# Computer-Aided Design of Antennas, Transmission Channels and the Optimisation of Transponder Systems

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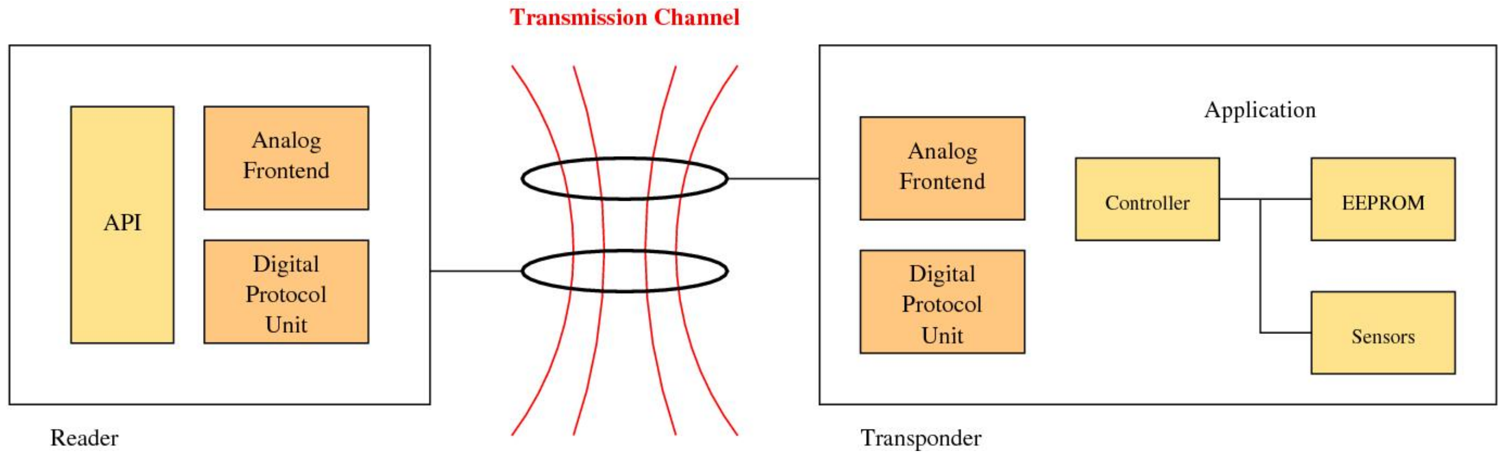
# Outline

- Introduction
- Transponder System Design and Objectives
- Modelling and System Calculation
- Optimisation Strategies
- Example
- Conclusion

