field (f=900 MHz)

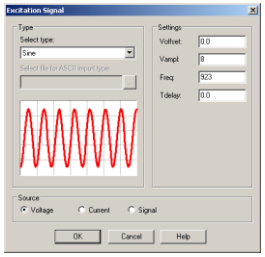
S-Parameters

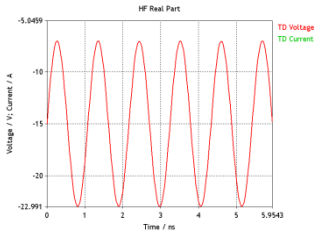



At 923 MHz the reader shows the best match. The HF-Signal for the AM-Generator is set to this frequency.

# AM Signal Generator in DesignStudio

**HF-Signal**

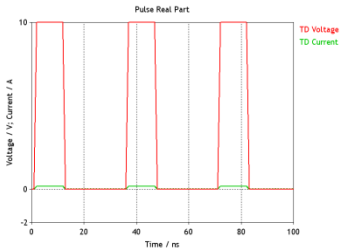


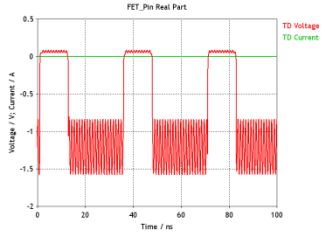





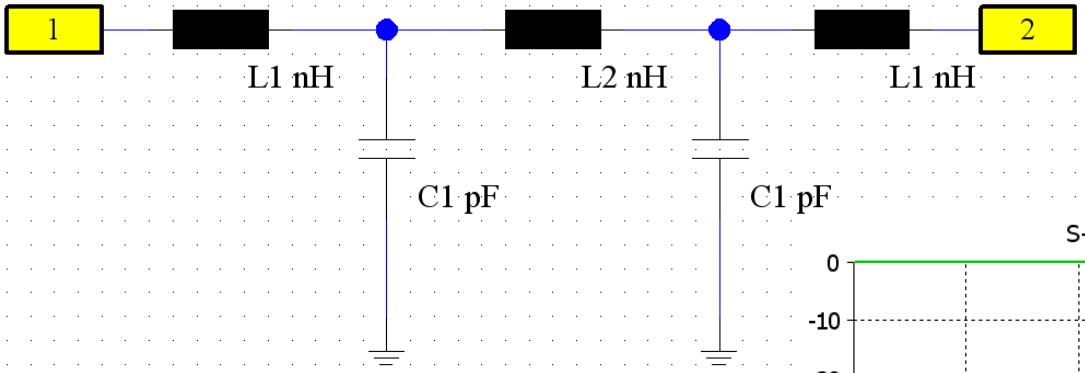




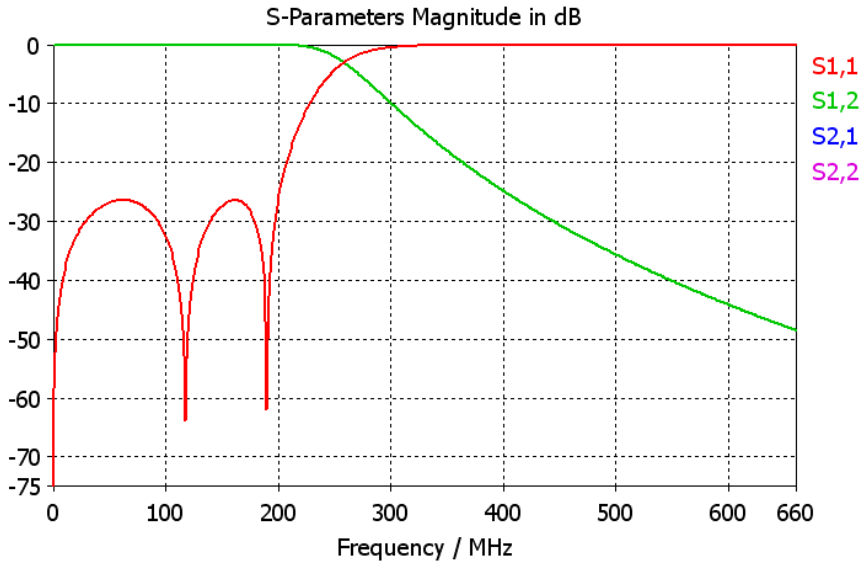



