Challenges in practical design of planar arrays

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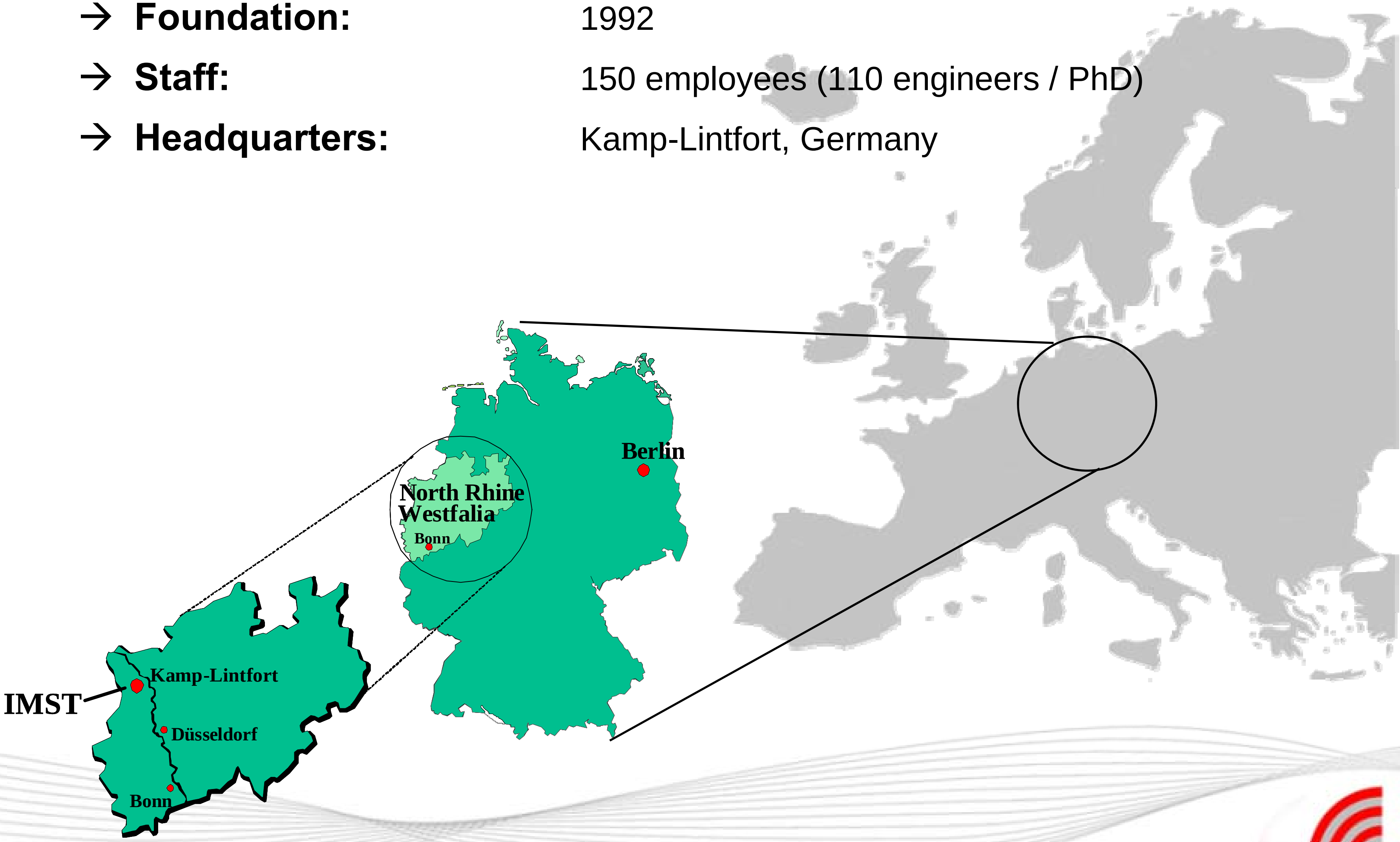
IMST GmbH: facts & figures

→ **Foundation:** 1992

→ **Staff:** 150 employees (110 engineers / PhD)

→ **Headquarters:** Kamp-Lintfort, Germany

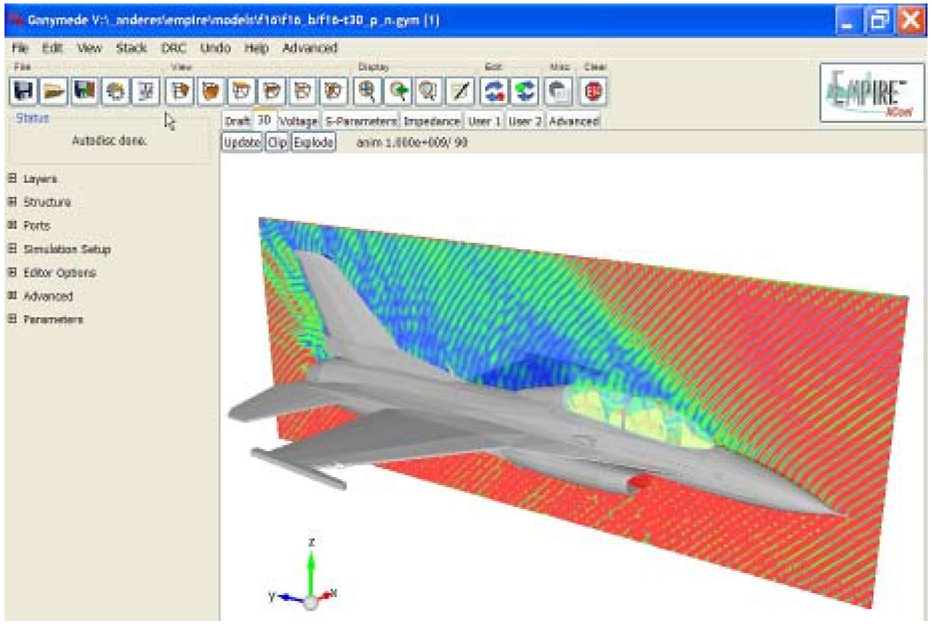


Target markets

- → Telecom and IT
- → Automation
- → Automotive
- → Medical Device
- → Security
- → Space

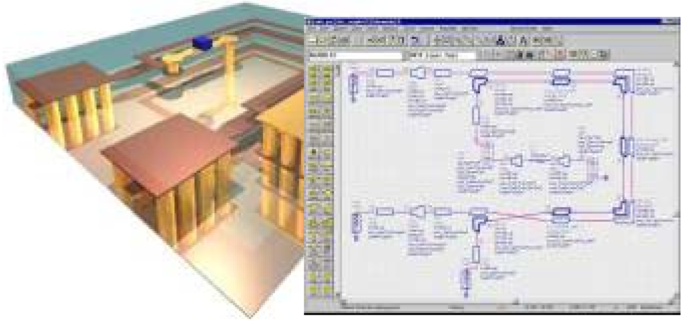
EM modelling tools

Full wave 3D FDTD simulation



For ADS™

Library for multilayered elements
Integrated in Agilent ADS™



FOR ADS™

Coplanar element library
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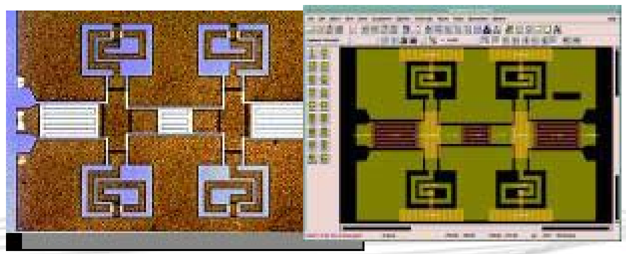
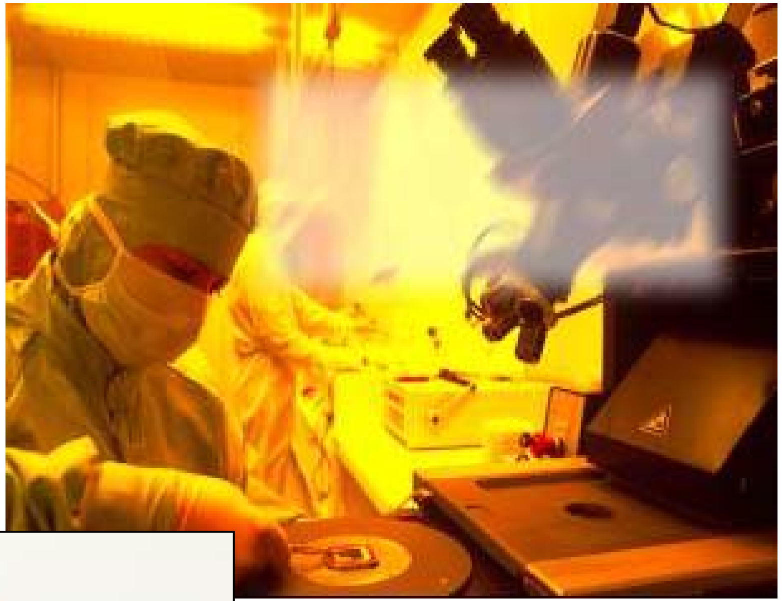
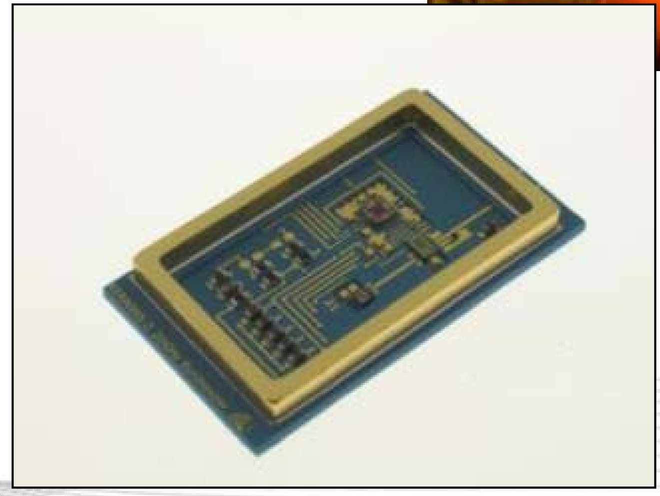


In-house Technology & Prototyping

- → Clean rooms: class 100 to 10,000
- → Thin film and thick film technology
- → Hybrid circuits, bonding
- → Etching techniques
- → Fast prototyping
- → LTCC capabilities





Measurements & testing

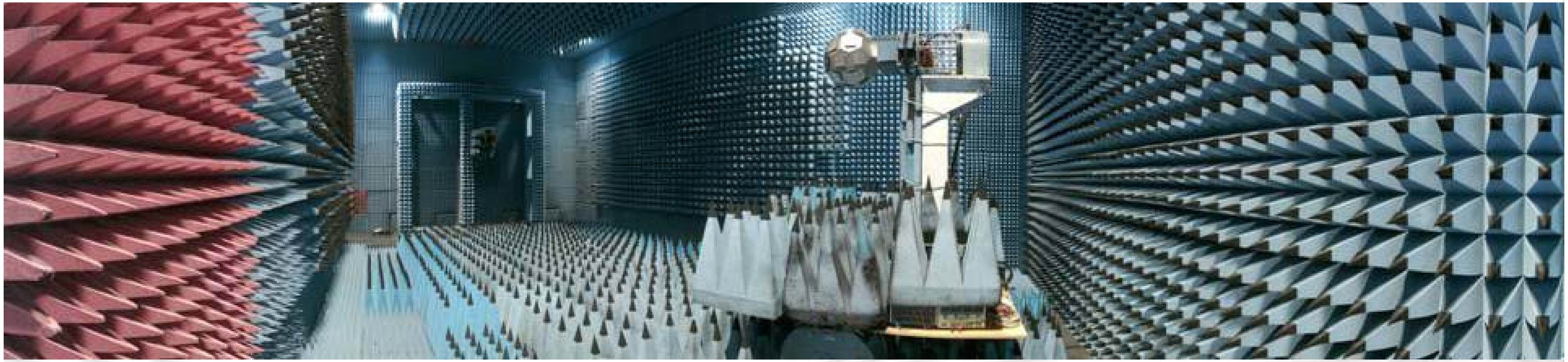
- → Indoor nearfield / farfield
- → 3D air-interface characterisation of mobile devices
- → Specific Absorption Rate (SAR)
- → RF measurements up to 110 GHz
- → CE certification

Deutscher Akkreditierungs Rat

DAT-P-152/98-01

TÜV CERT
DIN EN ISO 9001 : 2000
QA-Nr.: 0410020031543

CTIA Authorized Test Lab
LAB CODE 20070212-00



Scope of the talk

→ Introduction

→ Why planar arrays?

→ Technological considerations

→ Simulation

→ Measurements

→ Examples

→ Outlook

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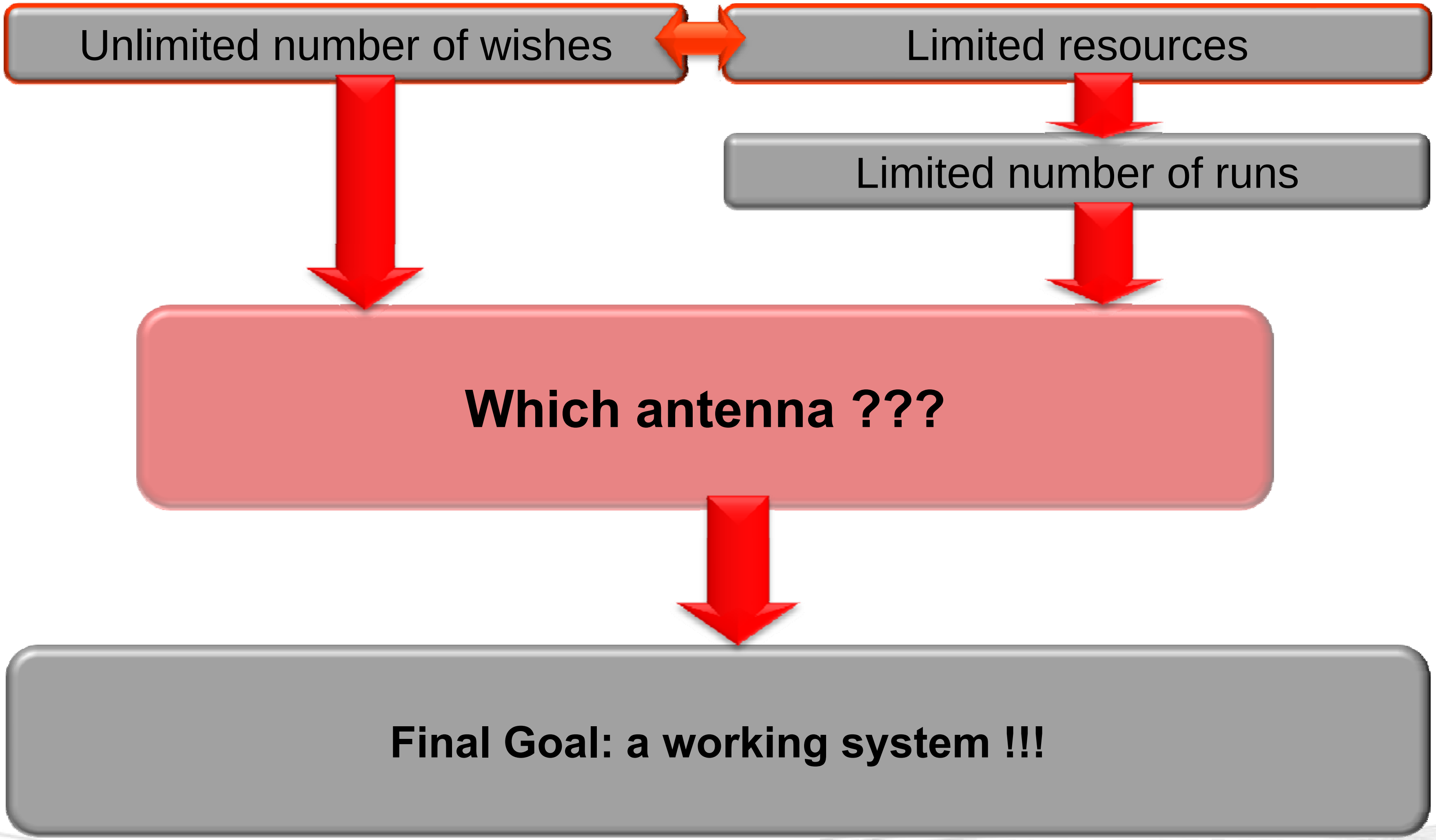
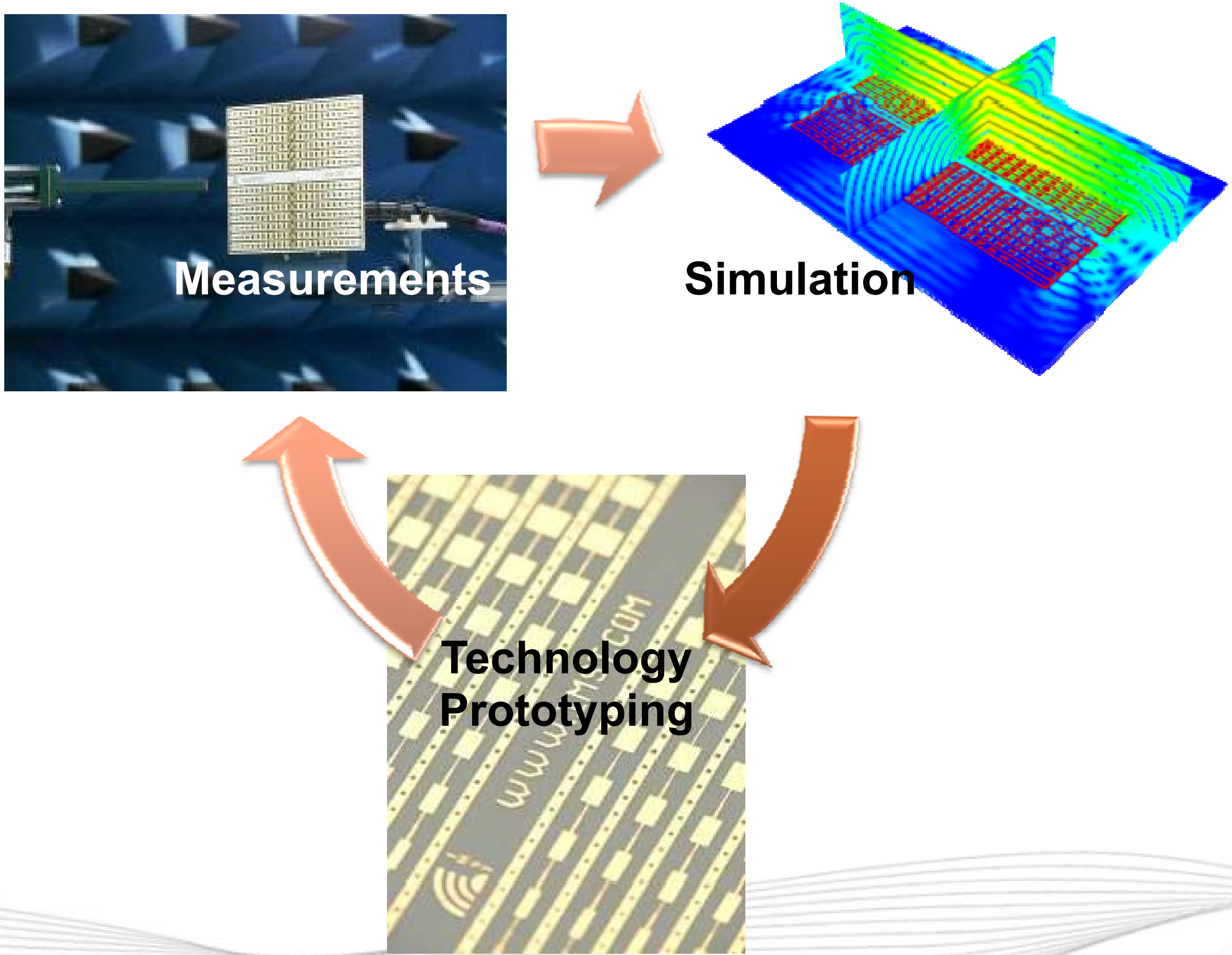
Goal


Unlimited number of wishes
Limited resources
Limited number of runs
Which antenna ???
Final Goal: a working system !!!

Design cycle



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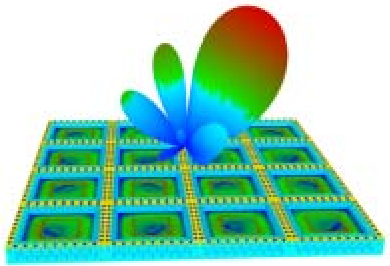
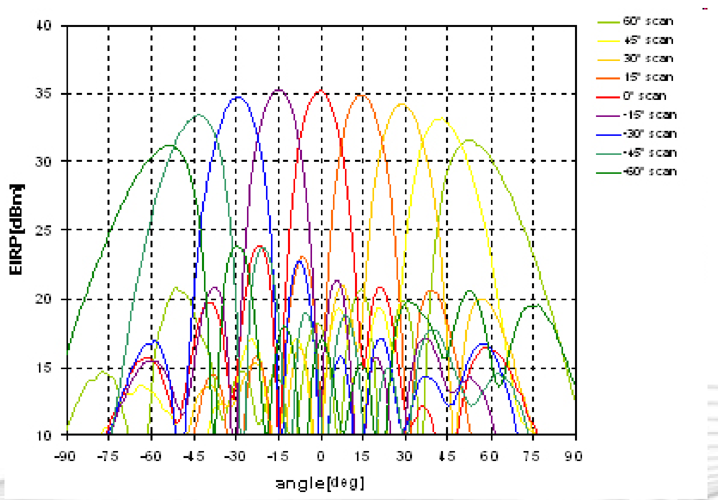
Arrays vs. fixed aperture antennas

→ More precise control of the radiation pattern

- Lower sidelobes
- Pattern shaping

→ Possibility of electronic beam scanning





A couple of equations…

→ Power received by the RX antenna

$$P_r = A(\theta,\phi)W$$

→ Power density at a distance *r* of the TX antenna

$$W(\theta,\phi) = \frac{G(\theta,\phi)}{4\pi r^2} P_t$$

→ Effective area of the RX antenna

$$A(\theta,\phi) = \frac{\lambda^2 G(\theta,\phi)}{4\pi}$$

… or, in other words:

$$P_r = \frac{\lambda^2 G_r G_t}{(4\pi r)^2} P_t$$

→ P_r decreases as the square of the distance ($1/r^2$)

→ P_r increases as the square of the wavelength (λ^2)

→ P_r decreases as the square of the frequency ($1/f^2$)

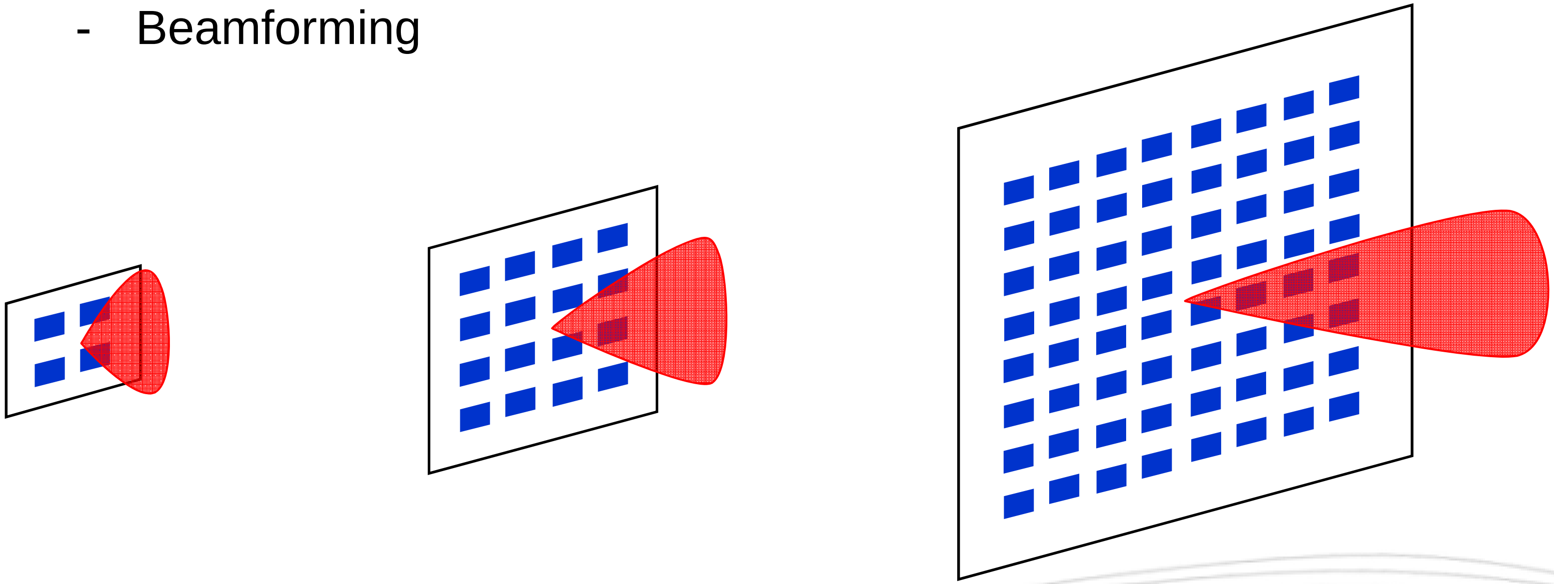
That means:

→ To increase the gain, larger apertures, that is, larger arrays are needed

→ Passive arrays: large gain = narrow beamwidth

→ By controlling amplitude and phase of the excitation of each element:

- Beamsteering
- Beamforming



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→ Measurements

→ Examples

Technological aspects

→ Choosing the right substrate
  - Soft substrates (PTFE)
  - Hard substrates (LTCC, HTCC)

→ Feeding strategy
  - Probe, microstrip, coupling…
  - Series, tree, corporate…

→ Number of layers

→ Technological limitations:
  - Line width
  - Via spacing

→ Technological parameters
  - Nominal values vs. real parameters
  - „Discrete“ values
  - Material and manufacturing tolerances

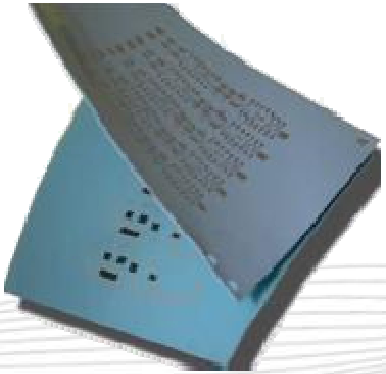
PTFE or LTCC??