# Introduction

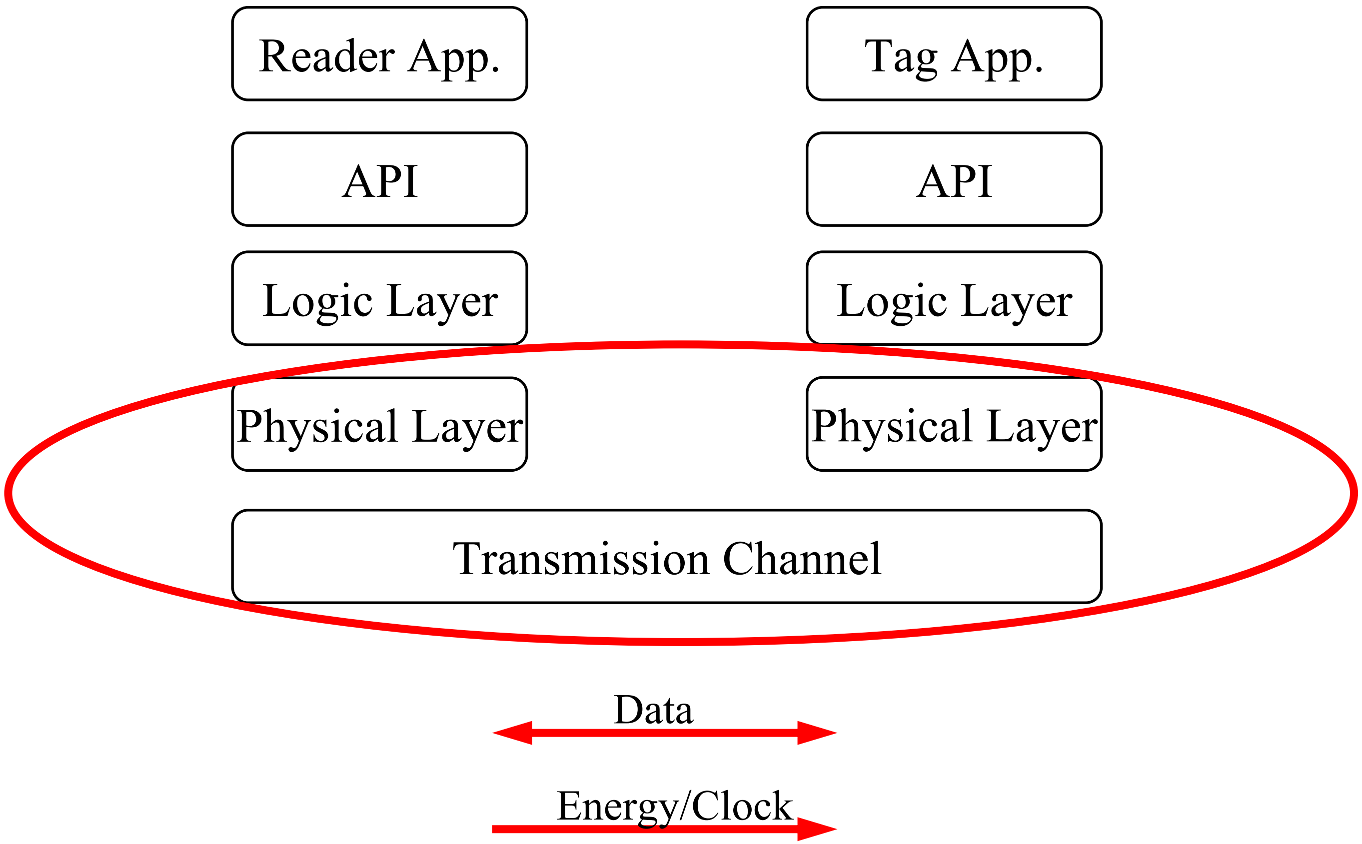
- Differentiation on RFID systems
- Communication & applications
  - Application → ID, object info, data logger, sensor systems
  - Type → active, passive
  - Antenna configuration
  - Environment
  - Link distance
  - Used protocol, compatibility (ISO, EPC, IEEE)

# Transponder System Design




- Reusable components for RFID communication
  - Front-end, digital protocol unit
- Application specific components
  - Customised analogue and digital parts
  - Memory
  - Sensors (temperature, humidity, pressure, acceleration…)
  - Antennas (transmission channel)

# Transponder System Design (2)




- Focus on systems with inductive coupling (LF and HF → 125 kHz, 13,56 MHz)

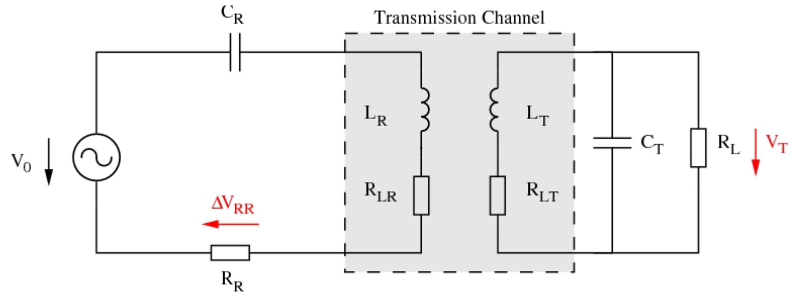
# Objectives – Summary

- General Objectives
  - Bidirectional data transfer
  - Unidirectional energy transfer
  - Optimised antennas for reader and transponder
- Objective Functions
  - Energy range
  - Transponder signal range
- Approach of modelling and optimisation
- Reducing prototyping

# Constraints – Summary

- Transmission Channel
  - Geometric dimensions of the antennas (min, max)
  - Surrounding
  - Link distance (constant or maximal)
- System
  - Transponder voltage (min, max)
  - Demodulator sensitivity (Reader)
  - Data rate/band width

# Objective Functions




## Transponder signal range

$$\Delta V_{RR} = V_0 R_R \left( \frac{1}{\mathrm{Re}[Z_R(Z_L)]} - \frac{1}{\mathrm{Re}[Z_R(Z_{LMod})]} \right)$$

$$\mathrm{Re}[Z_R] = R_R + R_{LR} + \frac{(\omega M)^2}{(-R_{LT} - Z_L)^2 + (\omega L_T)^2}(R_{LT} + Z_L)$$