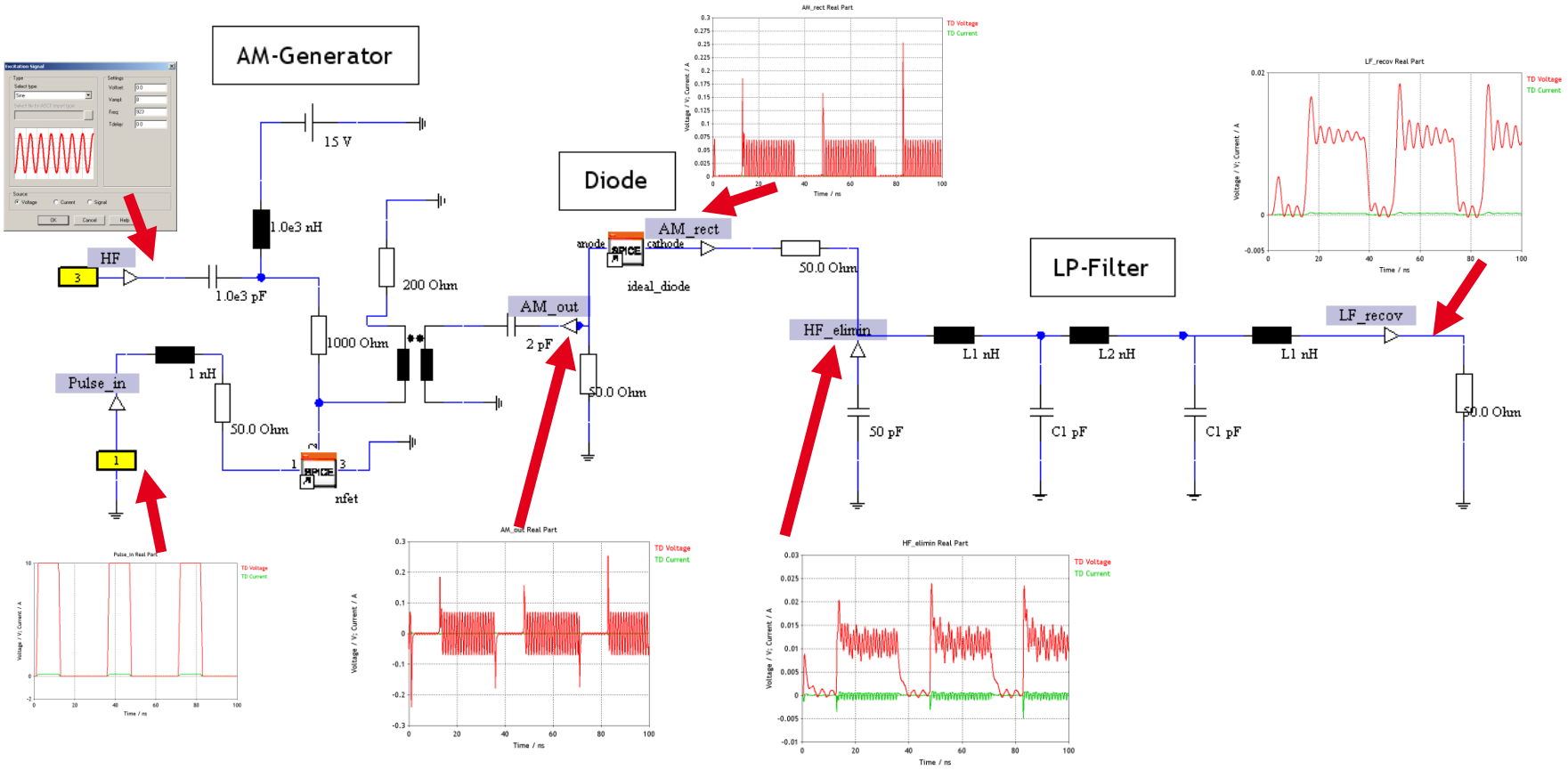
# Lowpass-Filter



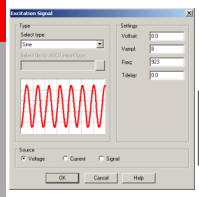

| Name | Value | Description |
|---|---|---|
| C1 | (1.3049e3/N)/Zo | |
| L1 | (0.7563/N)*Zo | |
| L2 | (1.5773/N)*Zo | |
| N | f*2*pi/1000 | |
| Zo | 50 | |
| f | 50*4 | corner frequency (MHz) |
| g1 | 0.7563 | Tchebychev Order = 5 |
| g2 | 1.3049 | Passband ripple = 0.01 dB (1.100747 VSWR) |
| g3 | 1.5773 | Return loss = -26.3828 dB |