PTFE

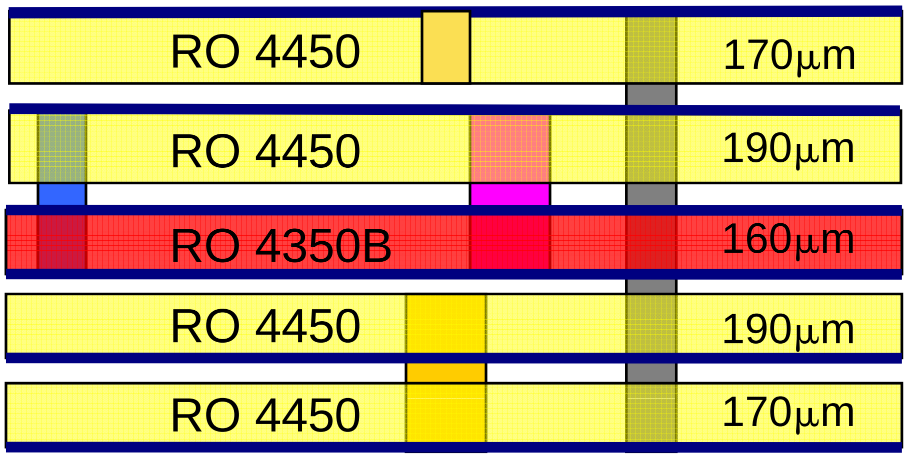
- → Good stability of permittivity
- → High TCE (close to Cu and Al)
- → Possibility of multilayer with prepeg technology
- → Large circuit areas, >50x50cm^2
- → Low production cost for low and medium volumes

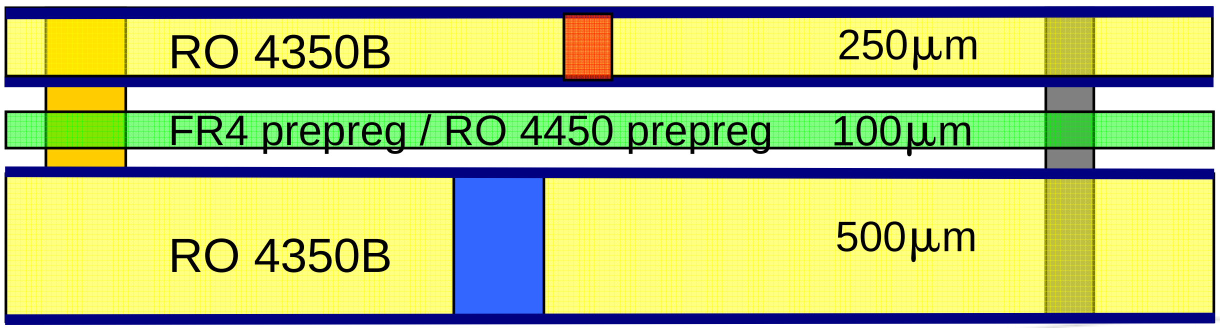
LTCC

- → Good stability of permittivity
- → Better thermal conductivity
- → Low TCE (close to Si and GaAs)
- → Indicated for multilayer modules
- → Robust against environmental influence
- → Low production price for medium and high volumes

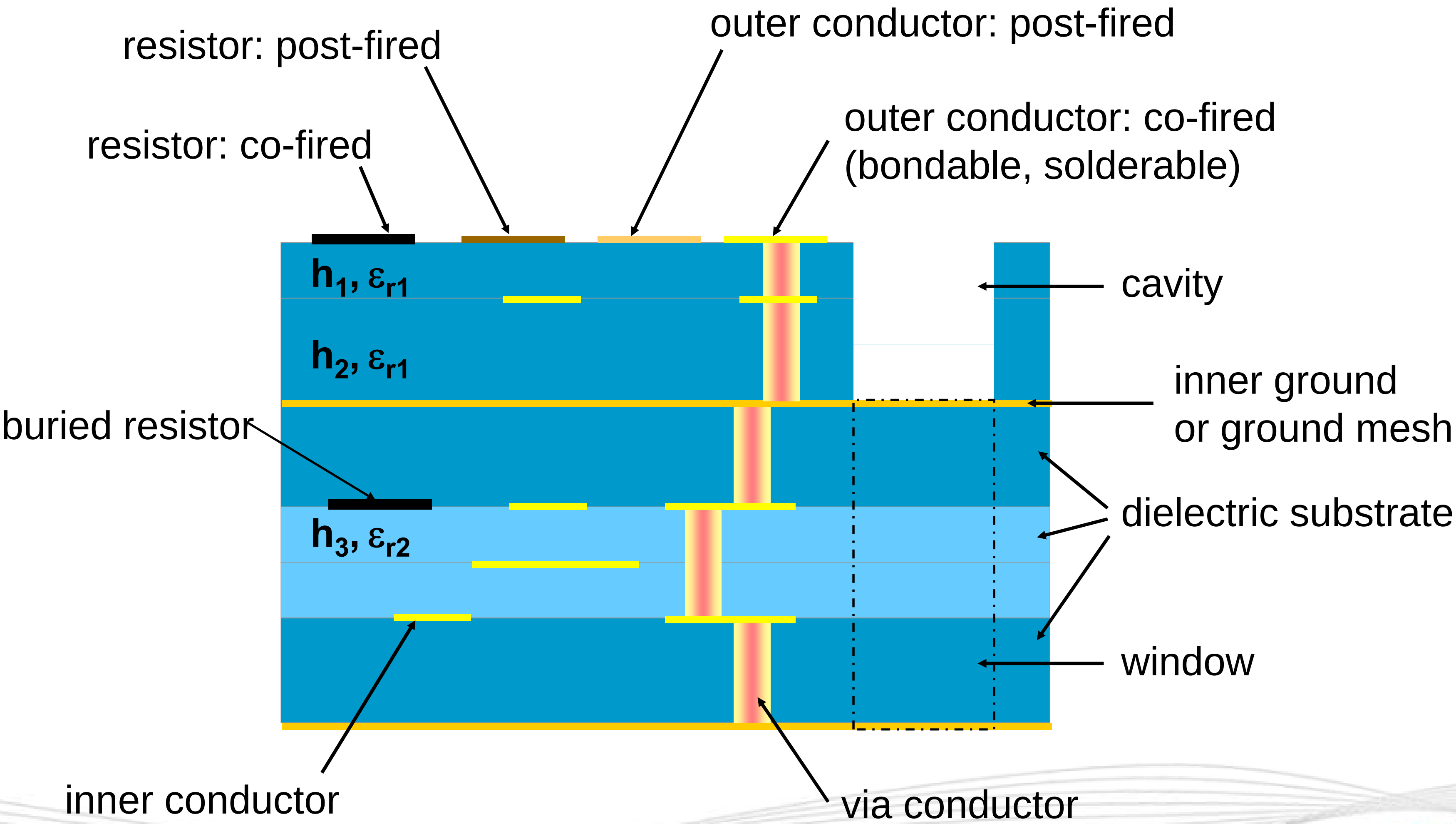


Example of multilayer structures (prepeg)

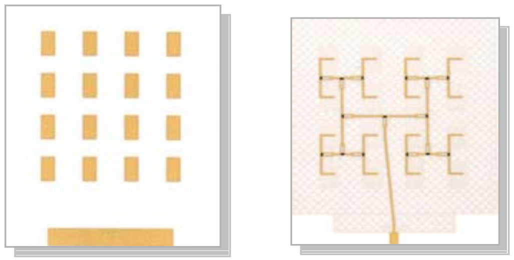




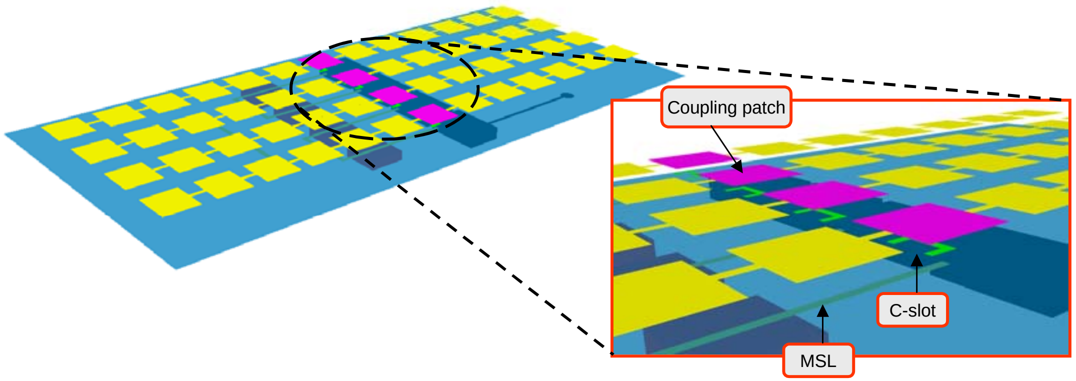
Example of multilayer structures LTCC

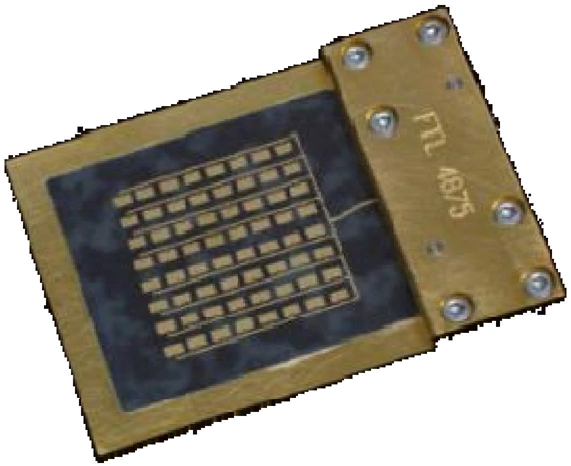


Examples

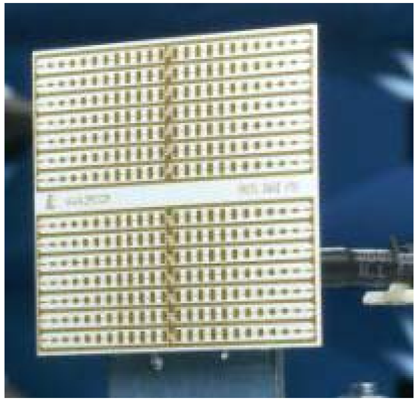


LTCC antennas @ 24 GHz



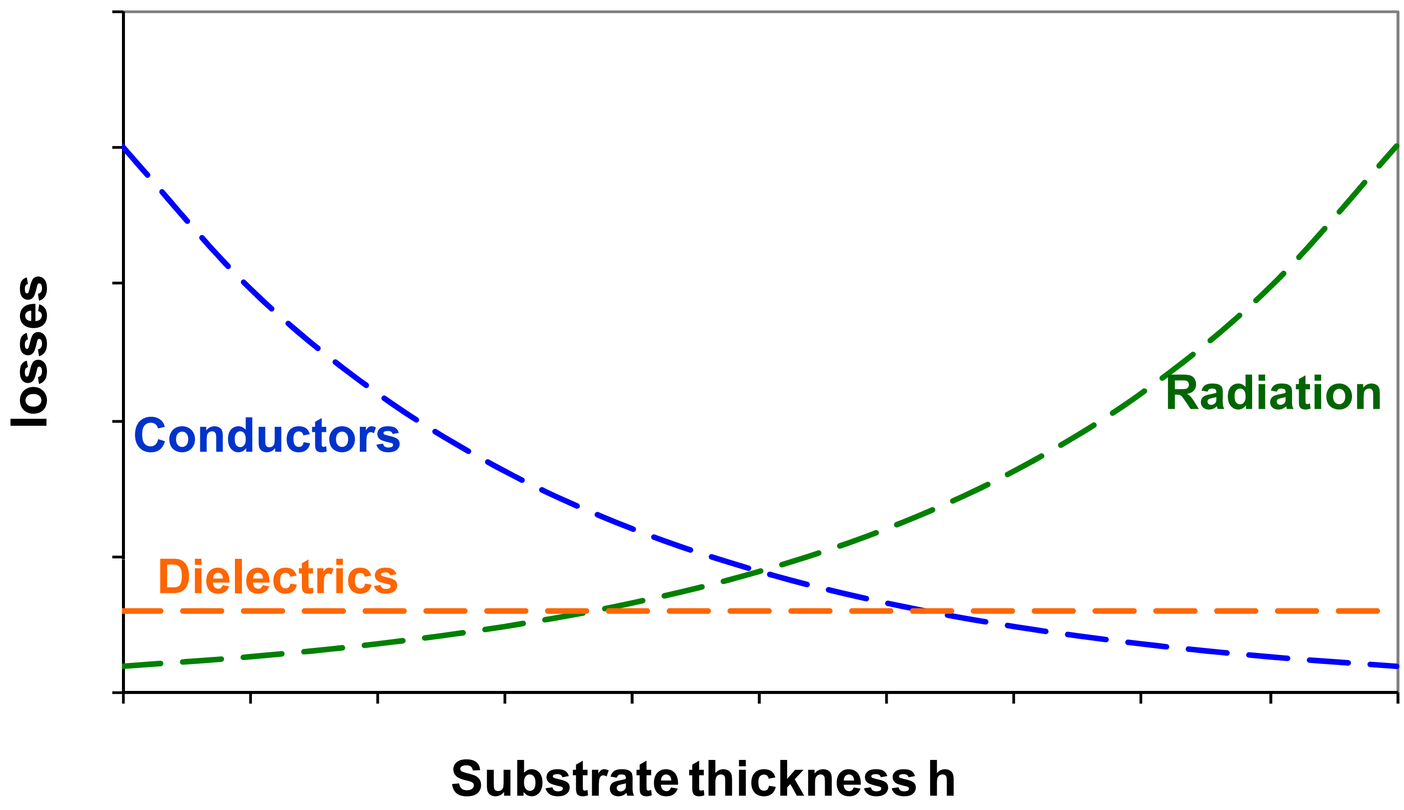


Antenna @ 60 GHz

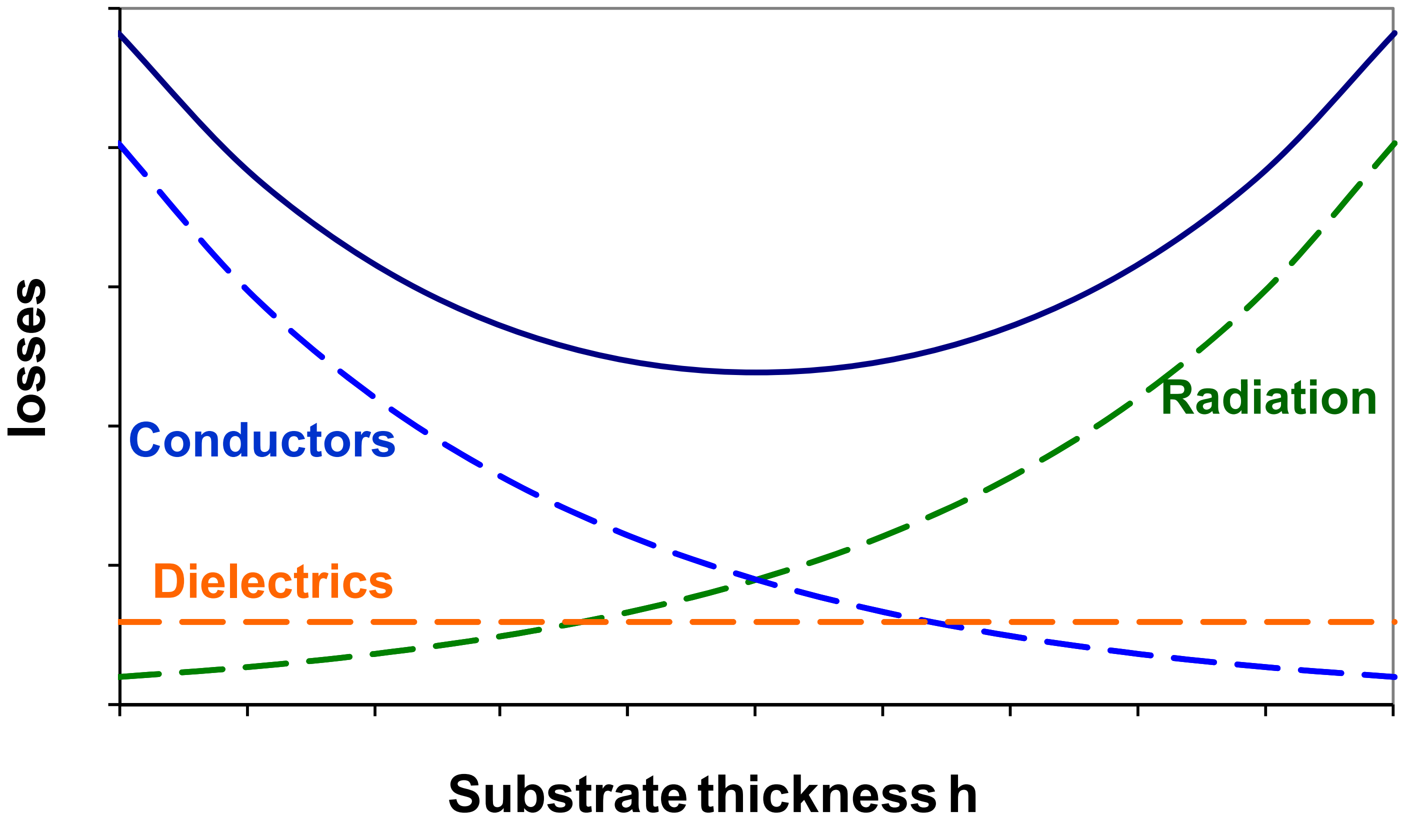


Radar antenna @ 24 GHz

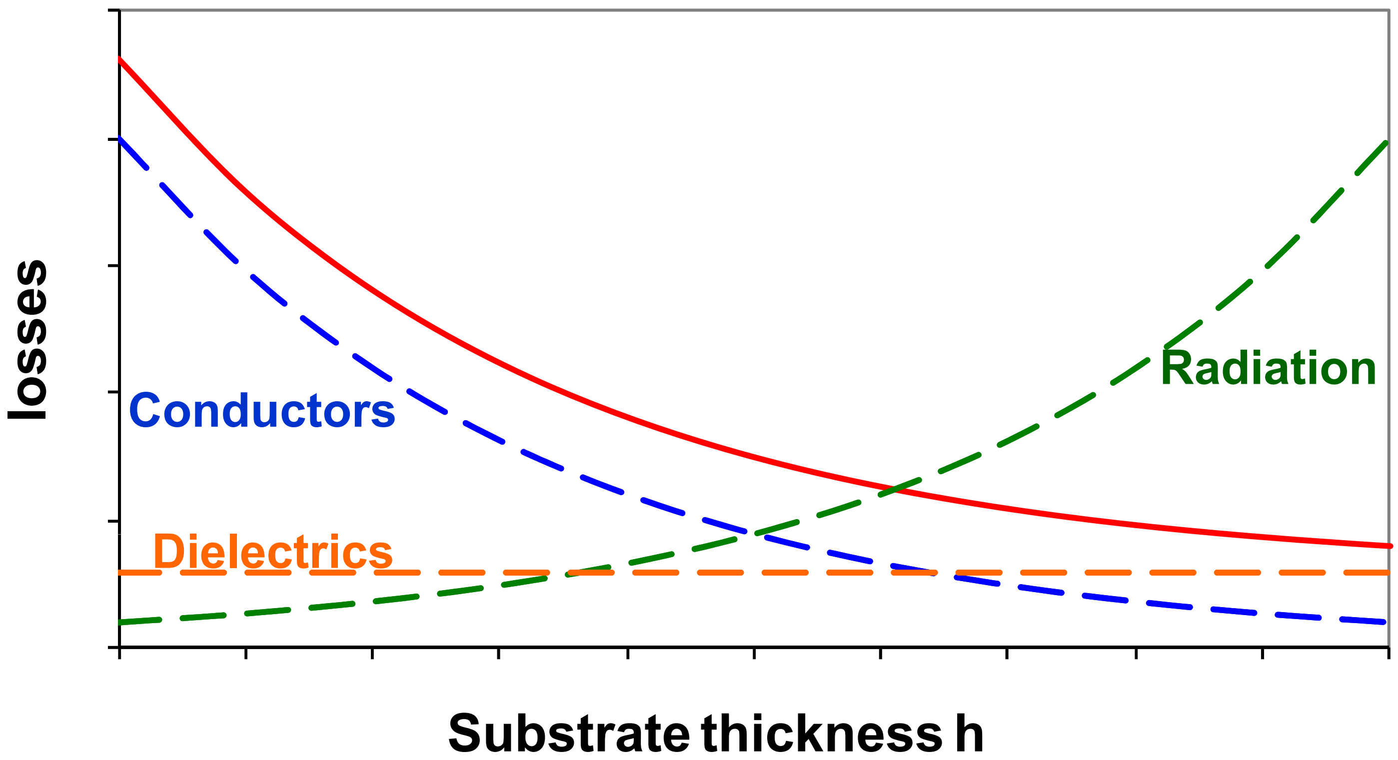
The problem of losses



The problem of losses (radiating lines)



The problem of losses (non-radiating lines)



Effect of the metallisation

→ Conductivity as function of frequency

→ Conductor roughness

- more than x2 increase in conductor loss (experimentally demonstrated)
- Effect on effective permittivity

→ "Saturation" does not occur, at least up to 50 GHz

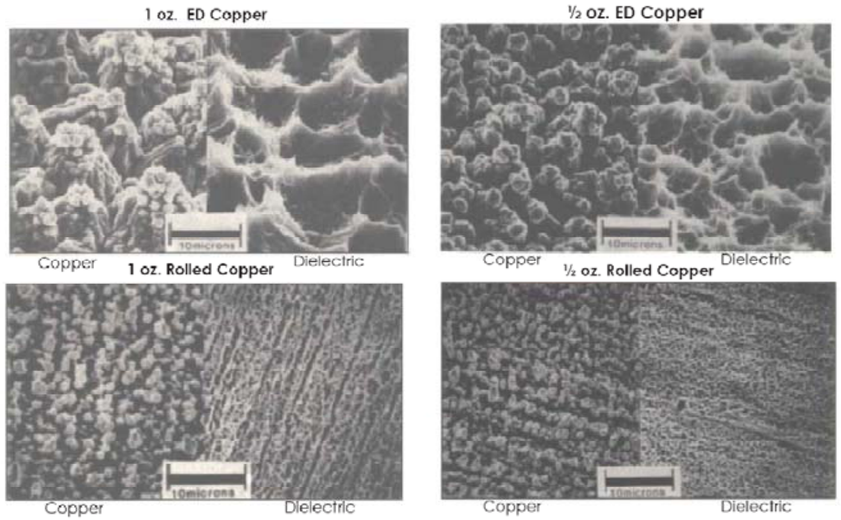
- Thinner metallisation: lower loss than thicker ones (even for HF)

→ Influence of conductor profile on phase constant

- especially in thinner substrates
- larger effect than predicted simply by including the loss
- seems related to the profile itself.