## Energy range

$$V_T = \frac{V_0}{(R_R + R_{LR})} \frac{j\omega M R_L}{\sqrt{2 R_{LT} R_L + \left( \frac{R_L R_{LT}}{\omega L_T} \right)^2 + (\omega L_T)^2}}$$

$$M = k\sqrt{L_R L_T}$$

# Objective Functions (2)

Transponder signal range

$\Delta V_{RR}=F(M,L_T,R_{LT},V_0,R_R,R_{LR})$

Energy range

$V_T=F(M,L_T,R_{LT},R_L,V_0,R_R,R_{LR})$

- Transmission channel
  - Impedance matrix

$$\mathbf{Z}_{TC} = \begin{bmatrix} R_{LR}(G) + j\omega L_R(G) & -j\omega M(GC) \\ j\omega M(GC) & -(R_{LT}(G) + j\omega L_T(G)) \end{bmatrix}$$

$L_T \leftrightarrow R_{LT}$

$L_R \leftrightarrow R_{LR}$

$M \leftrightarrow L_R, L_T$

- Electrical constraints
  - Quality factor of reader
  - Quality factor of transponder

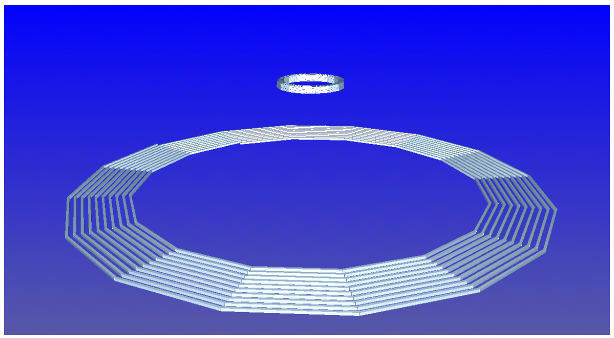
$$Q_R = \frac{\omega_0 L_R}{R_{LR} + R_R} \qquad Q = \frac{\omega_0}{B}$$

$$Q_T = \frac{2\omega_0 L_T R_L}{R_L{}^2 + 2R_L R_{LT} - \sqrt{R_L{}^4 - 4\omega_0^2 L_T{}^2 R_L{}^2}}$$

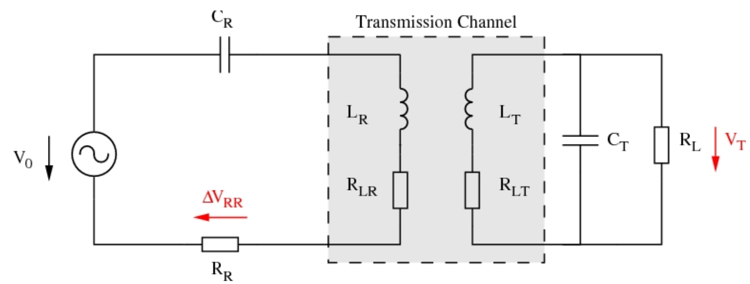
# System Calculations

- Coupling of two domains

## Electromagnetic model



## Electrical model




- Calculation impedance matrix of transmission channel

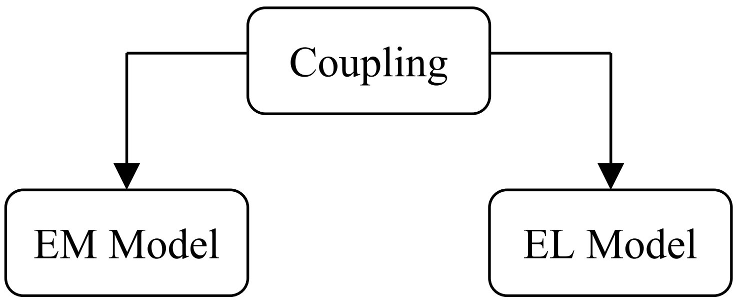
$$\mathbf{Z}_{TC} = \begin{bmatrix} R_{LR} + j\omega L_R & -j\omega M \\ j\omega M & -(R_{LT} + j\omega L_T) \end{bmatrix}$$