# AM Signal Generator / AM Demodulator



# AM-SignalGenerator+RF-IDs+AM Demodulator



AM Signal Generator

15 V

1.0e3 nH

200 Ohm

3

1.0e3 pF

HF

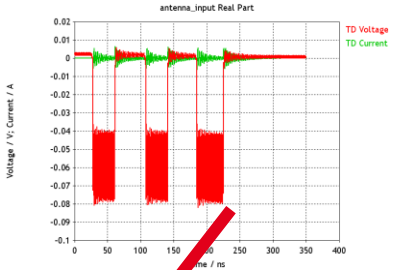
1000 Ohm

1000 pF

IDEALTRANSFORMER1

Ratio 20

antenna_input

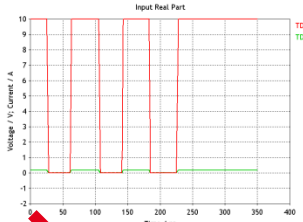



AM Input-Signal at RFID Reader-Antenna

20 Ohm

1.0 nH

1.4 pF




Input

1

1 nH

50.0 Ohm

SPICE

nfet

TAG_1

20 Ohm

20 Ohm

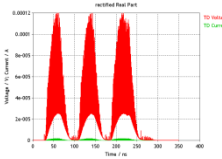
TAG_2

TAG_3

TAG_4

rectified

ideal_diode




anode

cath

SPICE

1.4 pF

20 Ohm

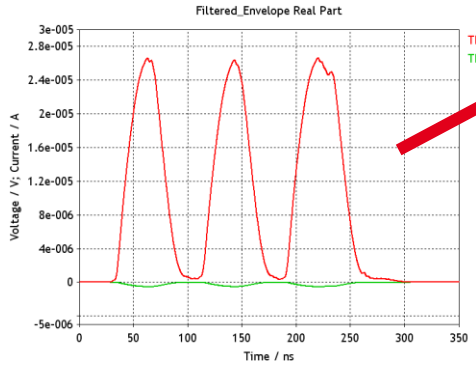
0.001 nH

Diode

Demodulator

LF-Signals at RFID Tag 3

Filtered_Envelope




LP-Filter

50.0 Ohm

30 nH

62.75 nH

30 nH

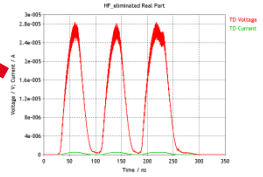
50.0 Ohm

21 pF

21 pF

HF_eliminated

100 pF

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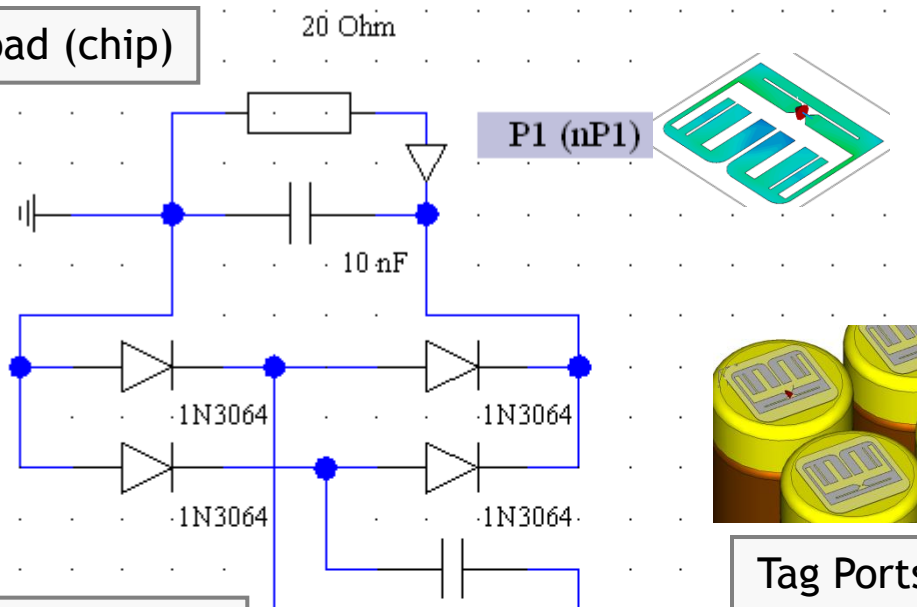
# Generating the DC-Voltage at the tag