Manufacturing

	E-deposited	Rolled
HF (>15 GHz)	☹	☺
Thermal shock environment	☹	☺
Mechanical stress	☺	☹
Bonding	☺	☹
High resolution (fine lines)	☺	☹



Source: Rogers

High frequencies

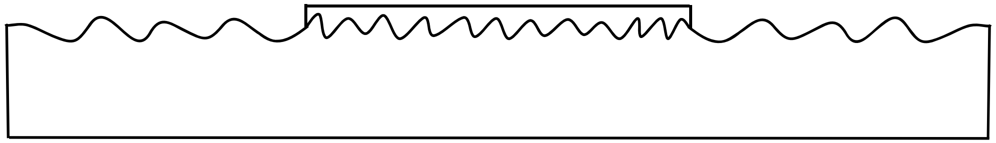
→ High resolution needed (<10μm)

→ Smooth surfaces needed:
  - Dielectrics: thickness control (impedance)
  - Conductors: minimise skin effect

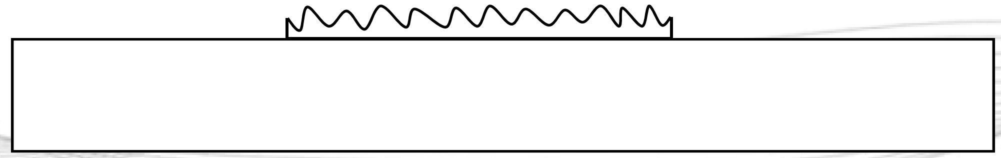
→ Drawback: poor adhesion between metal and dielectric

→ Historically:
  - high profile (“rough”) foils: used to increase adhesion to the substrate
  - lower profile foils: to improve etch definition or reduce conductor loss.

Standard



Reverse treated



The problem of permittivity

→ **Sheet measurement technique:** measure the capacitance of a very large sheet of known thickness to obtain the permittivity value

→ Measurement only at certain frequencies

→ Ex: IPC TM 650 2.5.5.5: X band:

„Limitations: The following limitations in the method should be noted. Users are cautioned against assuming the method yields permittivity and loss tangent values that directly correspond to applications. The value of the method is for assuring consistency of product and thus reproducibility of results in fabricated boards.

The measured effective permittivity for the resonator element can differ from that observed in an application.“

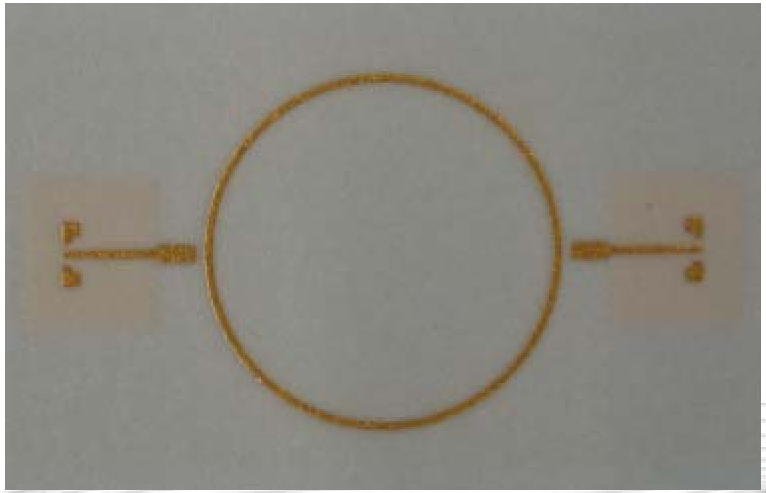
The problem of permittivity

→ Values differ from actual permittivity: experience needed!!!

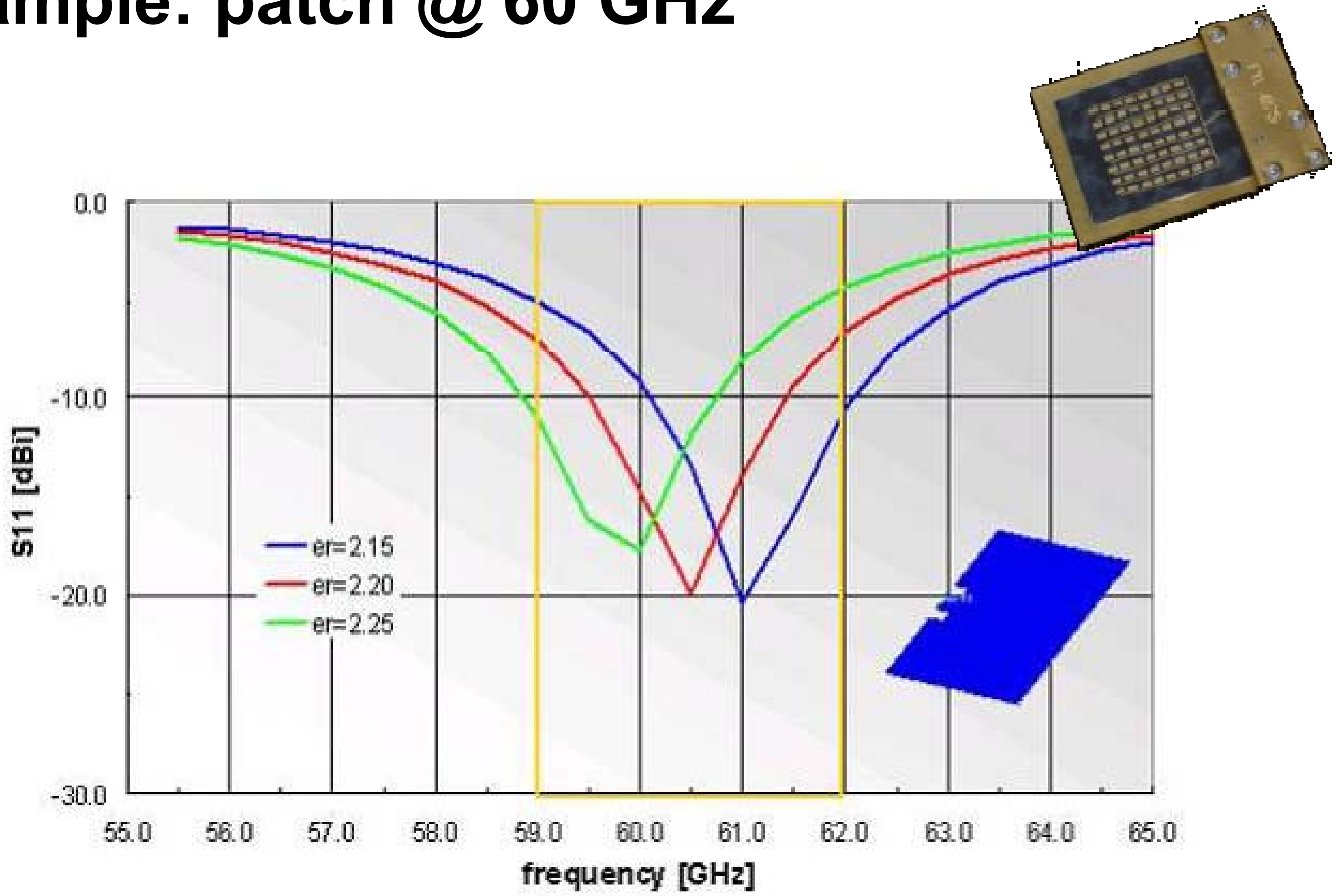
- Use recommended value, not nominal!
- Define test structures (lines, ring resonators)

→ Effect of permitivity deviation

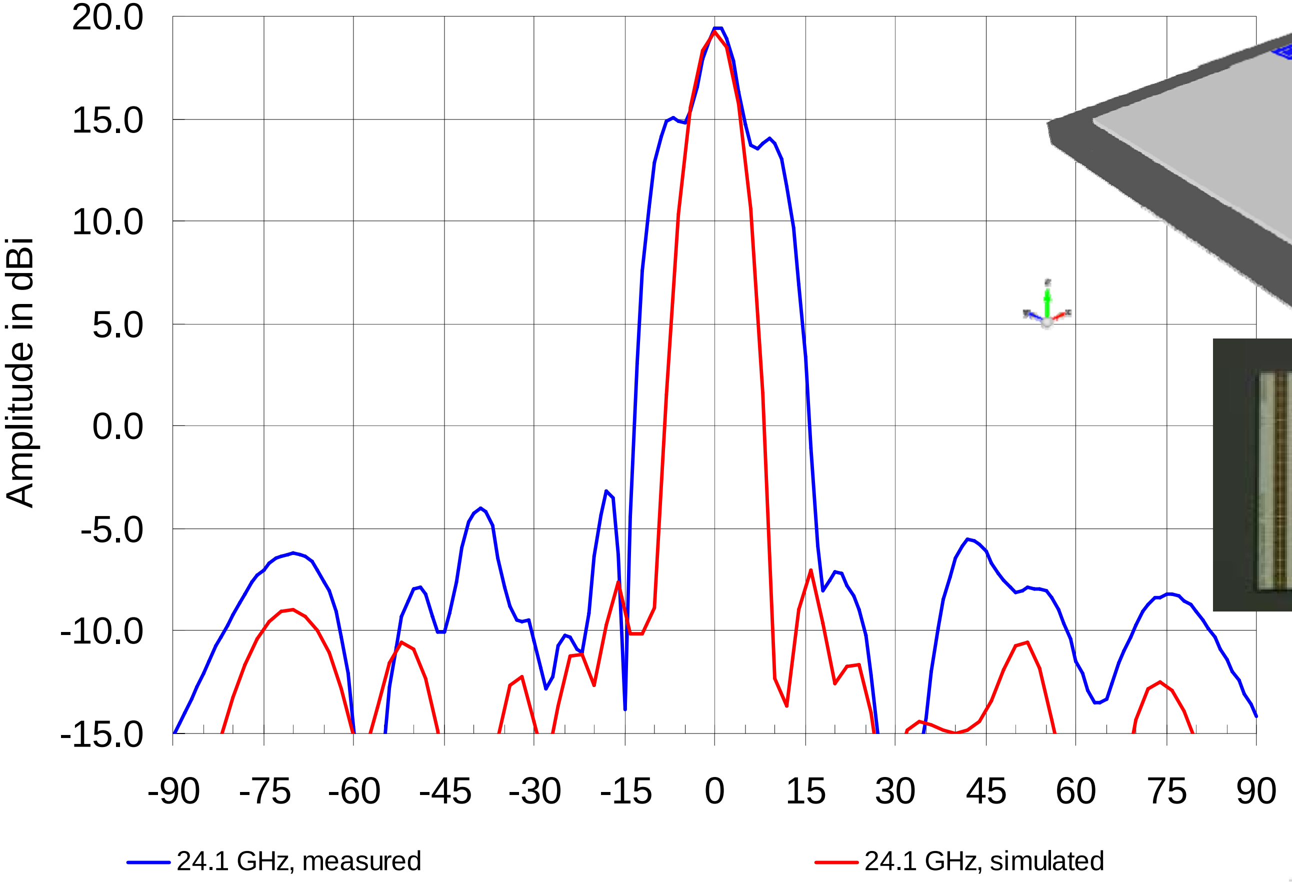
- Mismatching
- Deformation of radiation pattern (wrong operating frequency)
- Assymetry, squinting

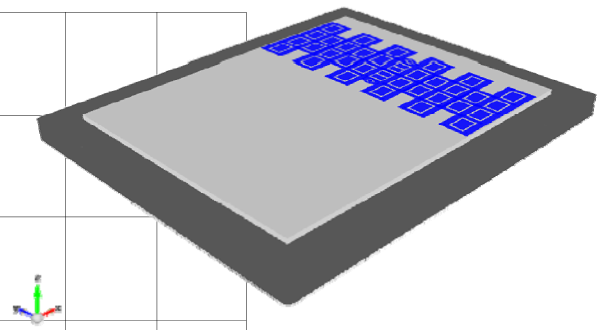


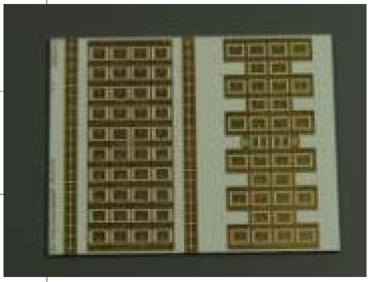
Example: patch @ 60 GHz



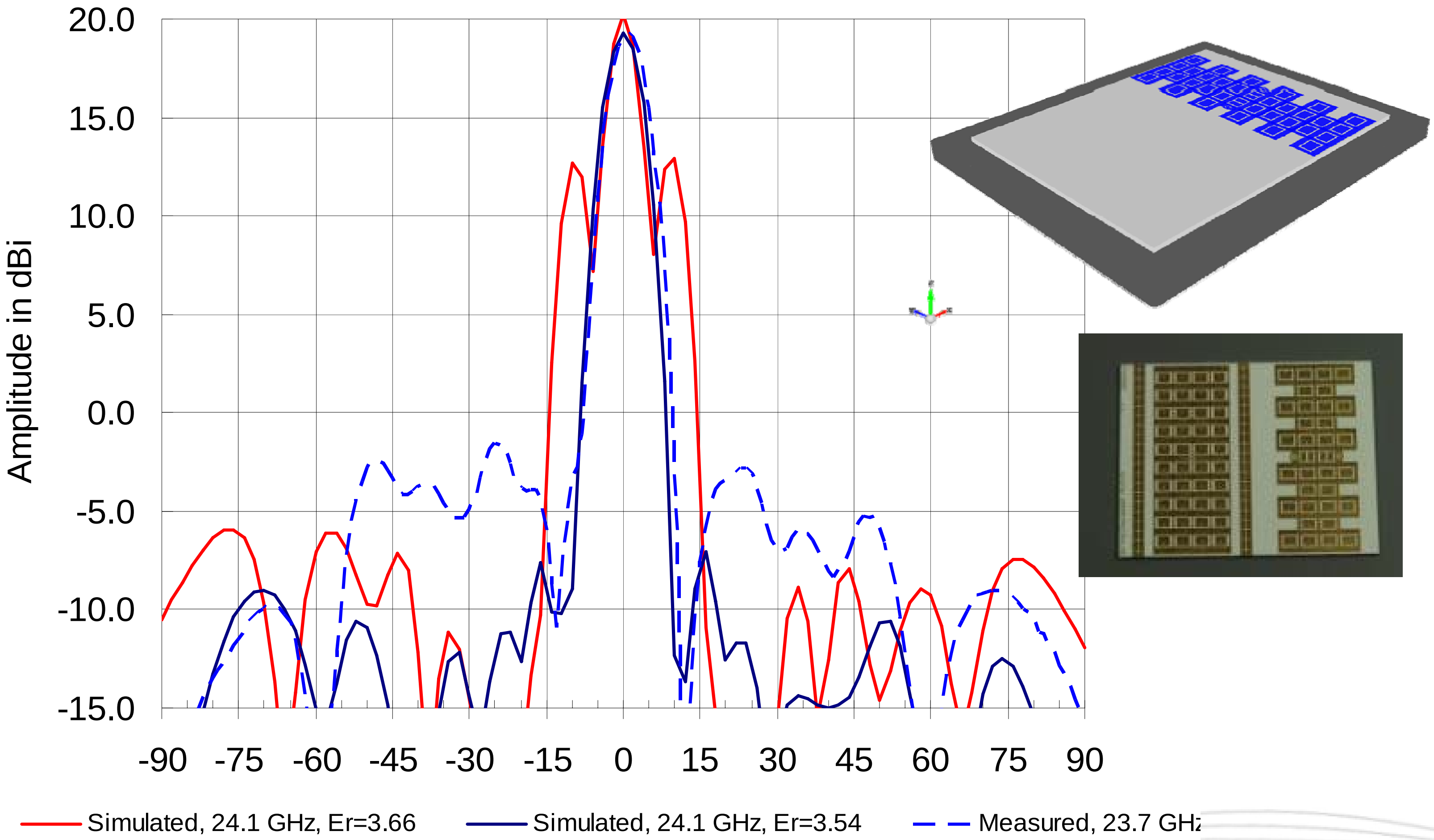
Example: array @ 24 GHz



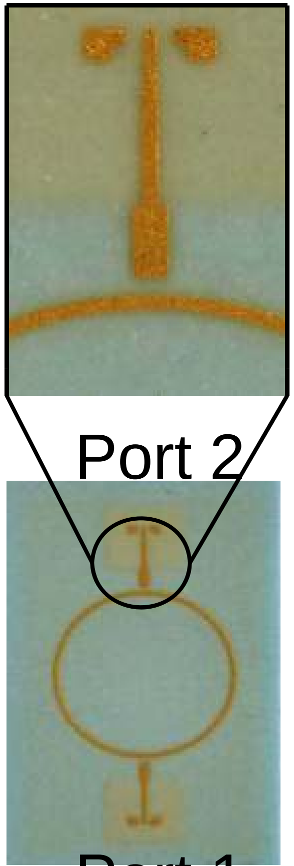


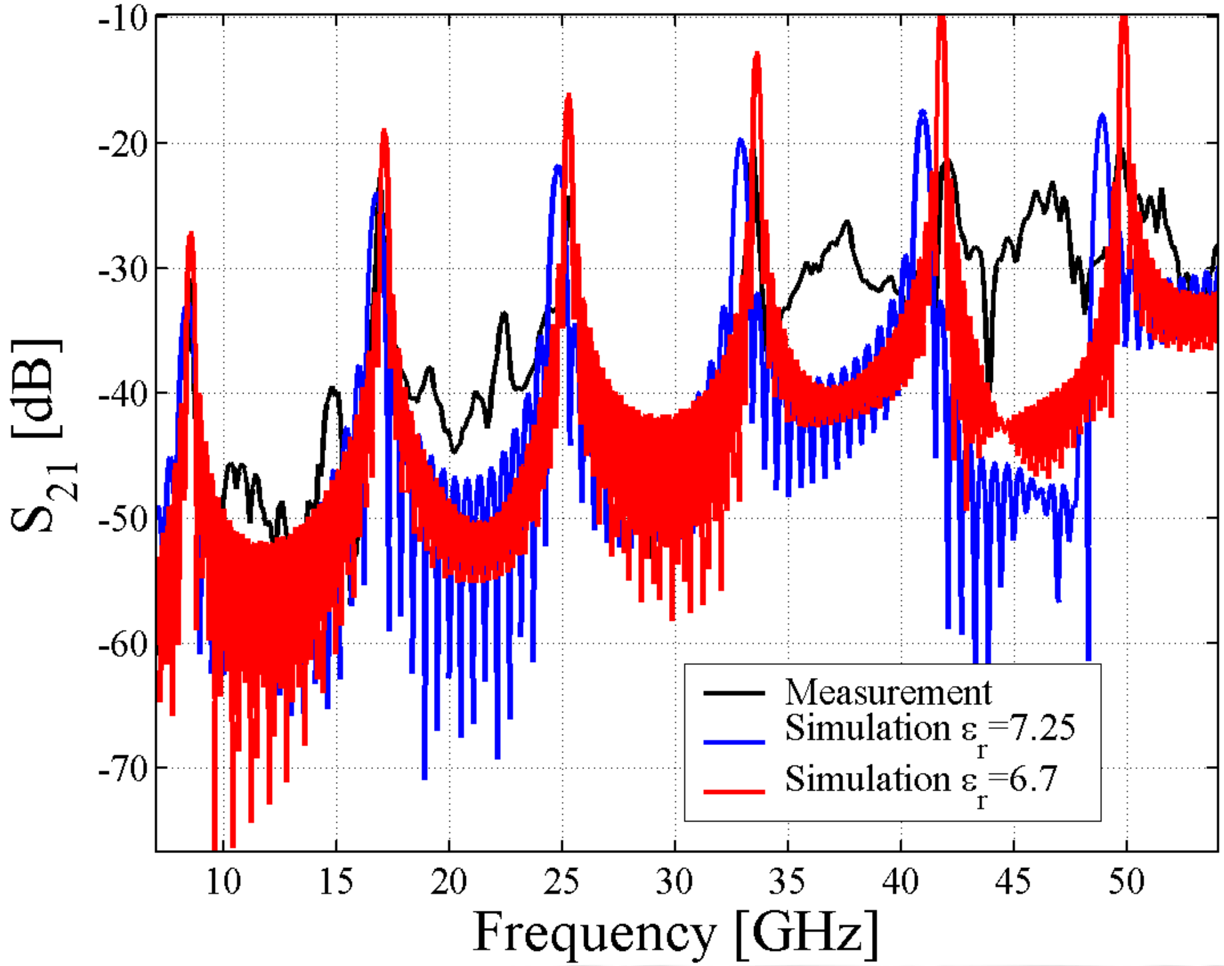


Example: array @ 24 GHz

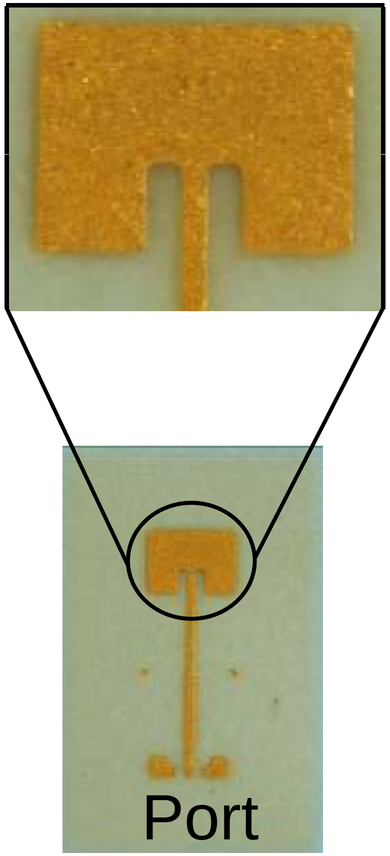


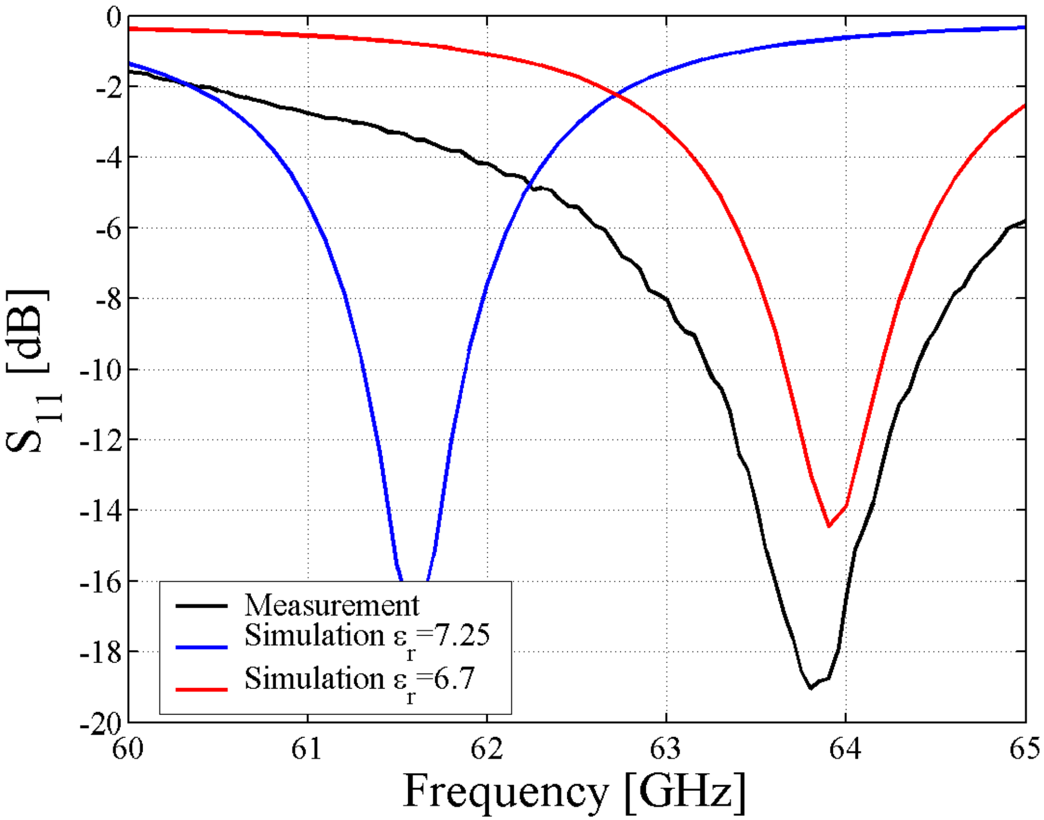
Example: LTCC material (1)