→

- Calculation of $V_T$, $\Delta V_{RR}$

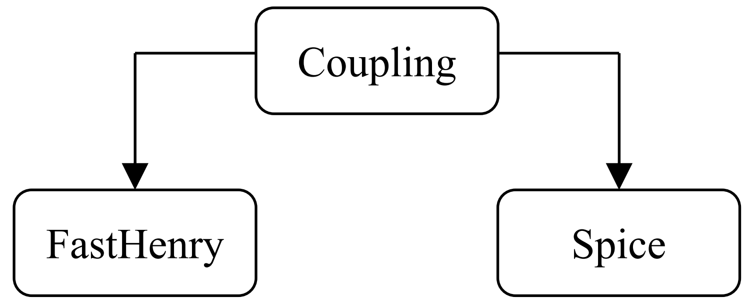
# Modelling and Model Coupling

## Model based coupling




- Analytic approach for EM and EL model
- C++ classes
- Standard geometries for antennas and electrical circuits
- Short calculation time

## Tool based coupling



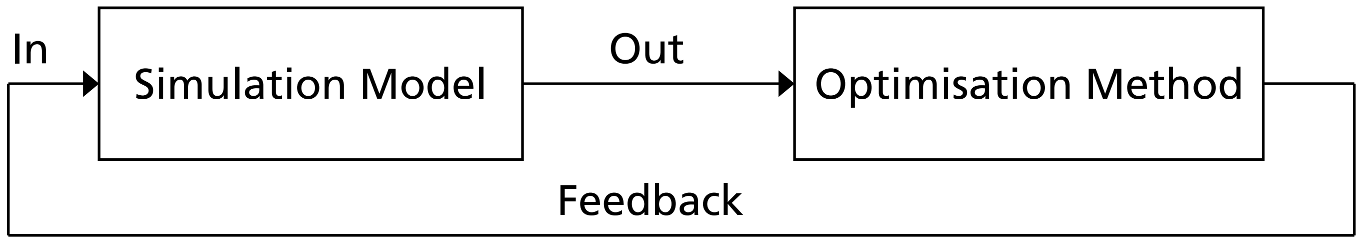

- Numerical approach for EM and EL model
- Analysing complicated antenna geometries
- Analysing complex electrical circuits
- Higher calculation time

# Optimisation

- Goal: Find optimal parameter set for transponder system
  - Dimensioning of reader and transponder antenna
  - Adaptation of electrical circuit
- Optimisation method
  - Find extremes
  - Find area of valid systems
- Optimisation method depends on
  - Properties of objective functions
  - Properties of parameter space
- Robust, reliable strategy
- Minimise calculation time/cost

# Optimisation (2)

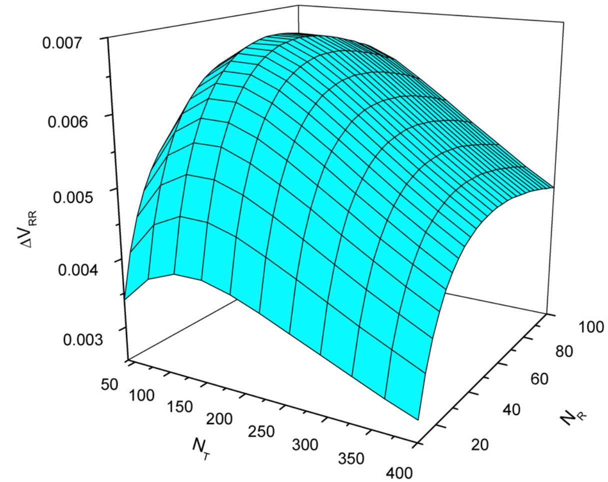
- Simulation based optimisation

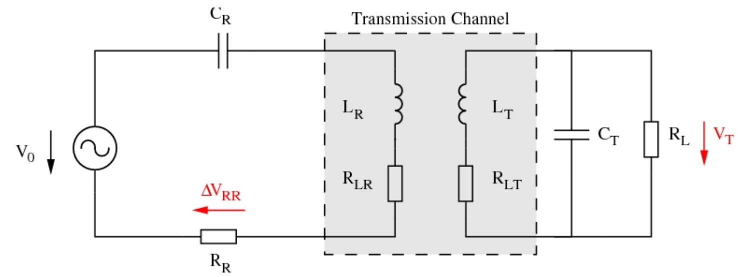



- Input parameter for simulation model:
  - Geometric antenna parameters
  - 4 DOF for each antenna + link distance
  - Optimisation method?