Tag-load (chip)



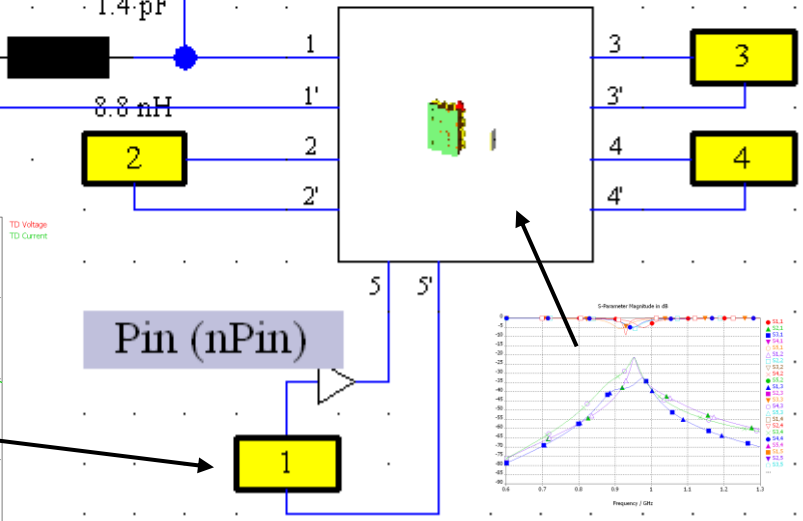

P1 (nP1)



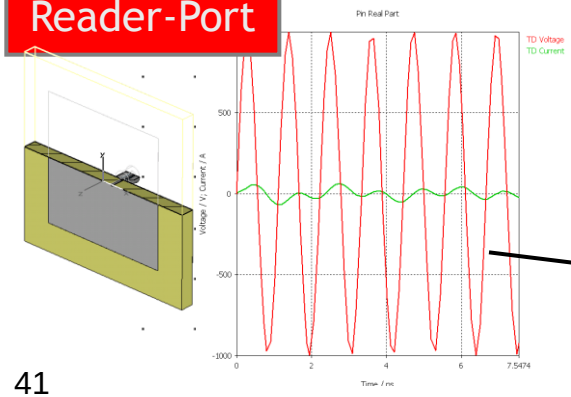


Tag Ports 2-5

Matching network



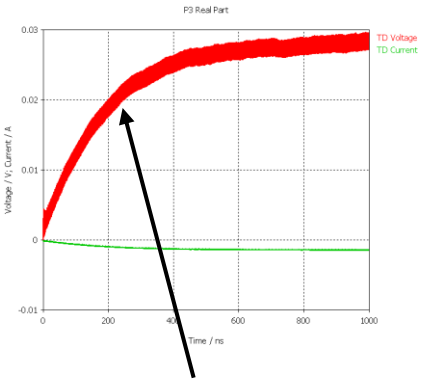

Reader-Port

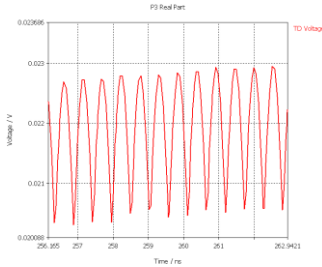


Pin (nPin)



broadband 0-4 GHz





tag P1



CST

# Summary

- CST RFID is a general concept using different technical principals
- complete technology approach offers best solution for each case
  - CST MWS Frequency Domain / CST EMS for inductive type
  - CST MWS Transient for microwave type
- Coupling between CST DS and CST MWS allows easy combination of circuit and 3D EM analysis, e.g. for
  - Tag matching networks
  - Reader circuits (using the new Transient solver in CST DS)