Example: LTCC material (2)

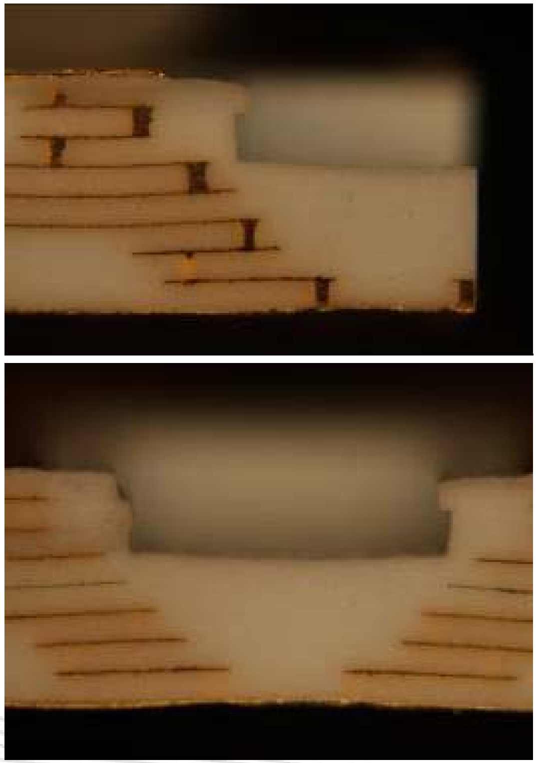


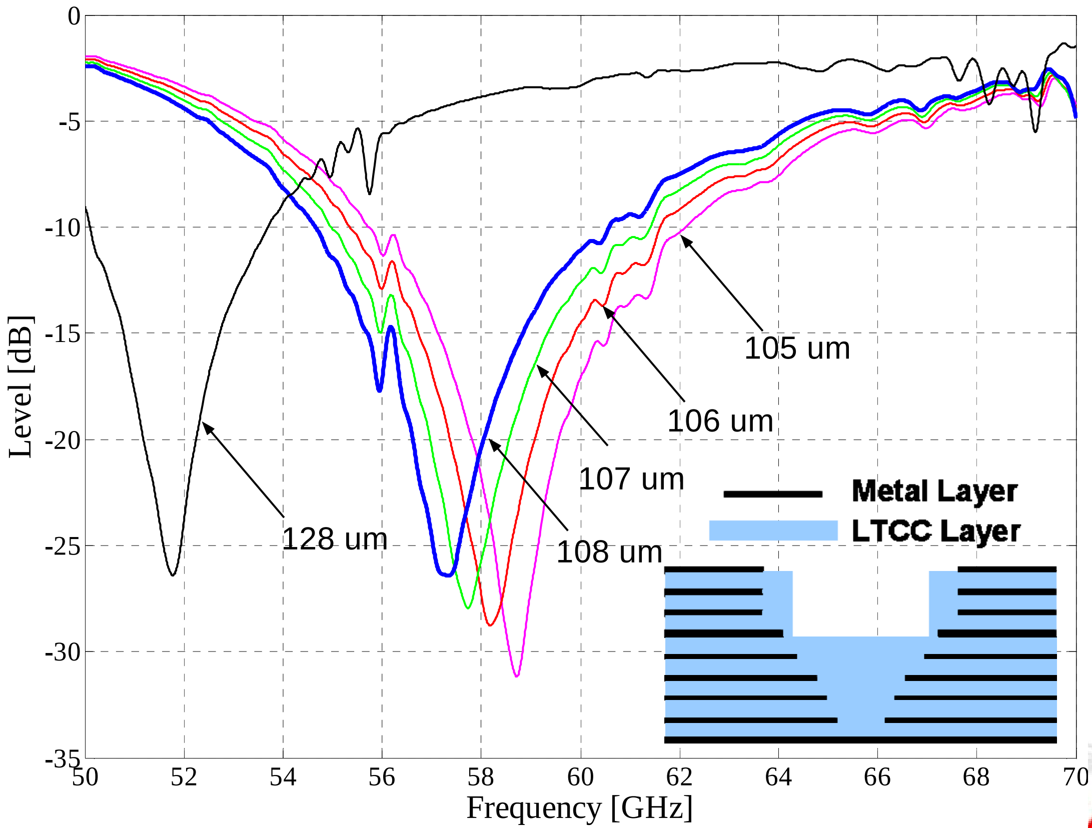


Example: LTCC material (3)

→ Layer thickness: 105µm-123µm (manufacturing tolerances)

→ Δh= 1µm => δf~600 MHz @ 60 GHz





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The challenge of simulation

→ Antenna size

→ Detailed description of the structure

→ Number of elements

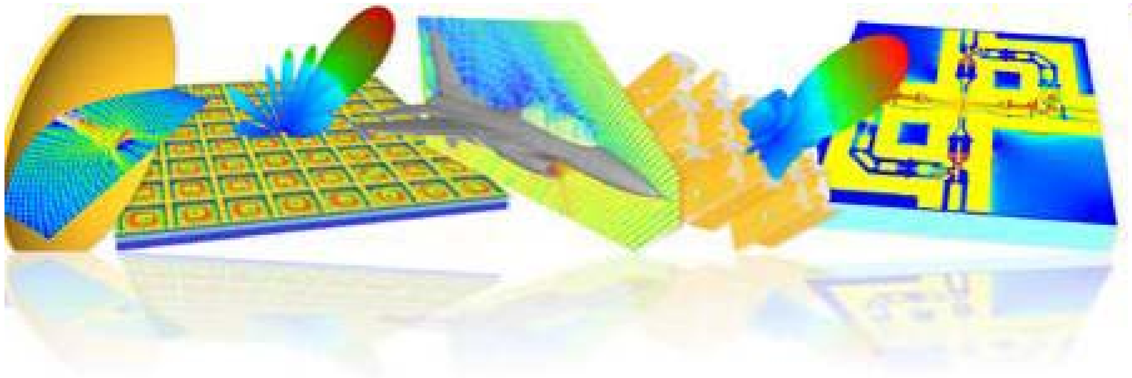
→ Simplified simulation vs. whole structure

- Effect of coupling
- Feeding networks

→ Feeding / interfaces

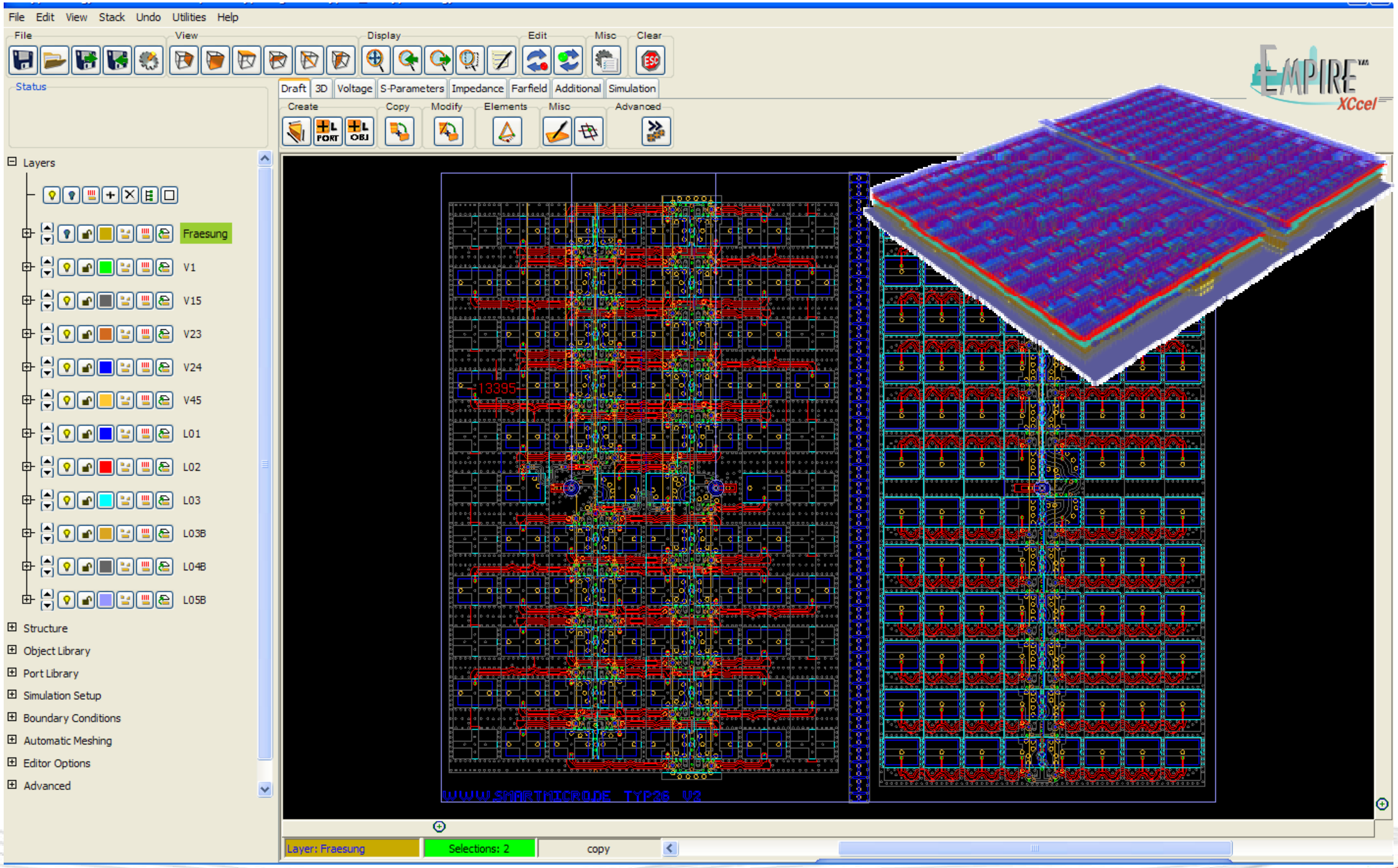
→ Advances:

- Hardware
- Software

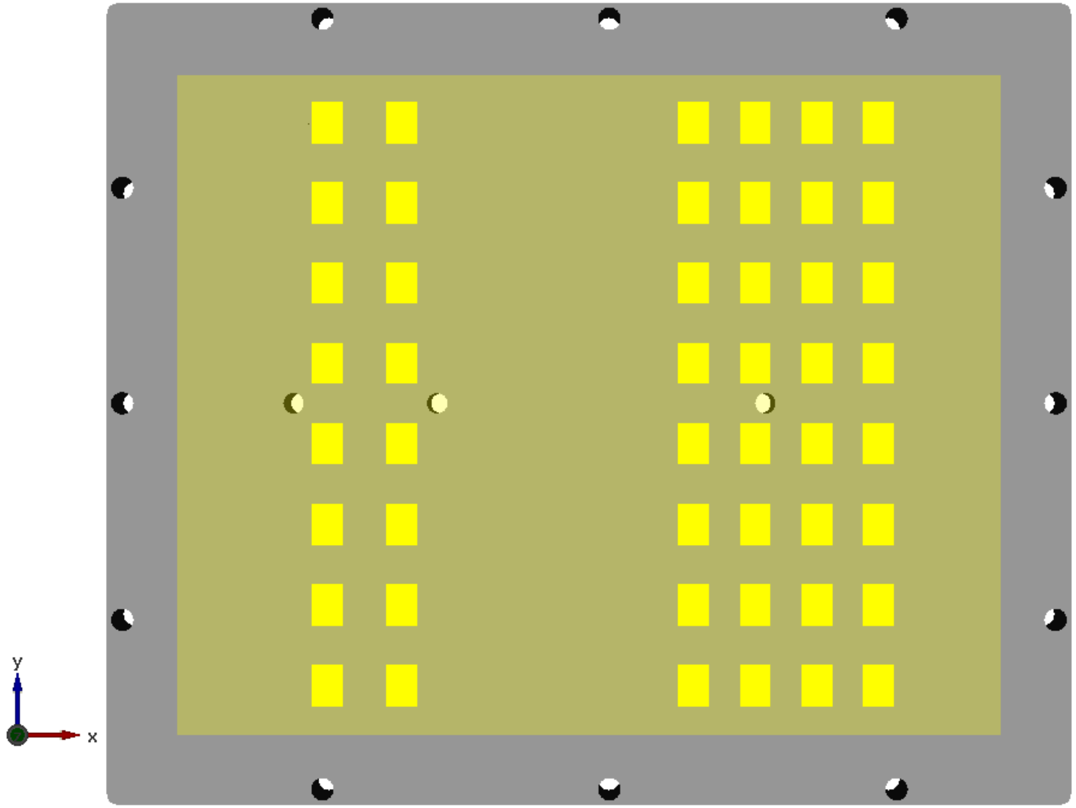


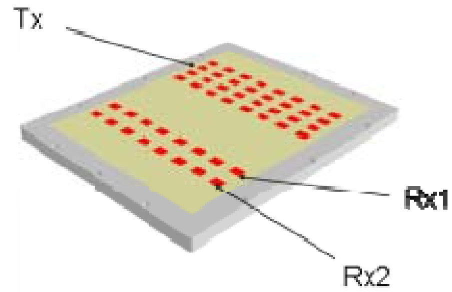
→ Importance of the user's experience!!!

When size matters



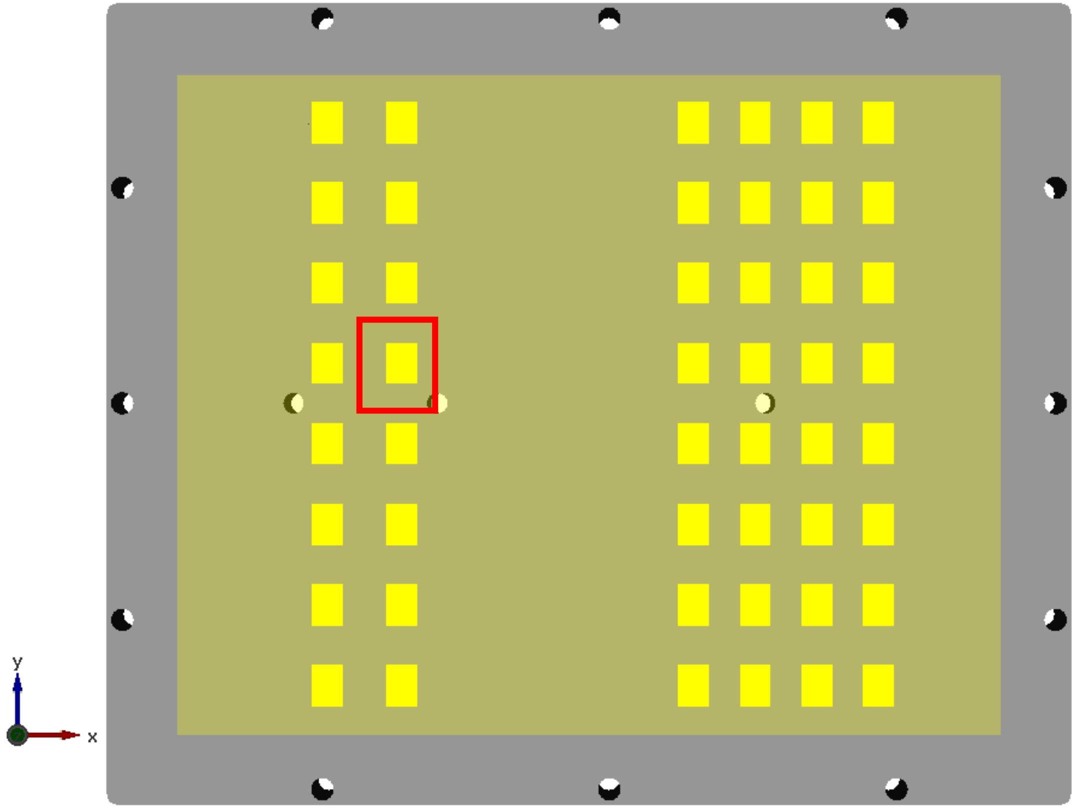
How to simulate?

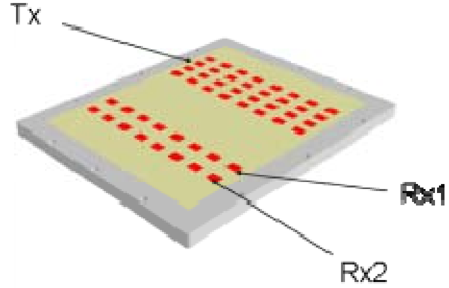




Divide into smaller problems!!!

Single element

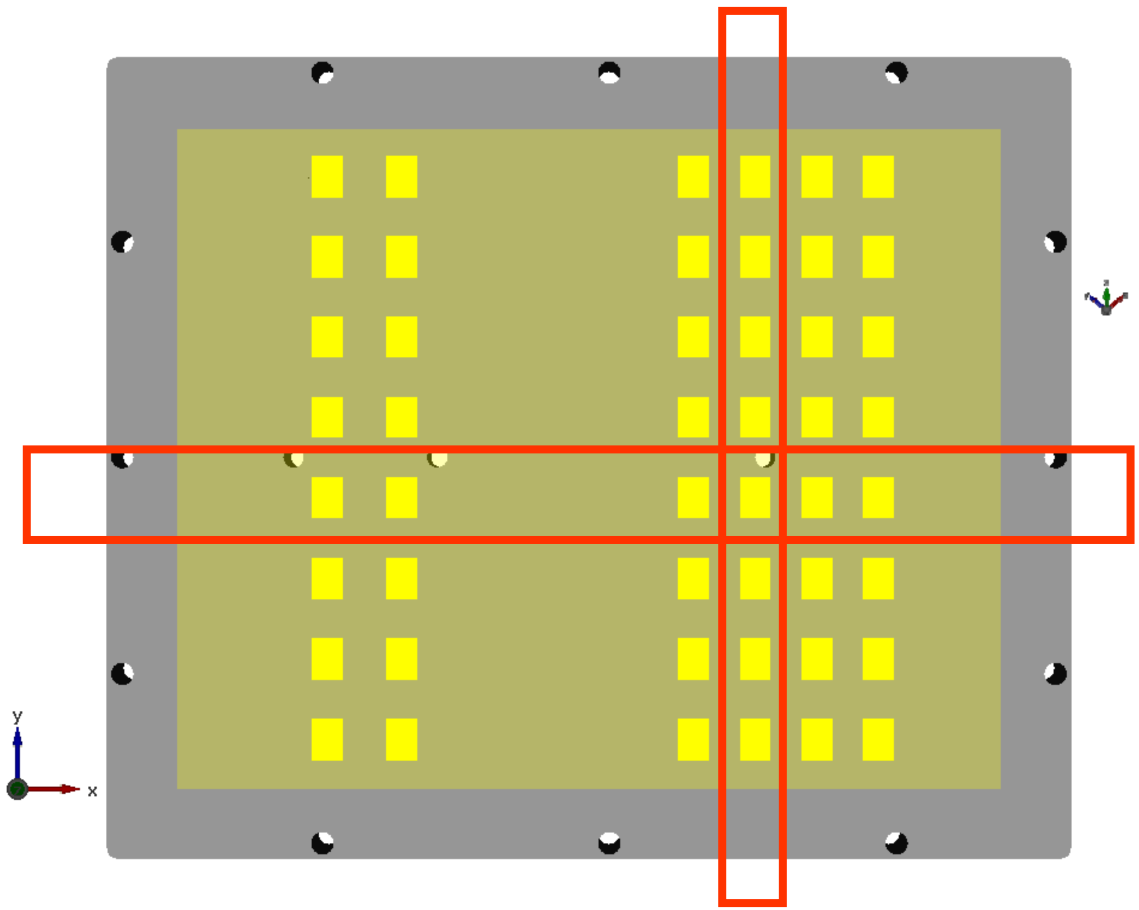


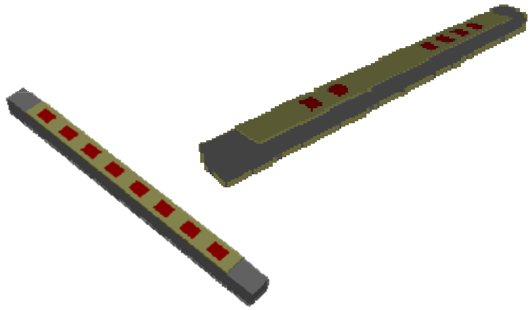


→ Frequency

→ Polarisation…

One column / one row



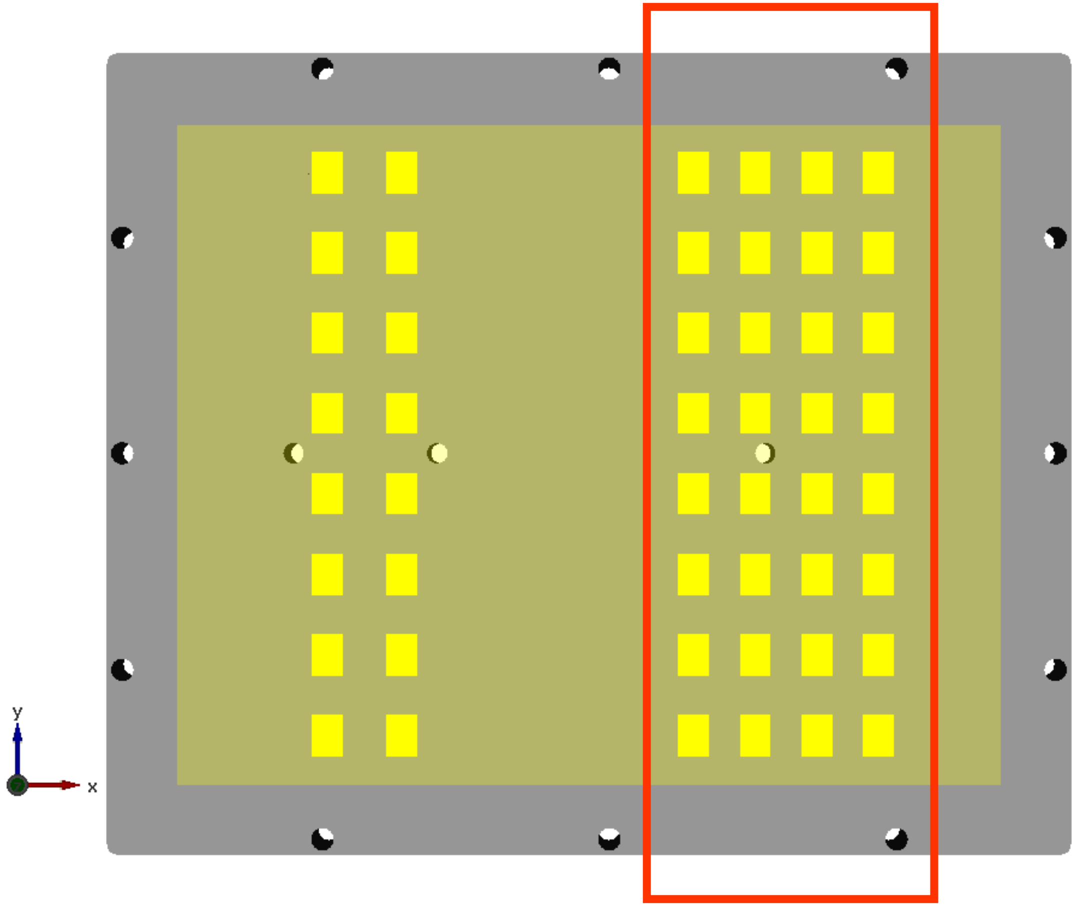


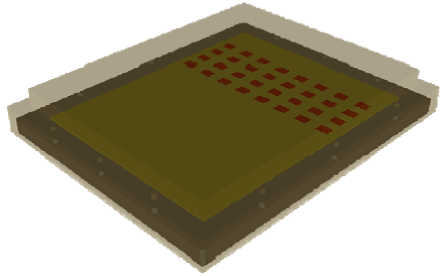
→ Azimuth / Elevation

→ Feeding lines (matching)