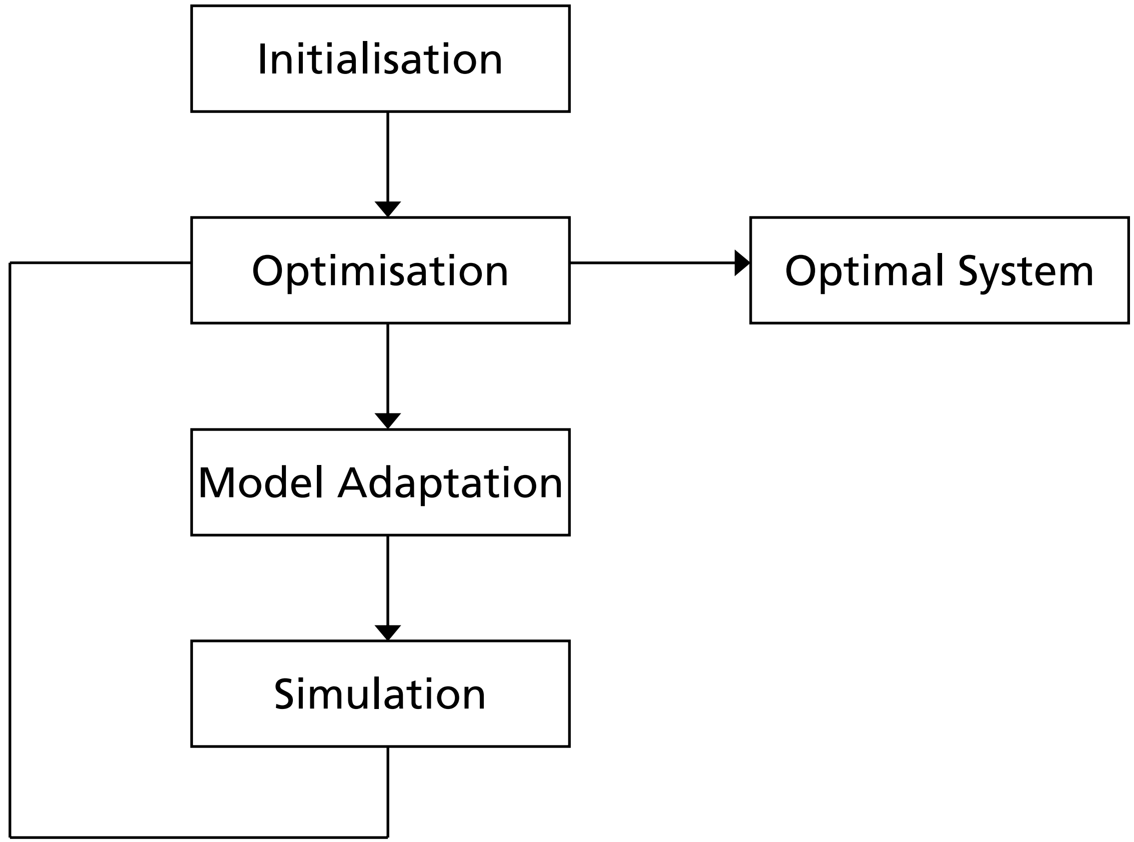
# Optimisation (3)

- Transform multi-dimensional parameter space to one-dimensional to simplify optimisation process
- Adaptation: 1 DOF for each antenna → number of turns
- Why 1 DOF?
  - Concave objective function
  - Discrete and finite parameter space
  - Use gradient based search method
- Direct dependency of N
  - Antenna (inductance, ohmic losses)
  - Mutual inductance (coupling)
- Indirect dependency of N
  - Electrical components ($C_R$, $R_R$ … )
  - Objective functions ($\Delta V_{RR}$, $V_T$)