→ Coupling

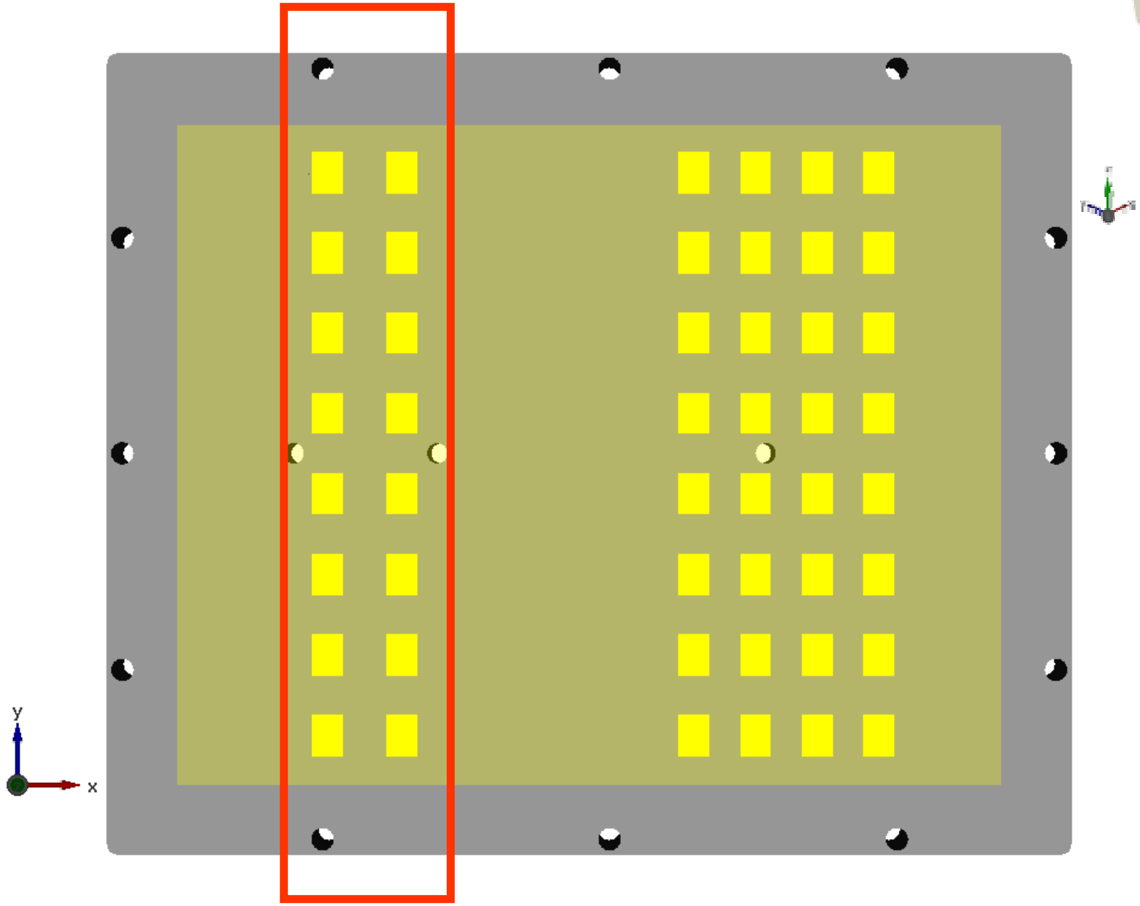
Array (Tx)

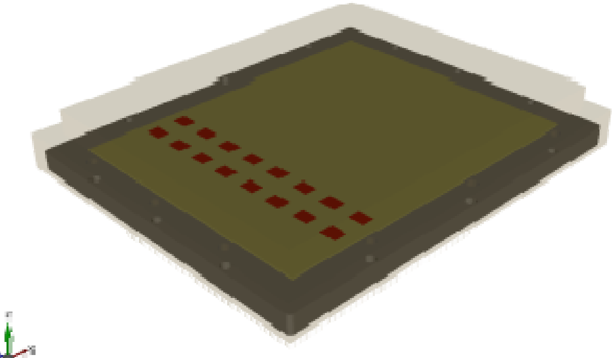




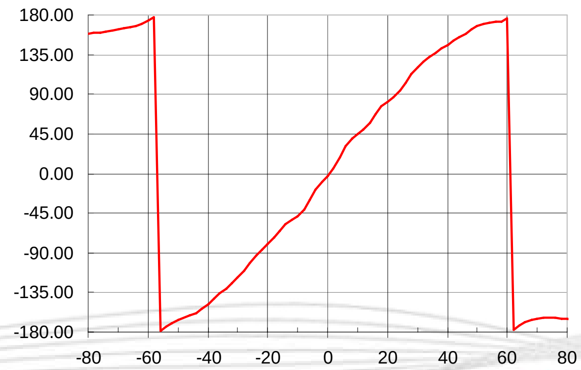
- → Azimuth & Elevation
- → Feeding lines (matching)
- → Groundplane, radome

Array (Rx)

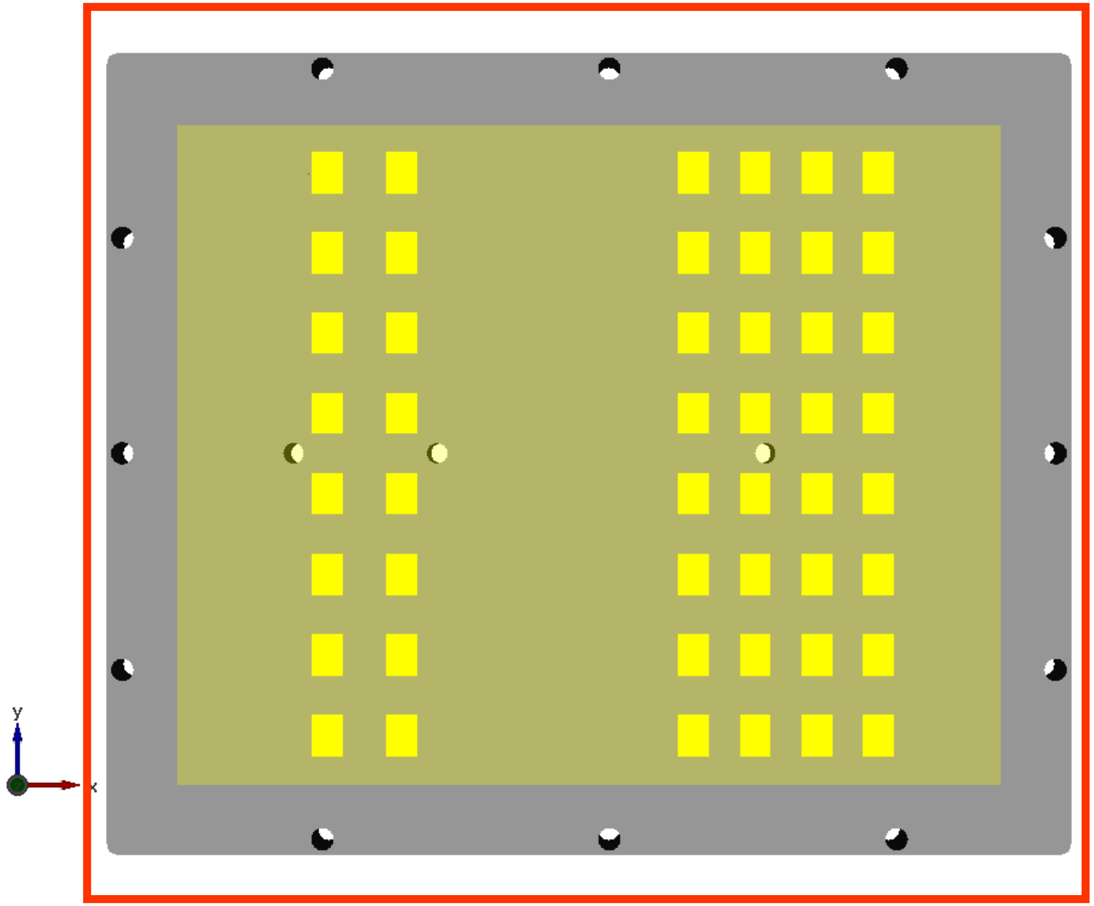


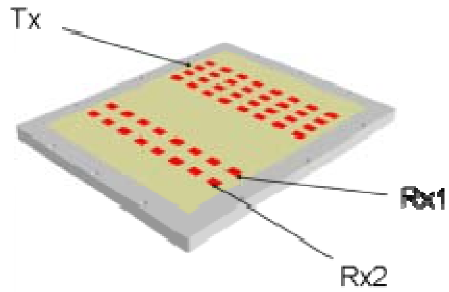


- → Azimuth & Elevation
- → Feeding lines (matching)
- → Groundplane, radome
- → Phase difference



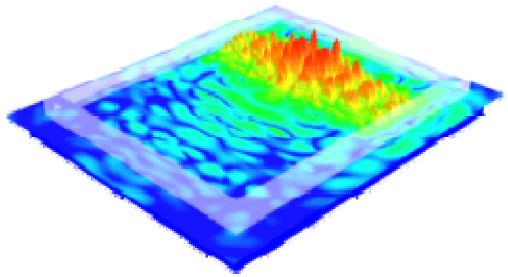
Whole antenna system





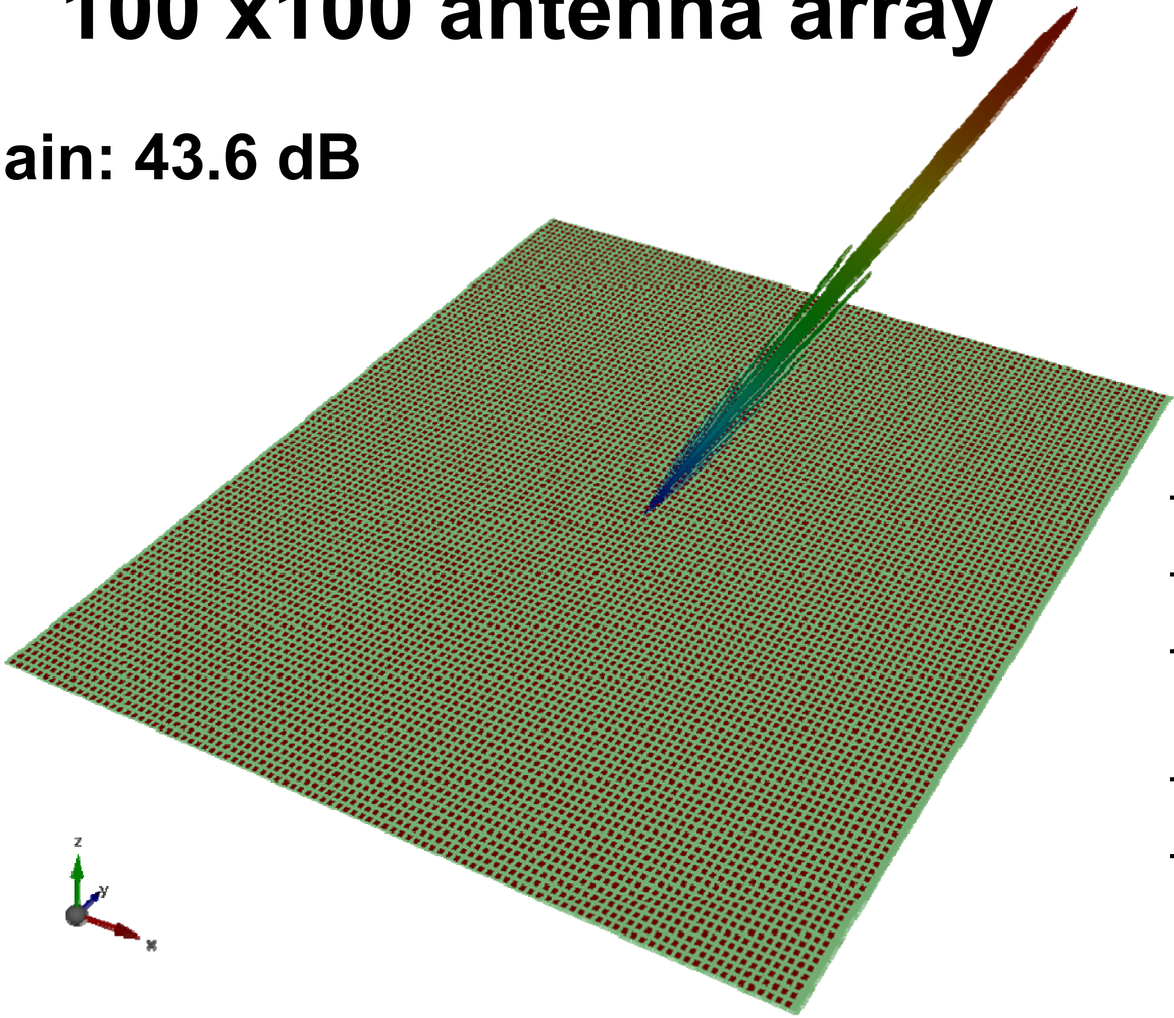
→ Coupling / interaction

→ Final check



100 x100 antenna array

Gain: 43.6 dB



→ frequency : 7 GHz

→ grid: 0.8 – 2.6 mm

→ 92 Million cells (1936x2142x29)

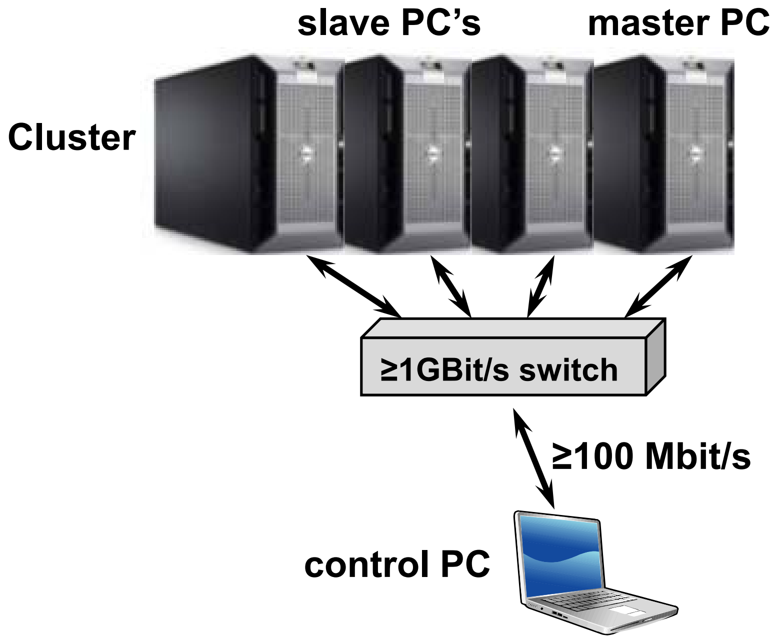
→ Memory usage ~ 6 GB

→ Simulation time: < 45 min

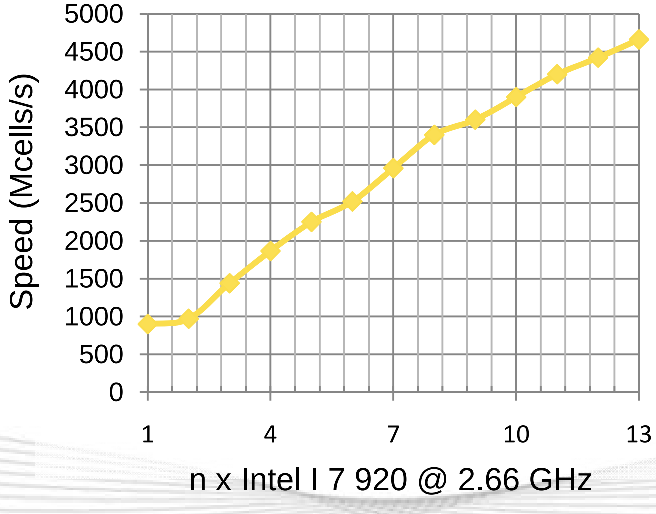
Simultaneous excitation of 10,000 ports with:
→ specific weight factor
→ individual phase delay!!!

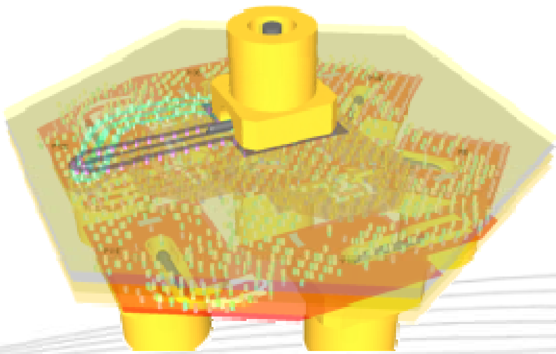
Cluster solver

- → Efficient use of multiple PCs for reduced simulation time
- → One simulation job on multiple PCs within a network
- → Use of standard PCs vs. expensive server workstation with hundreds of GBytes of memory
- → Example: 100 GB problem on 10 x 12 GB



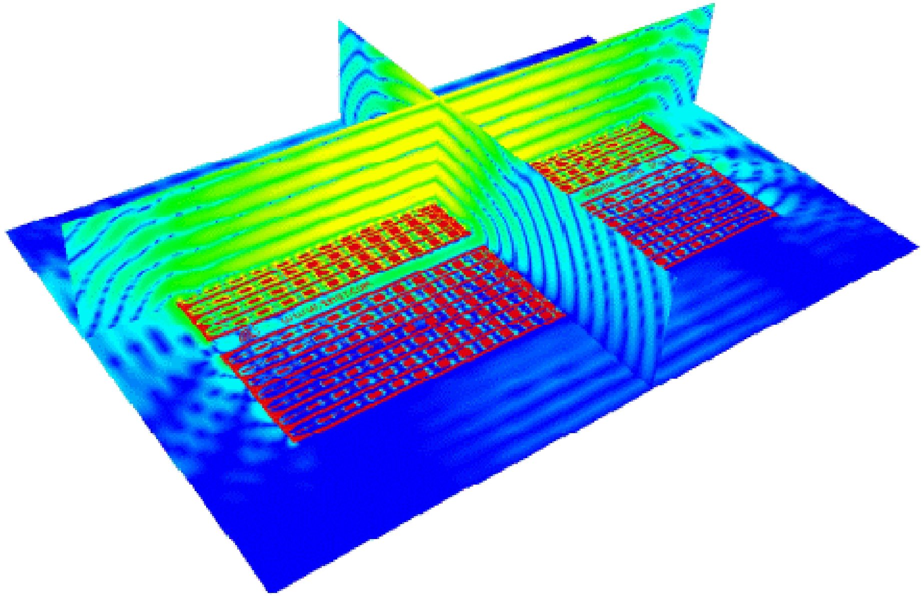
PERFORMANCE

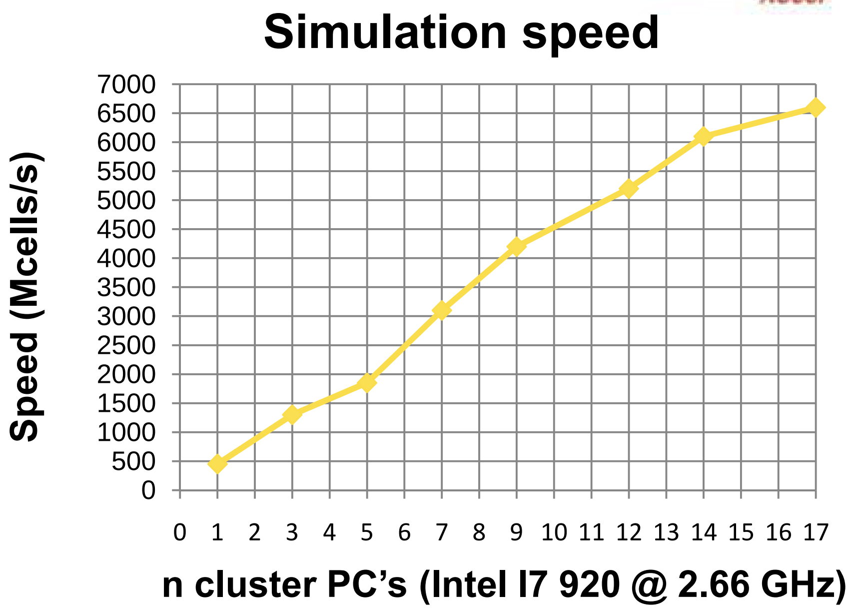




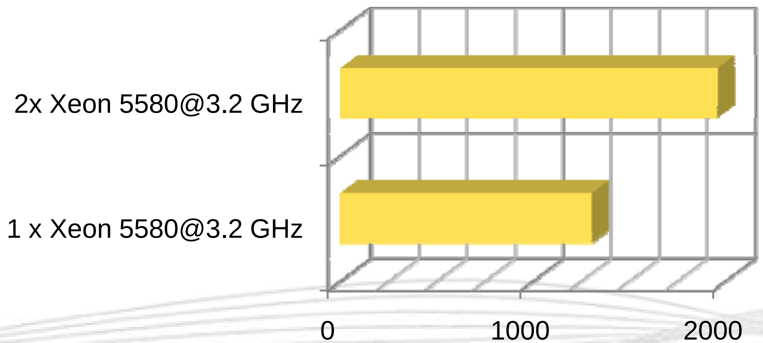
multifeed network

Multilayer Antenna: FDTD Performance

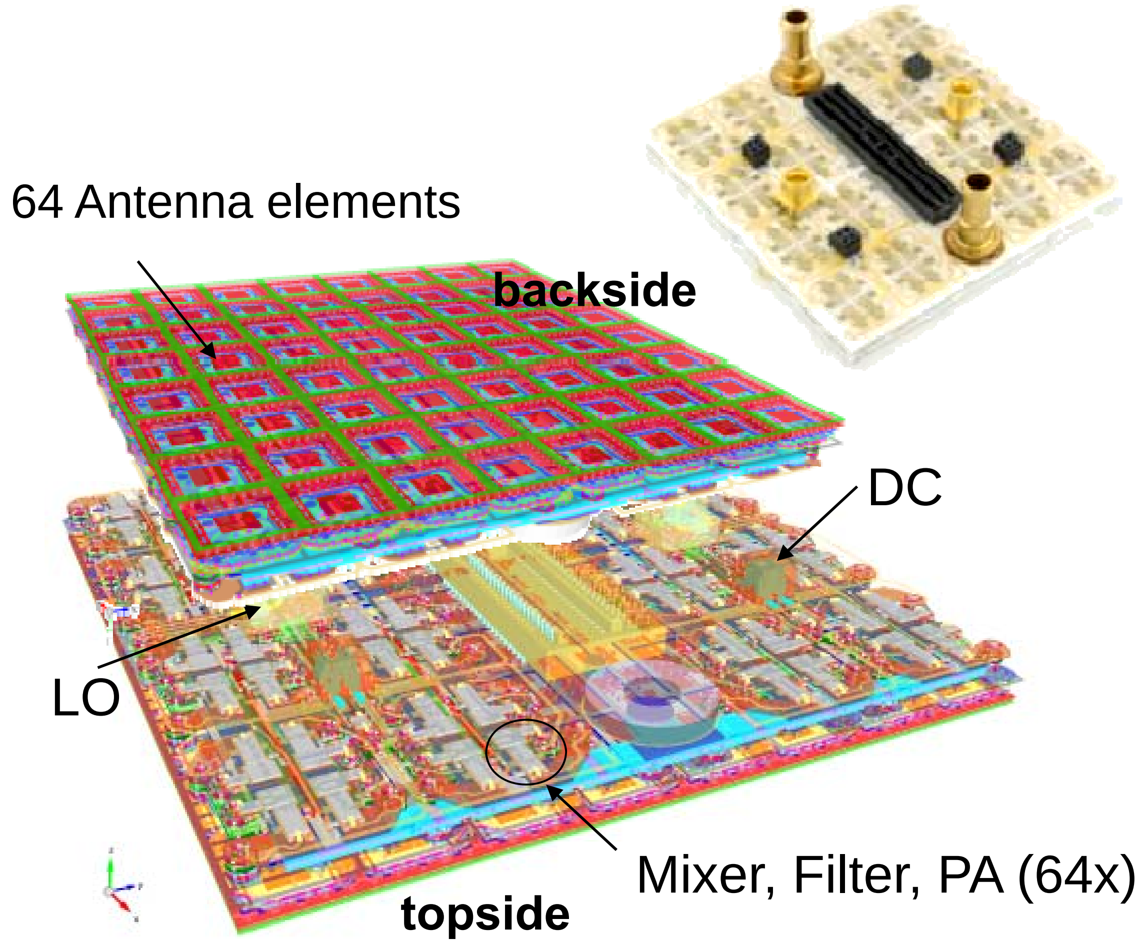




- → 24 GHz radar antenna
- → mesh: 80 x 2933 x 1846 cells (433 Million cells)
- → resolution 25 µm < Δ < 765 µm
- → memory usage: 12 GB
- → simulation time 45min .. 10h



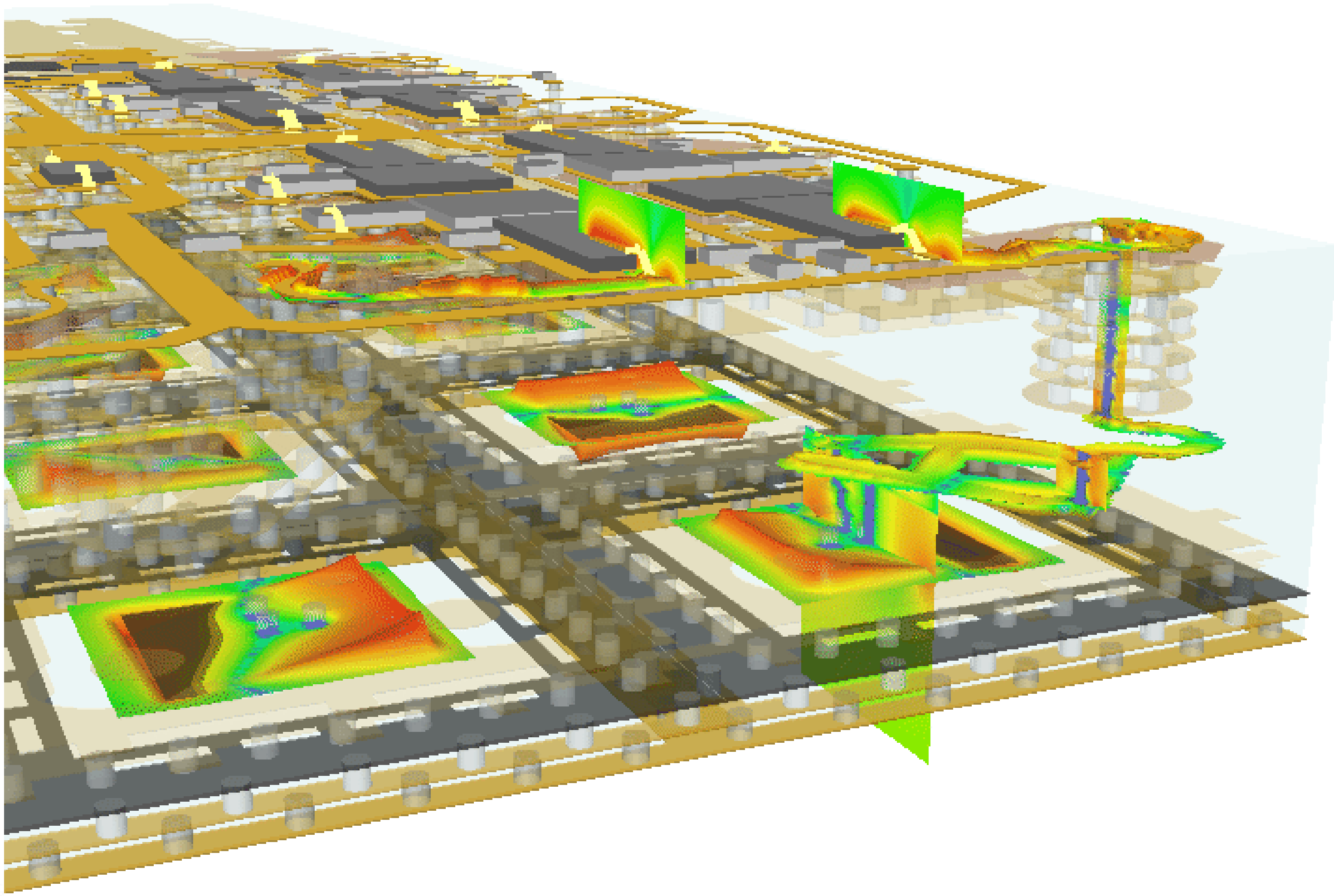
30 GHz DBF LTCC Antenna-Module



- → RF frontend incl. 8x8 array antenna:
- → 16 LTCC layers
- → 17 metallization layers
- → integrated 90° hybrid circuit, calibration network, LO feed network,…
- → simulation from PA output (incl. bond wire connection) to antenna
- → simultaneous excitation of all 64 ports

- → Simulation time < 9 h (Multi PC: < 4h); Memory usage ~20 GB
- → 600 Million cells ; grid: 10 µm < Δ < 215 µm

Antenna feed, 30 GHz DBF LTCC Antenna Module



Scope of the talk

→ Introduction

→ Why planar arrays?

→ Technological considerations

→ The challenge of simulation

→ Measurements

→ Examples

→ Outlook

Measurements

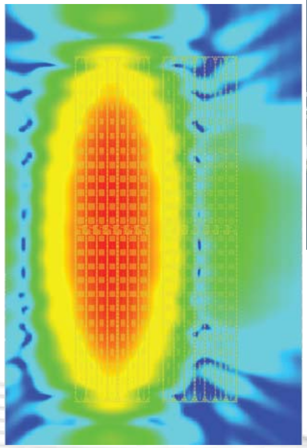
→ **Farfield measurements**: not enough information to pinpoint simulation discrepancies (manufacturing defects, unexpected losses, mechanical tolerances…)

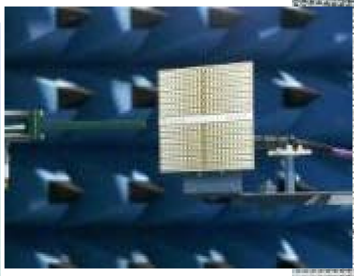
→ **Nearfield measurements**: powerful insight into the characteristics of patch arrays:

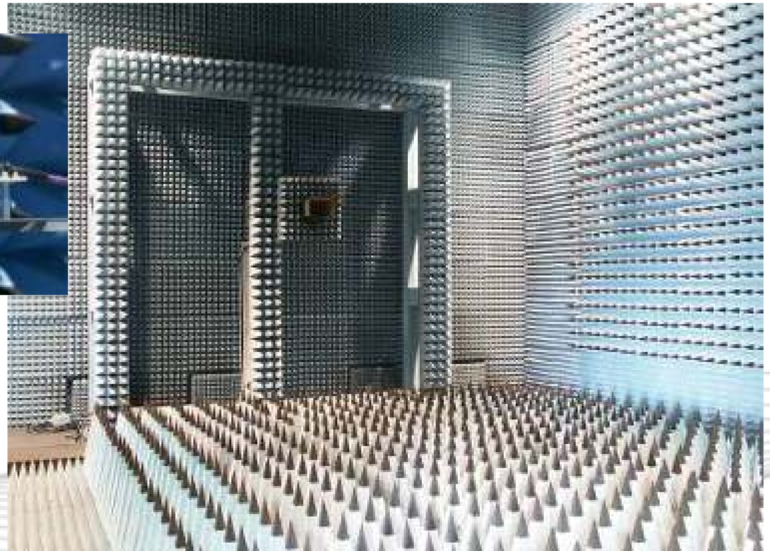
- Coupling and general interactions between radiating elements
- Effect of the feeding network

→ Field sampling in **amplitude** and **phase**:

- radiated waves (nearfield-to-farfield transformation)
- very near fields of the antenna (current distribution on the patches)



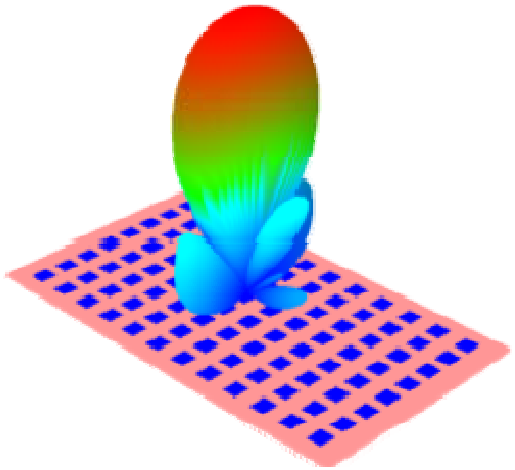


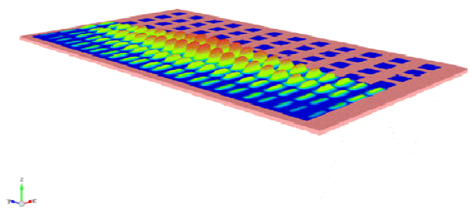


Example: 24 GHz antenna

→ **Radar antenna for automotive applications**

- Array of 8x12 microstrip patches
- 24 GHz ISM frequency band
- Structure size: 75 mm x 50 mm
- Substrate: 600 μm thick, ε_r=3.66
- Feeding network on the backside





→ **Target**:

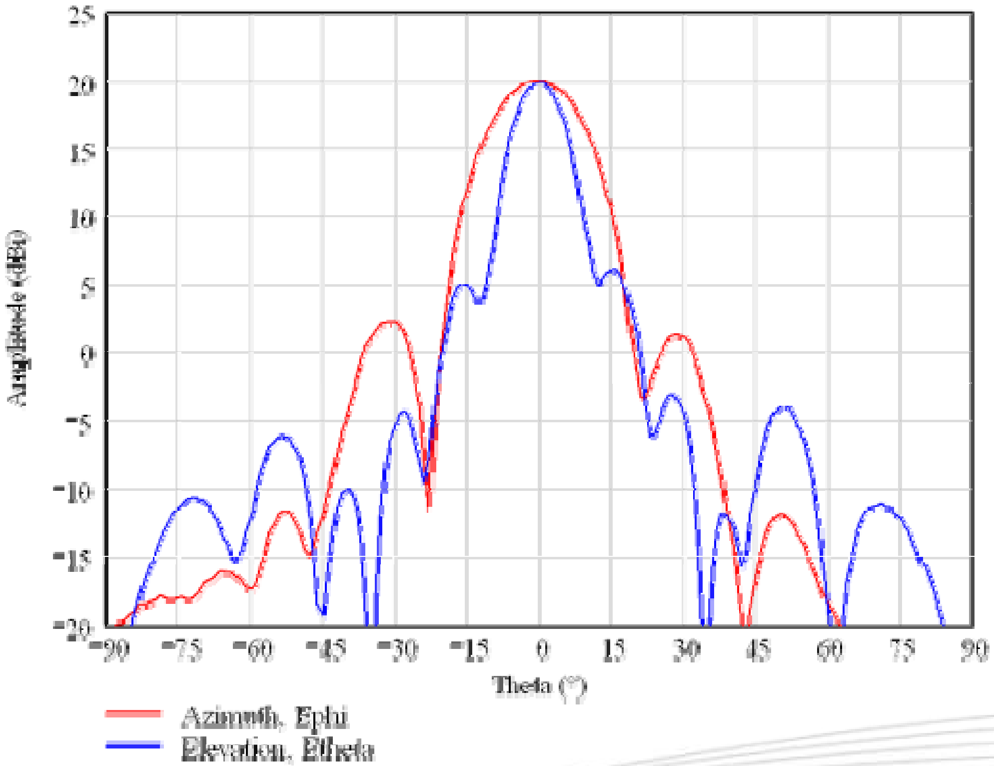
- Maximum gain
- Main beam pointing: broadside direction
- Symmetrical radiation with respect to broadside
- First sidelobe: -20 dB
- Sidelobe level better than -25 dB for angles beyond 35°

Farfield measurements

→ Good results in terms of gain (around 20 dBi)

→ Symmetrical main beam

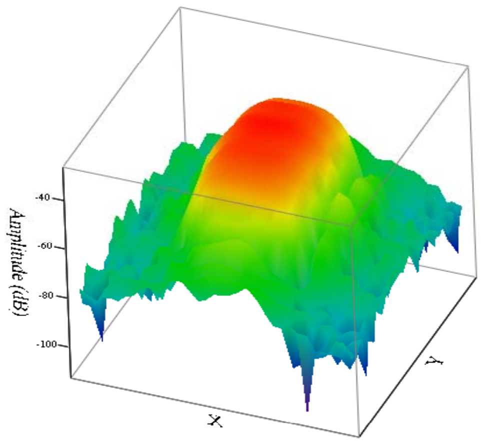
→ Sidelobes higher than desired



Nearfield measurements

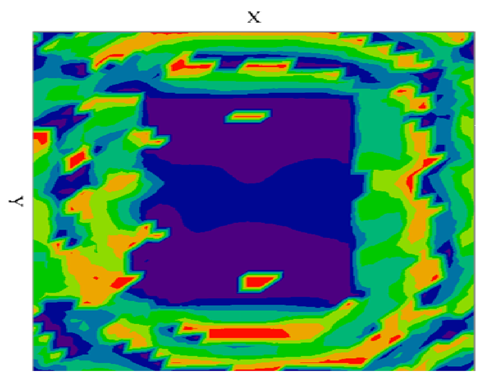
→ Amplitude distribution

- vertical component, electric near field
- corresponds to the desired tapering in X and Y directions



→ Phase distribution

- not completely uniform
- relatively high variation over the antenna aperture
- large phase variation at the last T-junctions (outer elements)
- Differences must be compensated: adjust the dimensions of the feeding network and/or the patches



Tuning of the antenna

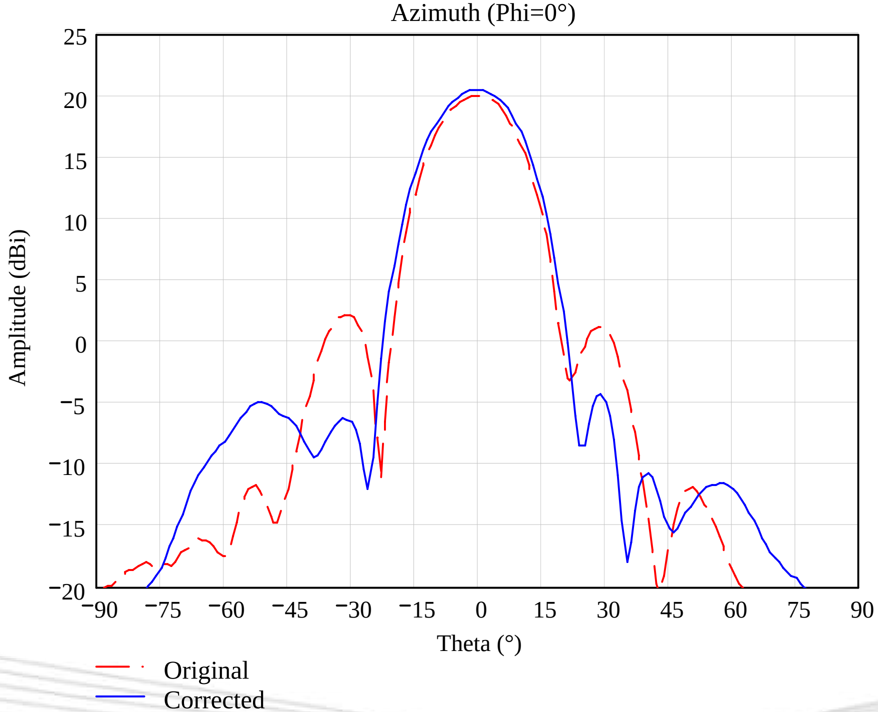
Adjustment of length and widths of the line sections

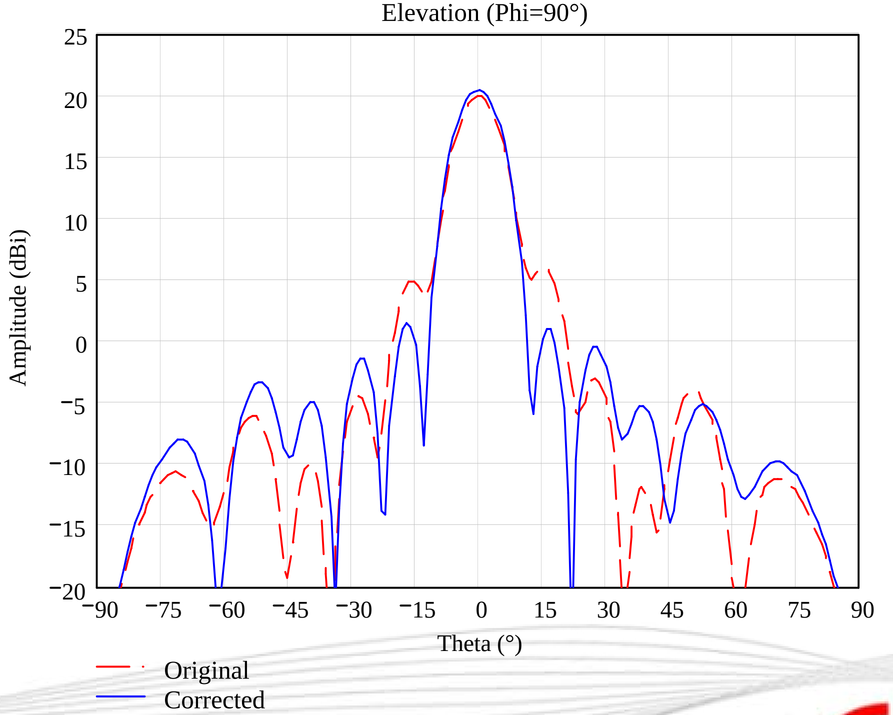
→ Gain increased by 0.5dB

→ Significant improvement in the side lobe levels

-25dB in the azimuth

-19dB in elevation.