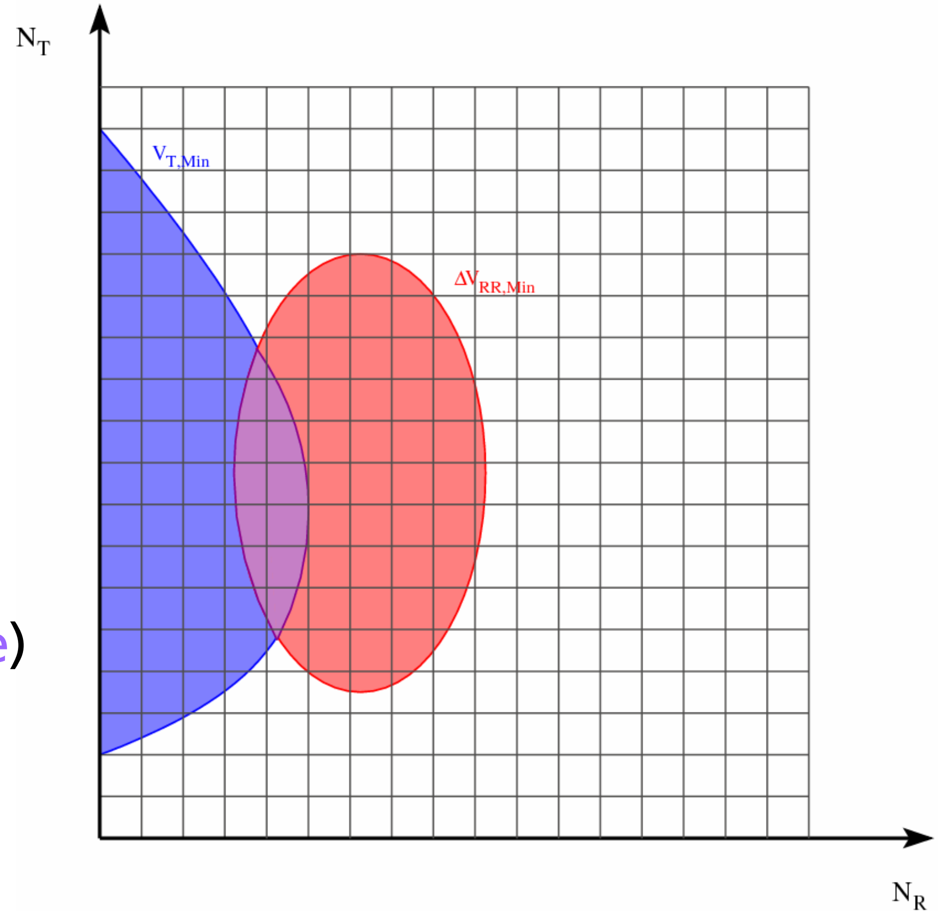



# Optimisation (4)



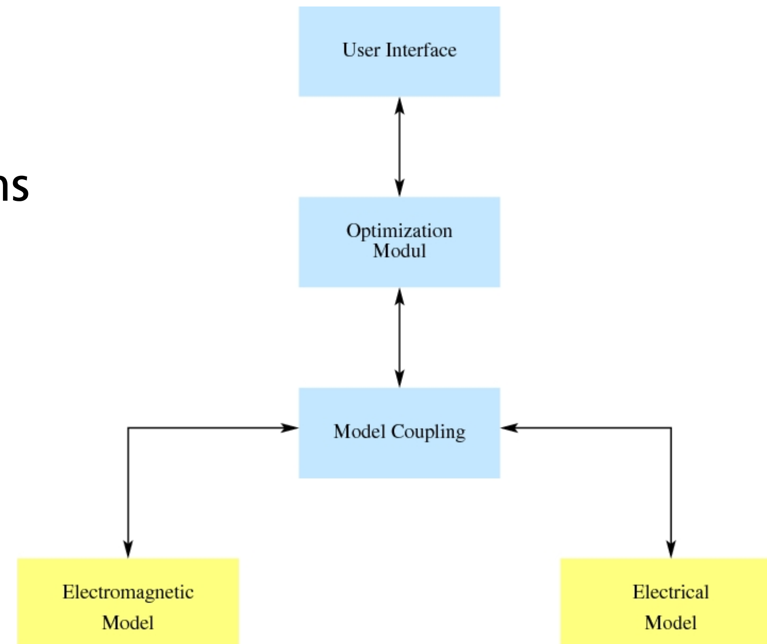
# Optimisation (5)

- Mesh with $N_T \times N_R$ nodes
- Each node represent one transponder system
- Search criteria:
  - $V_T > V_{T,min}$ (blue)
  - $\Delta V_{RR} > \Delta V_{RR,min}$ (red)
- Target area → all objective functions met constraints (purple)
- Find $d_{max}$:
  - Target area: 1 valid node
  - Use bisection algorithm