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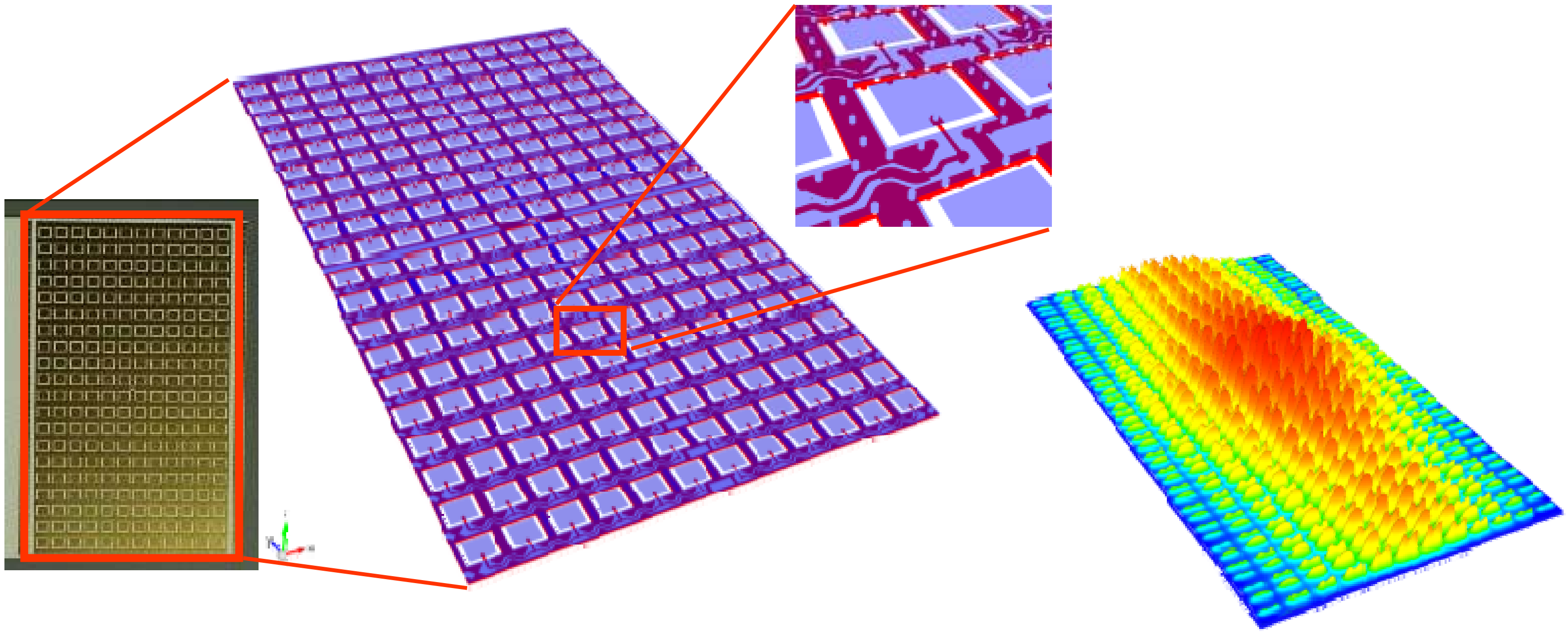
Multilayer antennas for 24 GHz Radar (1)



→ 20 x 12 elements, multilayer feeding network

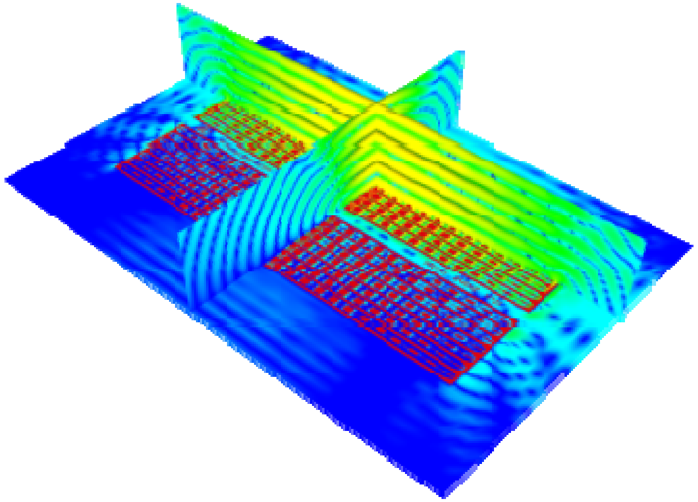
→ dielectric & conductor losses considered

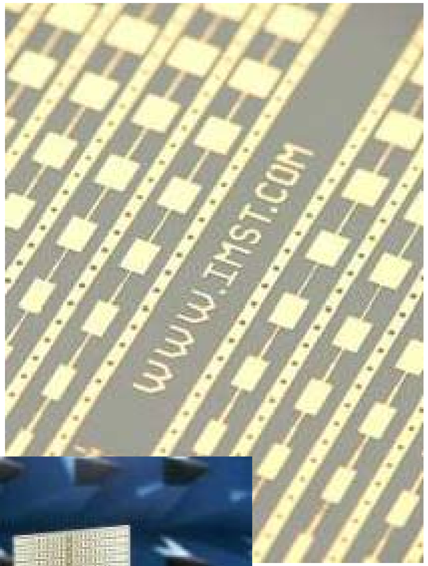
→ Simulation time < 2 h; Memory usage 4.1 GB

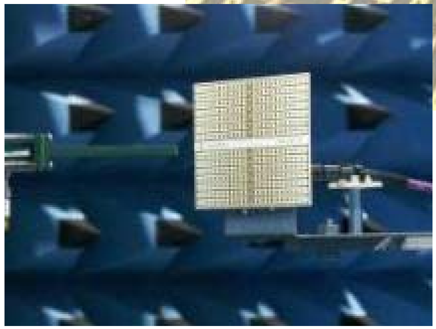
→ 108 Million cells ; grid: 40 µm < Δ < 500 µm

See: O. Litschke, A. Bettray, S. Holzwarth, A. Lauer, M. Martinez-Vazquez, S. Otto, B. Sanadgol, „Antenna Frontends for Radar Applications“, Proceedings of EUCAP 2010.

Multilayer antennas for 24 GHz radar (2)

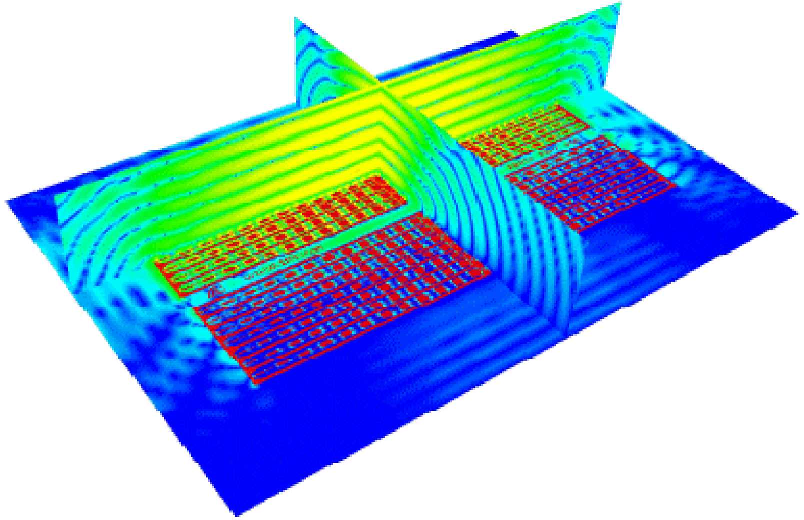




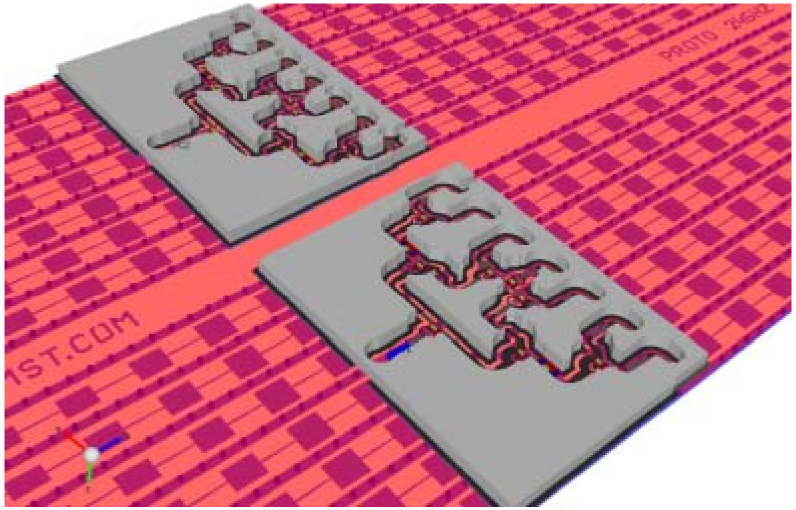


- → Integration of Tx and Rx antennas on one PCB
- → Serial feed to minimise number of layers
- → Customised pattern design
- → Steerable/Multibeam capability
- → High resolution
- → Combination of short/range sensory

24 GHz automotive Tx/Rx radar antenna



Antenna with near field at 24 GHz

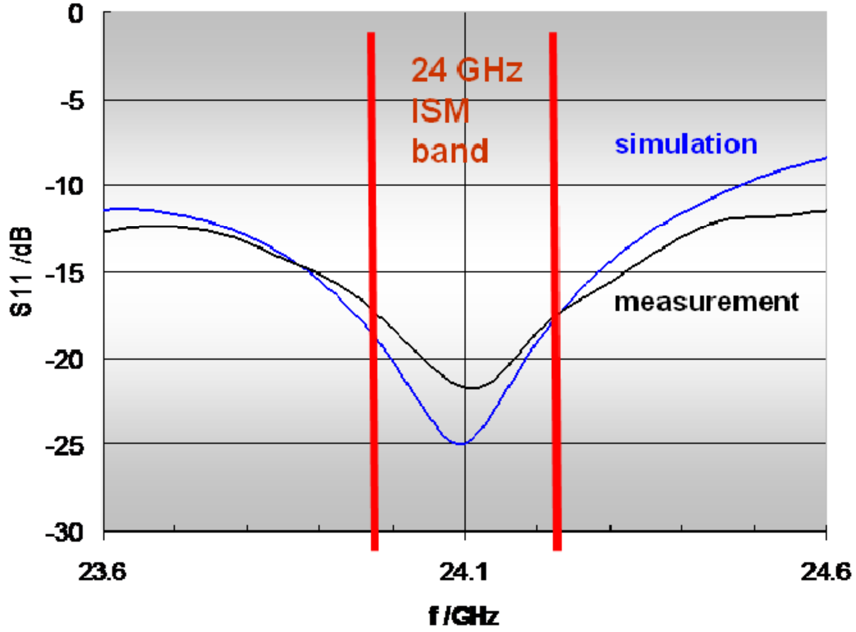


Backside feeding network with housing

- → 7 x 24 patches for Tx & Rx, size: 80 mm x 170 mm
- → Dielectric thickness ~ 1mm, 4 metal layers
- → 0201 SMD resistors for Wilkinson dividers & loads
- → Thickness casing 1.5 mm
- → Min. necessary resolution ~25 µm

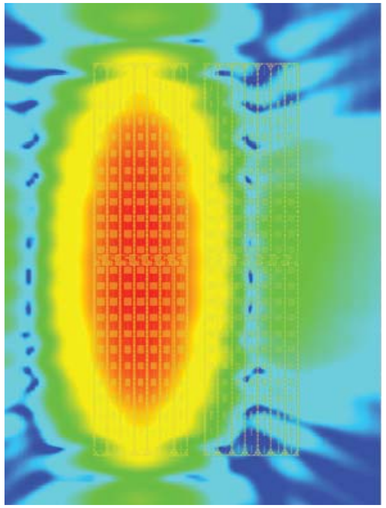
24 GHz radar antenna: results

Reflection coefficient

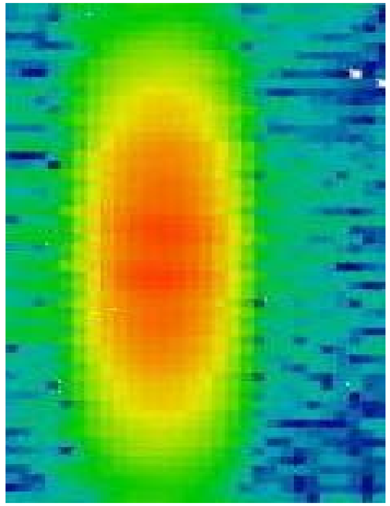


Nearfield

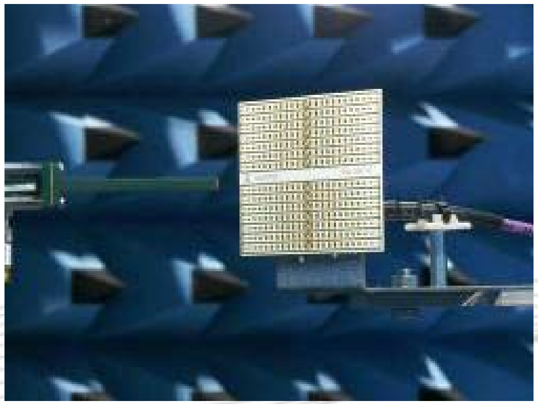
simulation



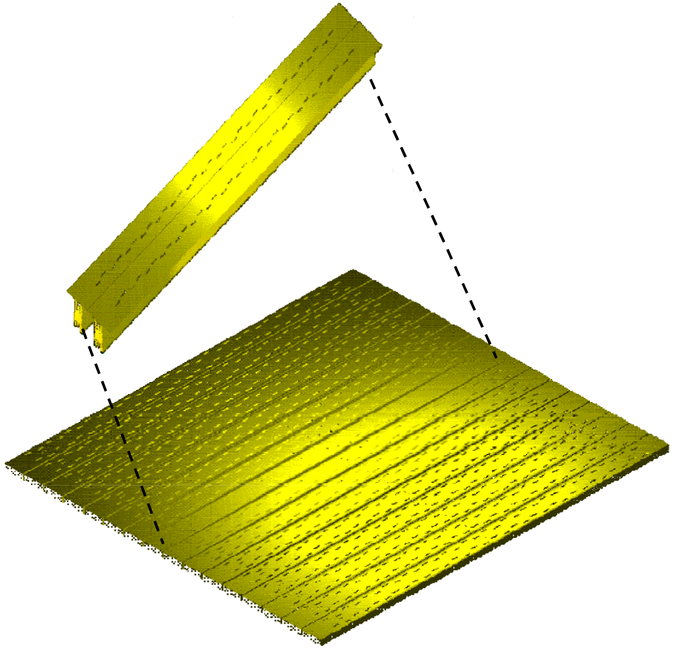
measurement

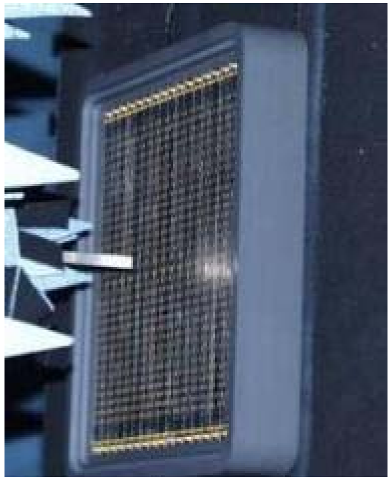


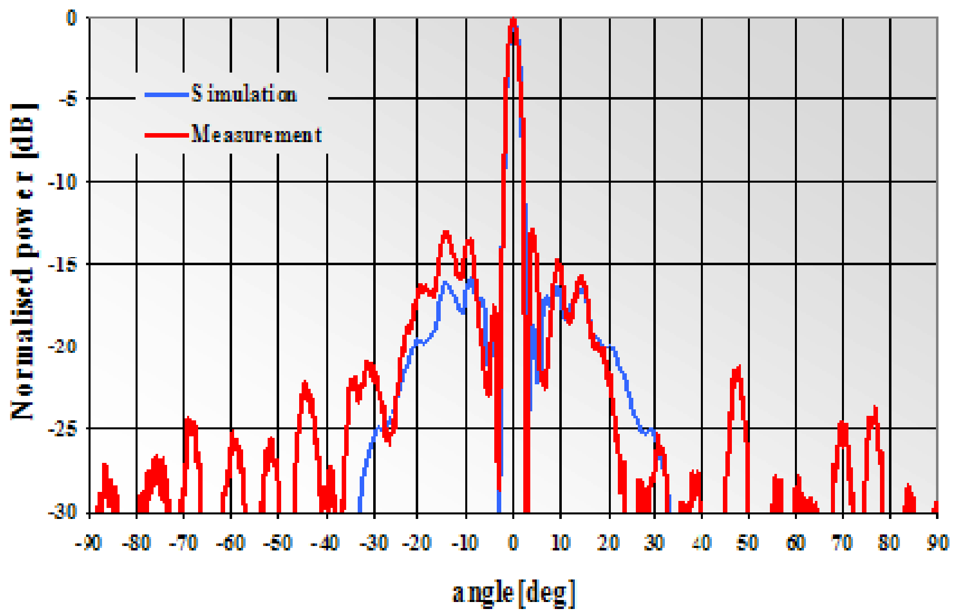
→ very good agreement between measurement and simulation!



Slotted waveguide array







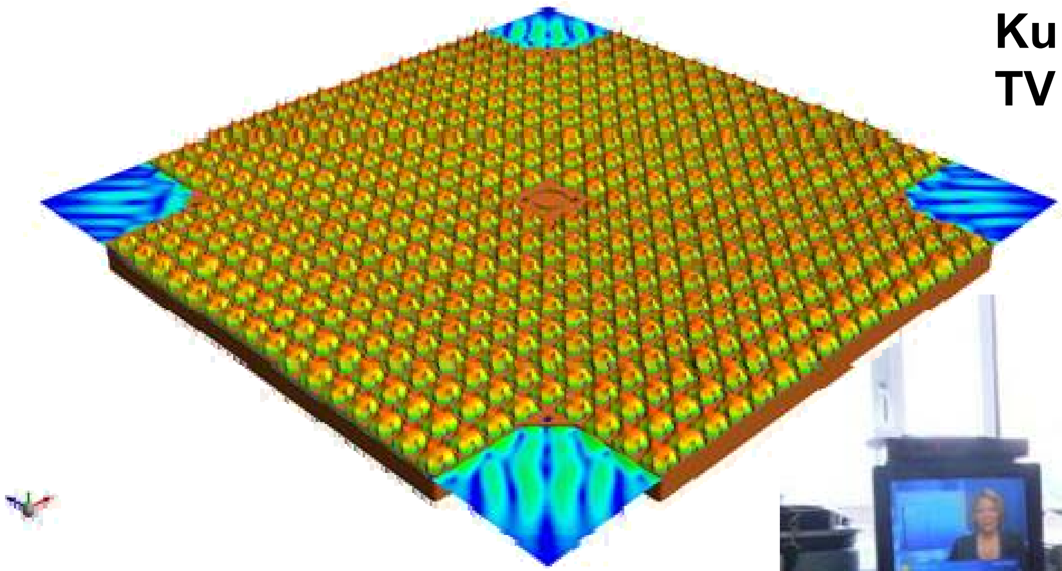
→28 GHz array

→2 x 32 elements in one row

→plastic injected moulding

Planar antennas for communications

Simulation model



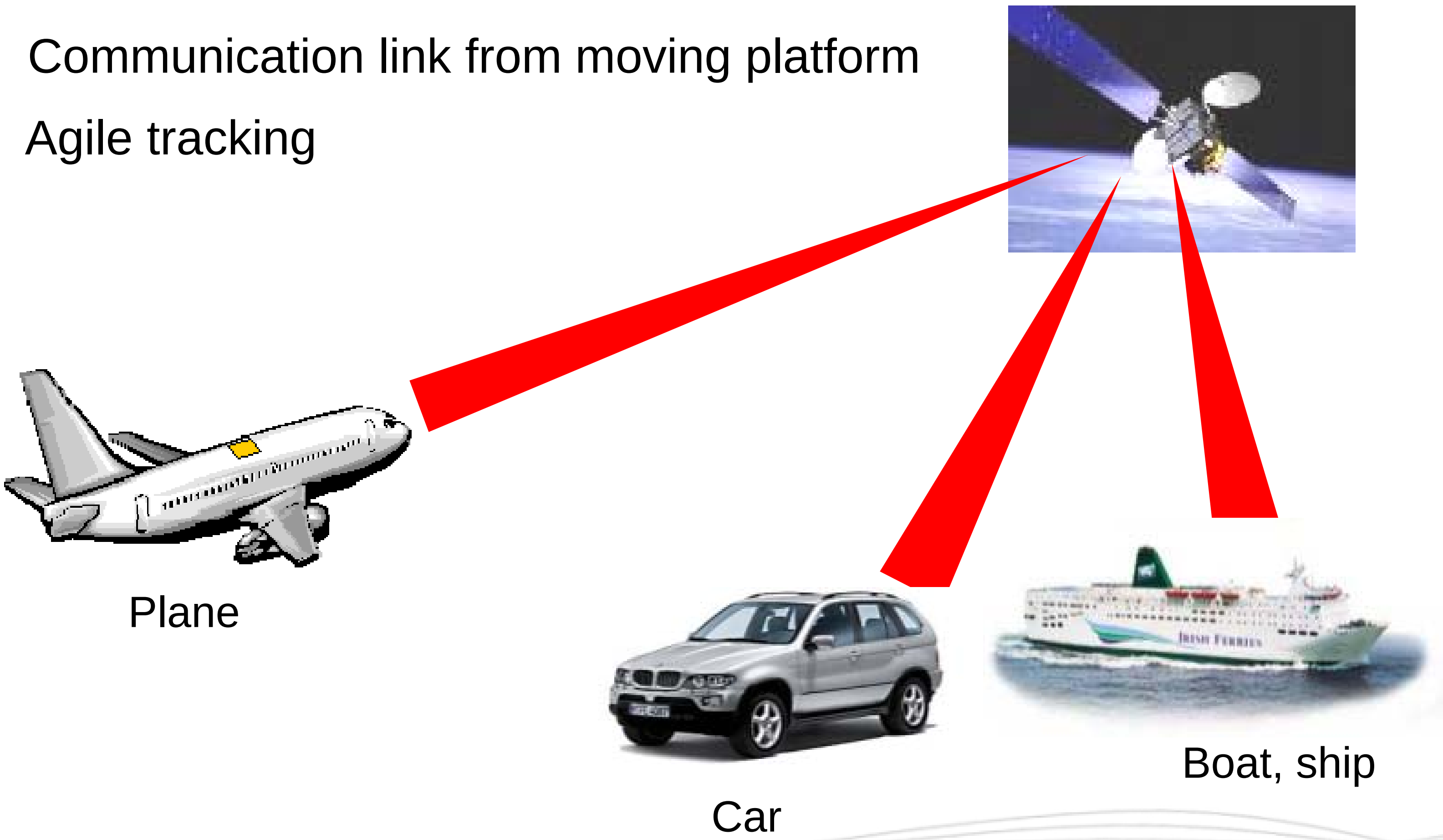
Ku band satellite TV antenna

Antennas for mobile SatCom

Requirements:

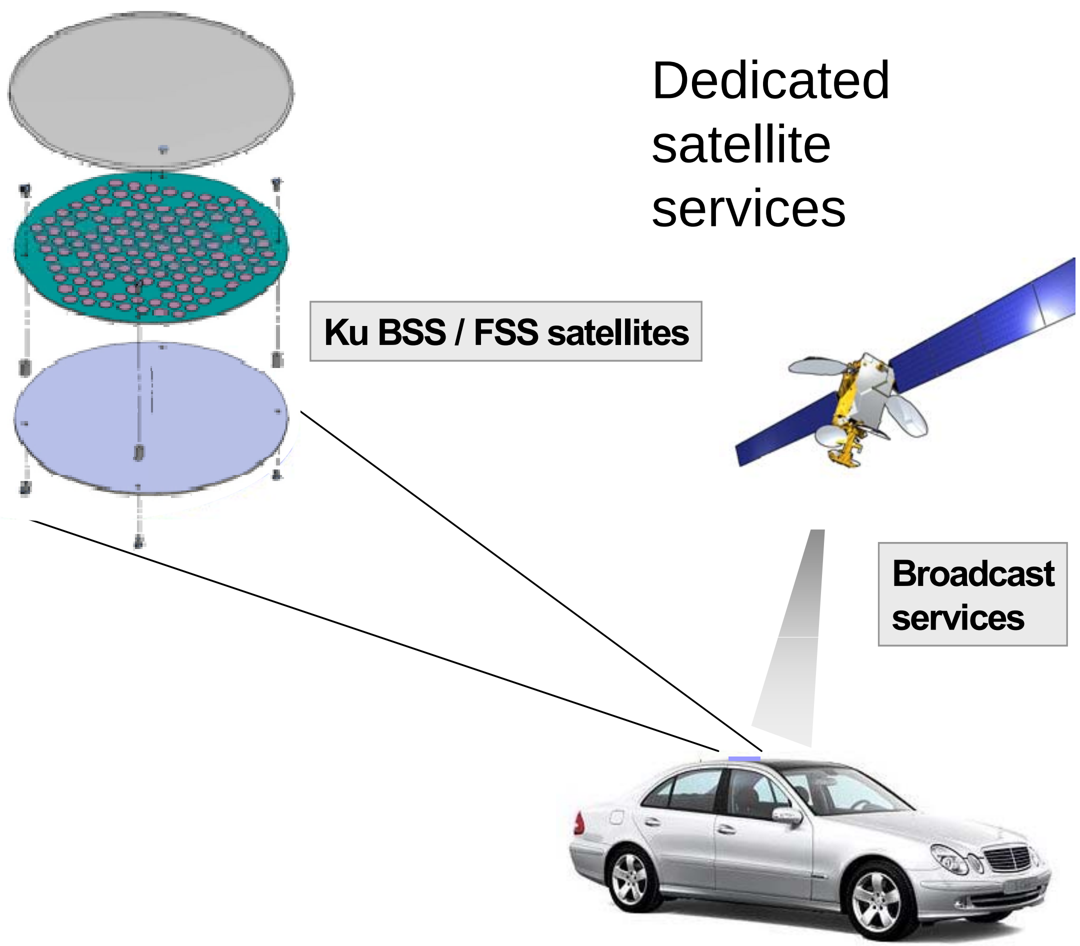
→ Communication link from moving platform

→ Agile tracking



NATALIA*: Ku-band receive antenna

Satellite antenna for automotive applications

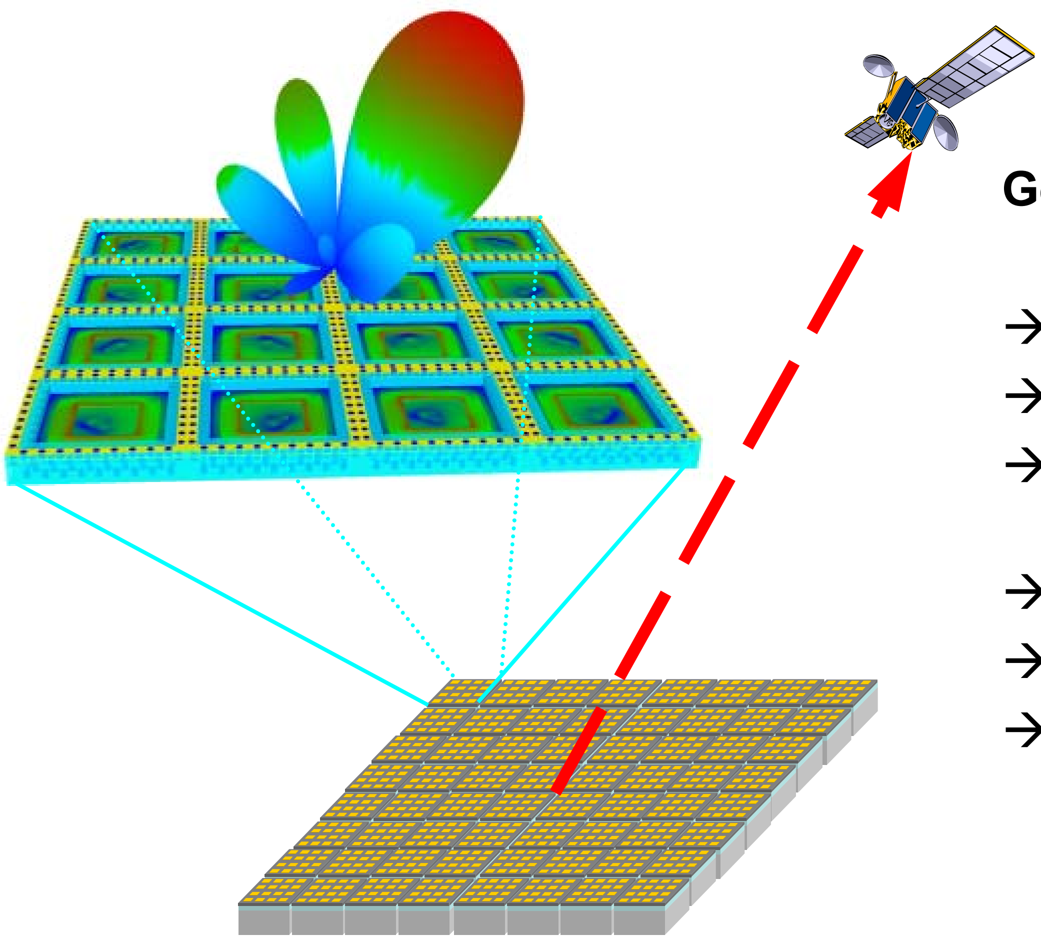


- → Phased array
- → Diameter: 20 cm
- → Height: 1.5 cm
- → 150 radiating elements
- → Polarisation tracking

* funded by ESA

See: Vaccaro, S.; Llorens del Rio, D.; Padilla, J.; Baggen, R., "Low cost Ku-band electronic steerable array antenna for mobile satellite communications", Proc. of EUCAP 2011.

Electronic beamforming in Ka-band*



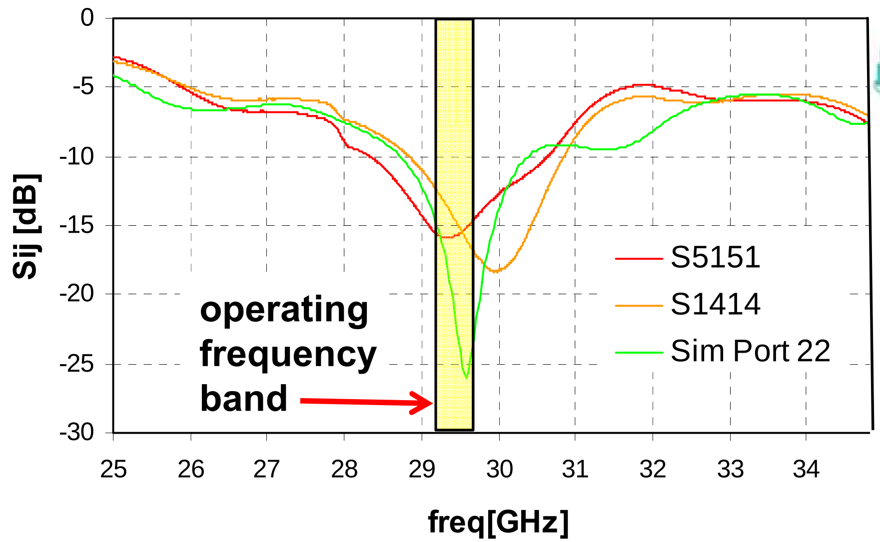
General Profile:

- → 4x4 and 8x8 antenna array
- → Building block for large arrays
- → Mobile satellite communication to GEOs
- → Electronic beamforming
- → Downlink 20 GHz
- → Uplink 29.5 – 30.0 GHz (transmit mode)

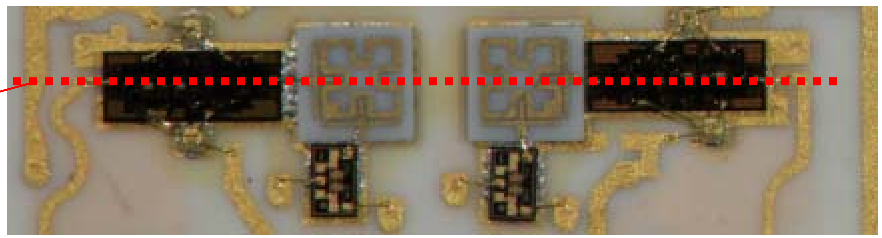
* funded by DLR Bonn, Germany

See: S. Holzwarth & al, “Highly integrated antennas and front-ends for 60GHz WLAN Applications”, Proc. of EUCAP 2011.

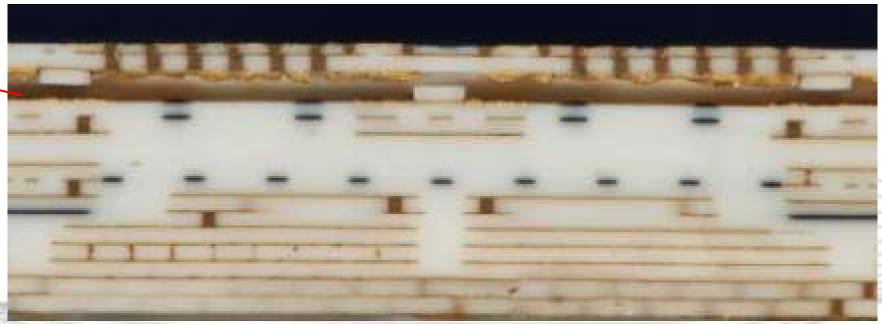
30 GHz LTCC front-end



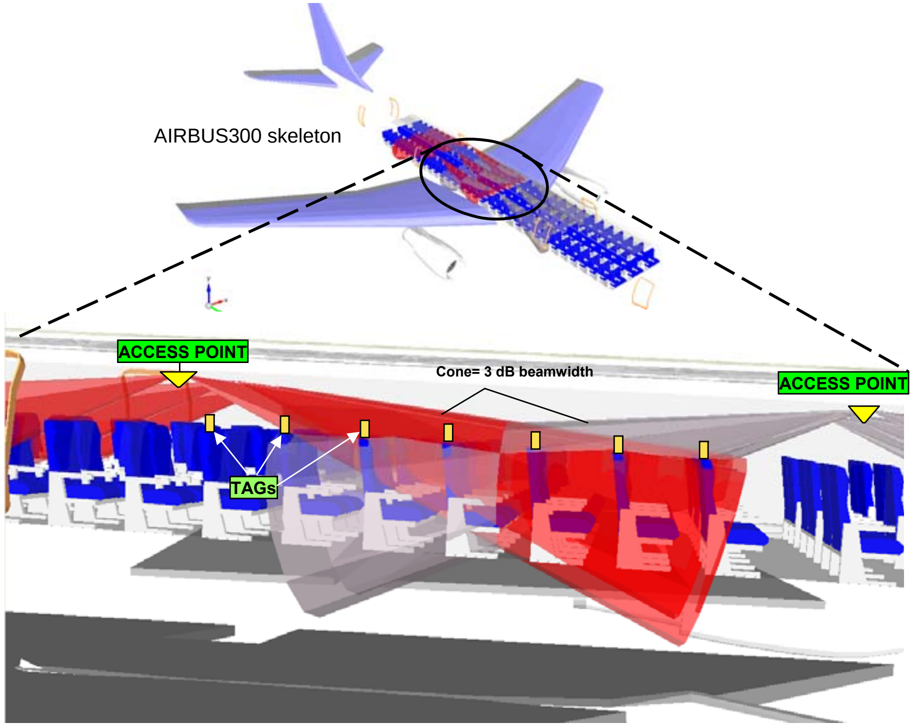
Cut through LTCC

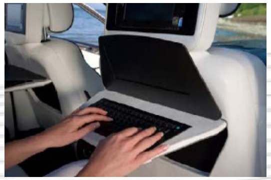


Cooling channel



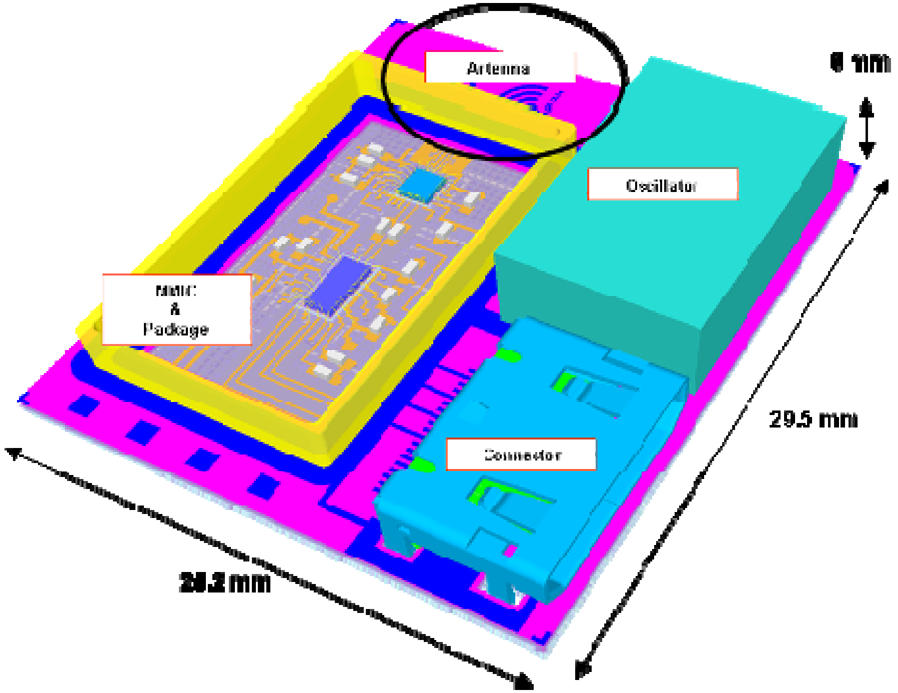
Antennas for WPAN: typical scenarios

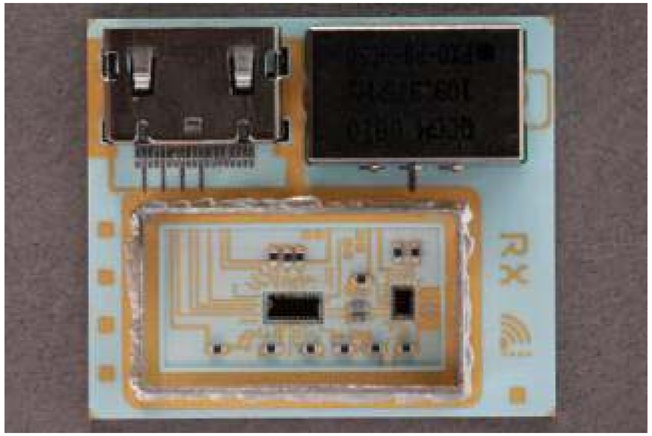




→ Frequency: 60 GHz
→ Data rate up to 7 GBit/s (WiGig)

EASY-A*: 60 GHz modules with integrated antennas





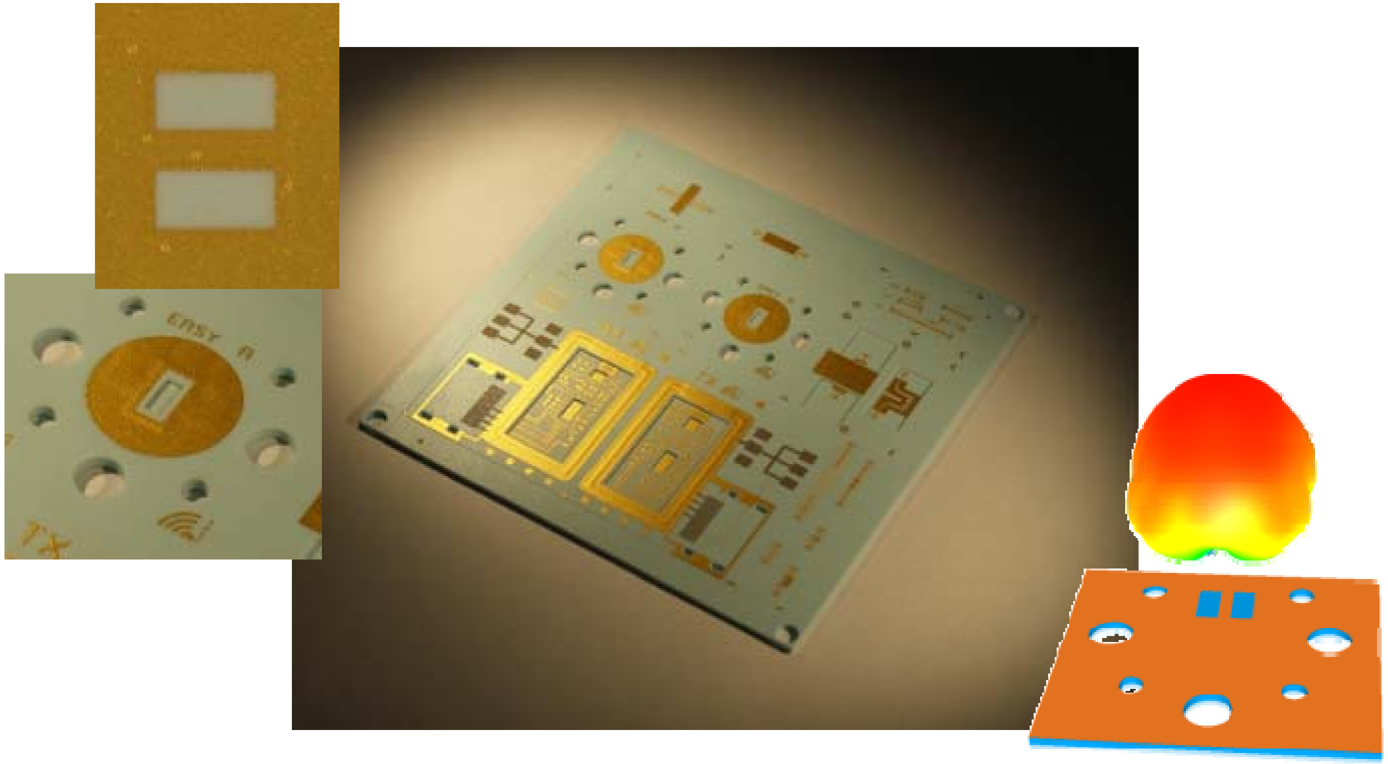
→ TX / RX in a single LTCC block

→ Balanced-fed antennas for optimised power transfer

* funded by the Ministry of Education and Research (BMBF), Germany

See: M. Martínez-Vázquez & al, "Highly integrated 8×8 antenna array demonstrator on LTCC with integrated RF circuitry and liquid cooling ", International Journal of Microwave and Wireless Technologies, volume 3, issue 02, 2011, pp. 157-170.

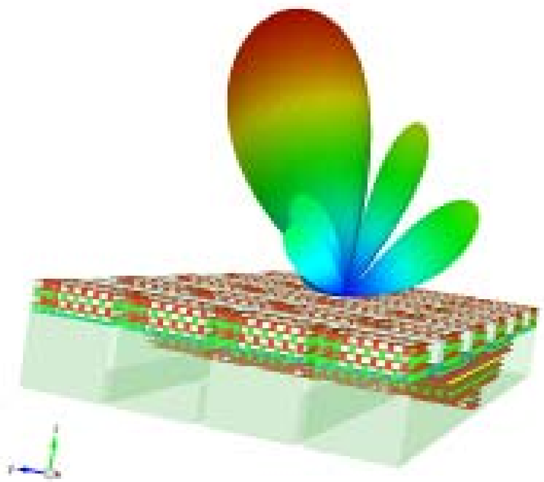
60 GHz modules with integrated antennas



→ LTCC-filled cavities, via walls

→ WG to stripline transition for measurements

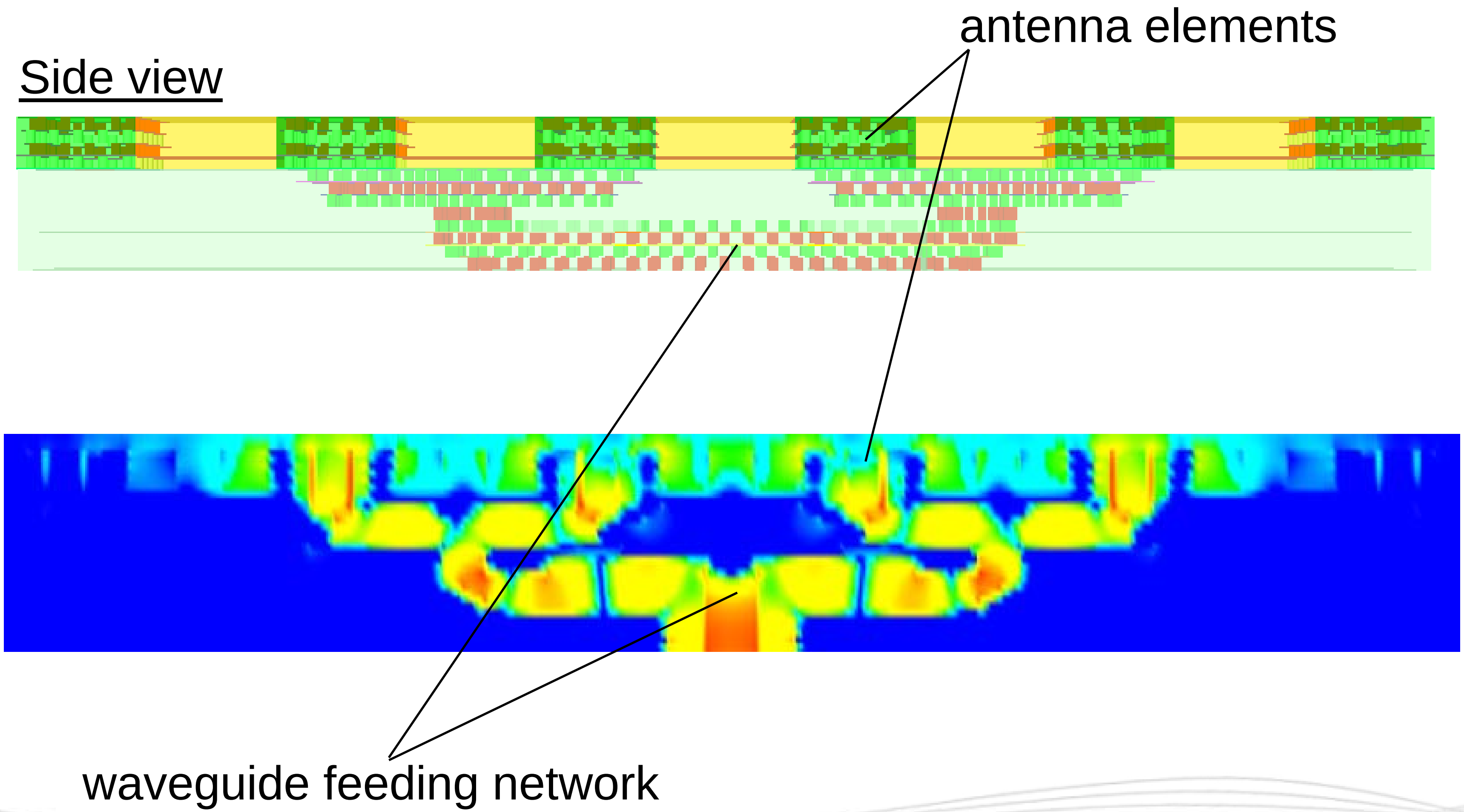
Steerable array for wireless HDTV



- → Electronic beamforming
- → Data rate: up to 4 GBit/s
- → LTCC-filled cavity antennas
- → Feeding: waveguides integrated in LTCC substrate

See: B. Sanadgol, S. Holzwarth, A. Milano, R. Popovich „60 GHz Substrate Integrated Waveguide Fed Steerable LTCC Antenna Array", Proc. of EUCAP 2010.

Steerable array for wireless HDTV



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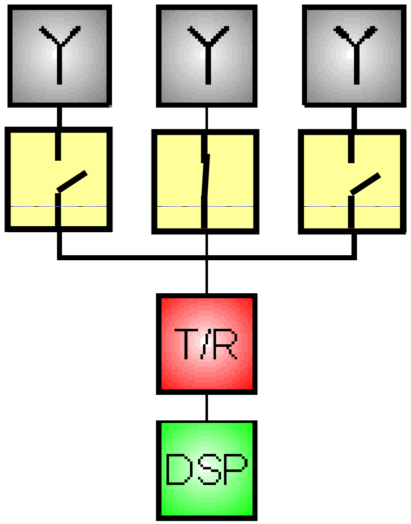
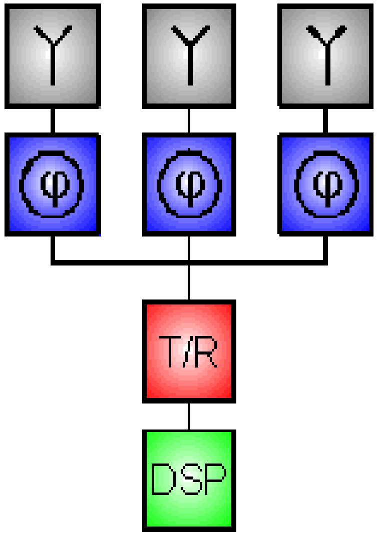
Electronicaly steerable arrays

Switched Beam



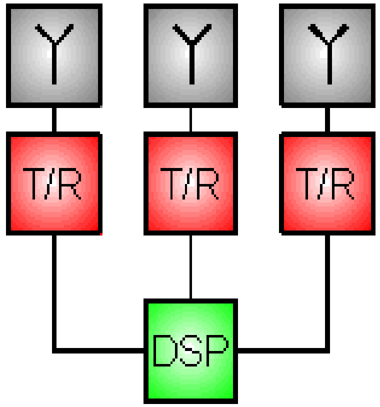
- → Switching between pre-defined states

Phased Array



- → phase and amplitude in RF
- → shifters
- → low system flexibility

Digital Beamforming



- → phase and amplitude in baseband
- → complete Rx/Tx circuitry for each element
- → high system flexibility
- → high packaging density

low — **Complexity & flexibility** — **high**

Challenges for planar arrays

→Active antennas

→High gain

→High integration

→Beamforming

→Thermal dissipation

Thank you for your attention!

martinez@imst.de

For more information please visit:

http://www.imst.com