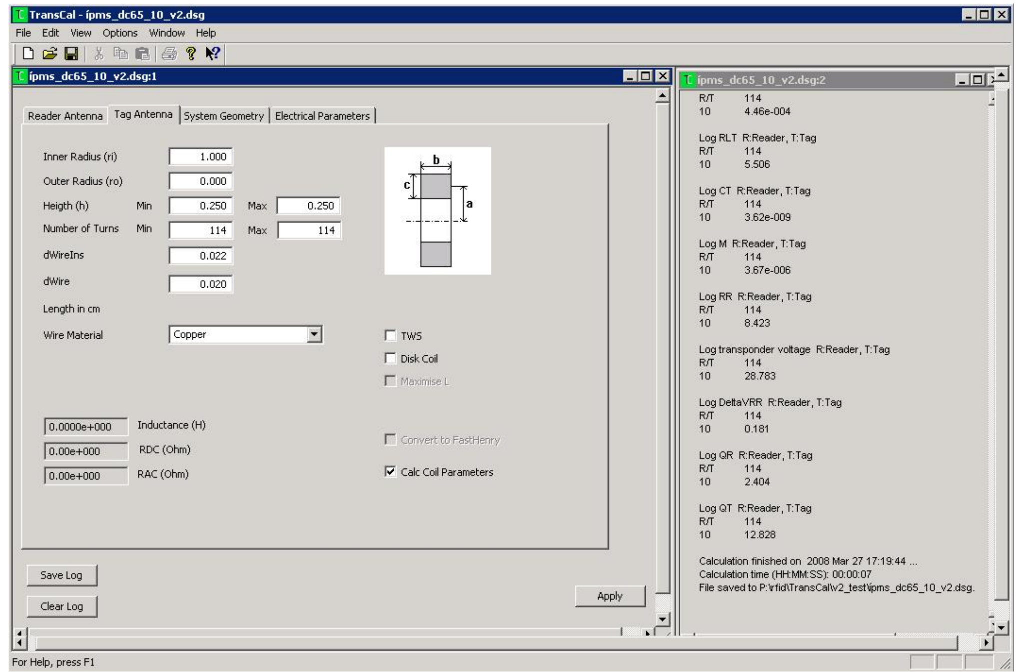
# TransCal – Introduction

- Tool for computer-aided design of RFID systems
- Goals:
  - Calculate & analyse transponder systems
  - Optimisation & automated design
- Written in C/C++ using MFC and open source math libraries



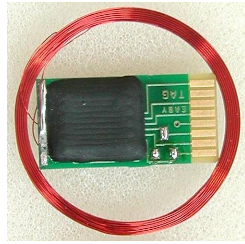
# TransCal – Introduction (2)

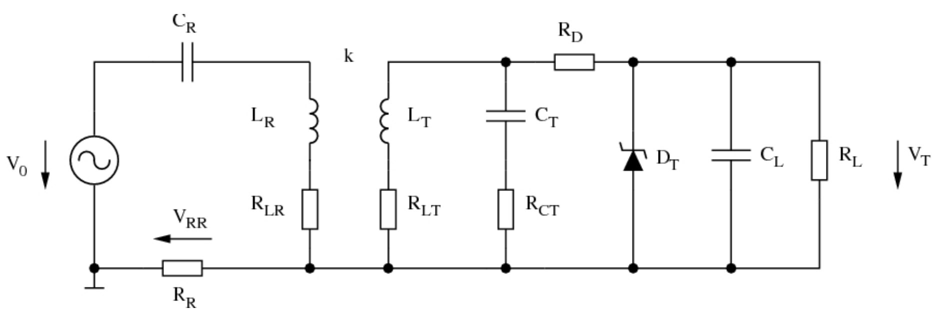
- Dialog based input:
  - Reader/transponder antenna
  - Positioning of transponder
  - Electrical parameters (reader & transponder)
  - Importing Spice netlist
  - Options for simulation
- Text based output (log file)
- Automatic model generator for FastHenry
- Netlist analyser for user defined Spice netlists



# Example

- Passive transponder with temperature sensor
- ISO 18000-2 protocol
- Programmable transponder IC – ST1 (IPMS)
- Digital temperature sensor – TSic-506 (ZMD)



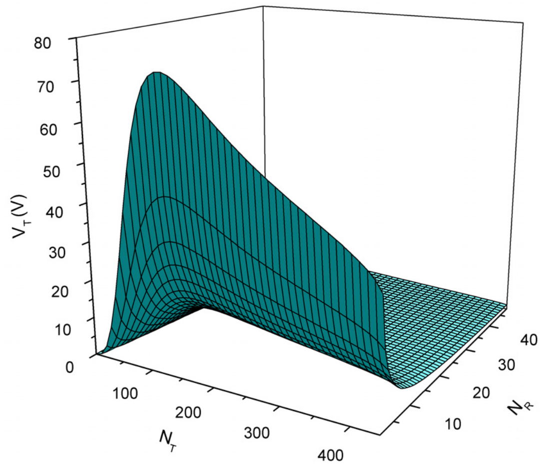


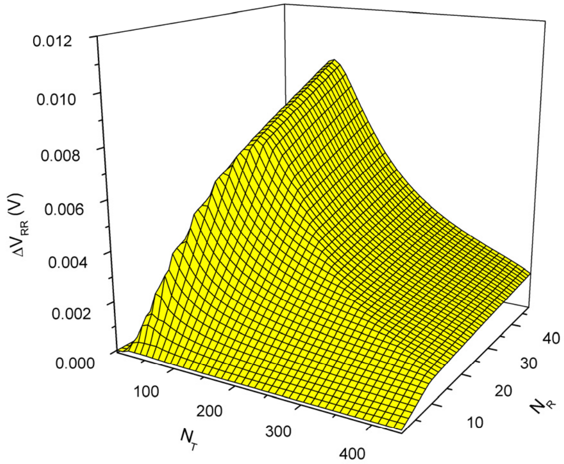

| | Reader | | Transponder | |
|---|---|---|---|---|
| **Antenna Parameter** | ri (mm) | 120 | ri (mm) | 20 |
| | ro (mm) | 150 | ro (mm) | 30 |
| | hmax (mm) | 20 | hmax (mm) | 2.5 |
| | Nmin | - | Nmin | - |
| | Nmax | - | Nmax | - |
| | dWireIns (mm) | 2.5 | dWireIns (mm) | 0.22 |
| | dWire (mm) | 0.9 | dWire (mm) | 0.2 |
| | Type | MLC | Type | MLC |
| **Electrical Parameter** | $V_0$(V) | 6 | Vmin (V) | 5 |
| | $\Delta V_{RR}$(mV) | 0.005 | Vmax (V) | 5.5 |
| | | | $R_L$ (Ω) | 21500 |
| | | | $C_L$ (pF) | 30 |
| | $f_{Res}$(kHz) | 125 | | |
| | B (kHz) | 10 | | |
| **Link Distance** | dmin (cm) | 28 | | |

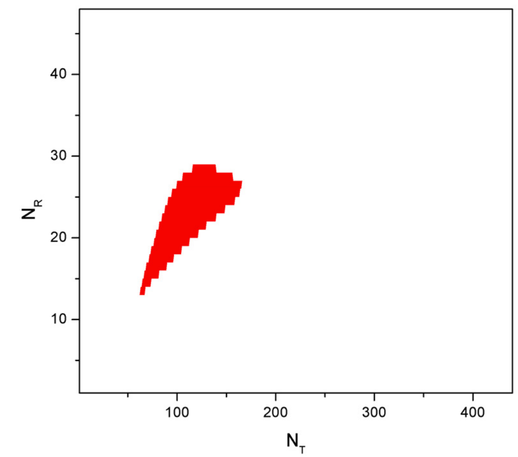
# Example (2)

- Nodes calculated/ total: 3309/23760
- Systems@28cm: 734
- Calculation time (numerical): 9.4h
- $d_{max}$ = 29.9 cm

| | Reader | | Transponder | |
|---|---|---|---|---|
| **Antenna Parameters** | ri (mm) | 120 | ri (mm) | 20 |
| | ro (mm) | 135 | ro (mm) | 22.5 |
| | hmax (mm) | 10 | hmax (mm) | 2 |
| | N | 21 | N | 95 |
| | dWireIns (mm) | 2.5 | dWireIns (mm) | 0.22 |
| | dWire (mm) | 0.9 | dWire (mm) | 0.2 |
| | Type | MLC | Type | MLC |
| **Link Distance** | (cm) | 29.9 | | |



# Conclusion

- Antenna design and system optimisation can be done using
  - Analytical and numerical models for calculation
  - Coupling of electromagnetic and electrical domains
  - Simulation based optimisation method
  - Adapted parameter space
- All methods and algorithms can be combined and controlled by one tool providing a computer-aided design process

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