Wireless Multi-Gigabit-Systems Workshop
TU Braunschweig, Germany

Beam-forming antenna array configurations for 60-GHz broadband communication

M. Imran Kazim

Technische Universiteit **Eindhoven** University of Technology

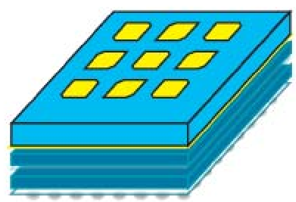
Where innovation starts

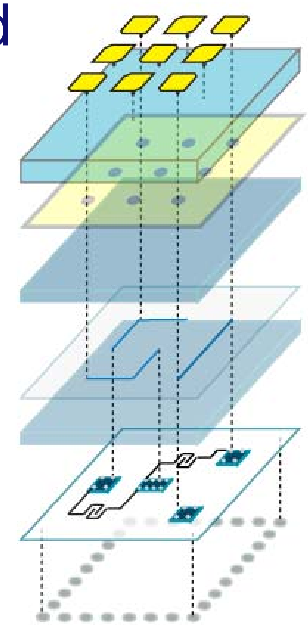
Outline

- Introduction
- Antenna element
- Measurements
- Antenna array
- Packaging
- 3D/Conformal antenna array

Introduction

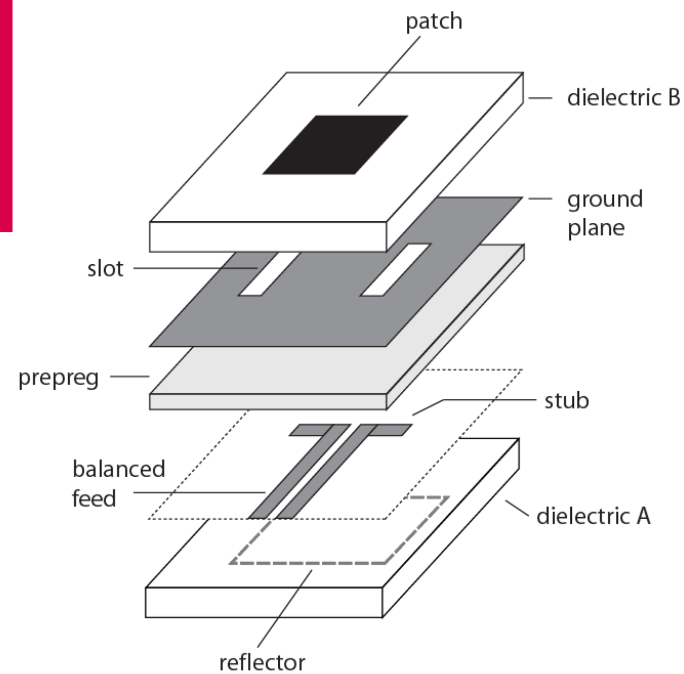
- Broadband communication in the 60 GHz band
  - Unlicensed bandwidth of around 7 GHz
  - Data rates of multiple gigabits-per-second
  - Applications
    - wireless USB 2.0
    - wireless HDTV
    - wireless gigabit ethernet
    - telecom backhaul
- Low-cost integrated package
    - transceiver chip-set
    - antenna
    - other passive components



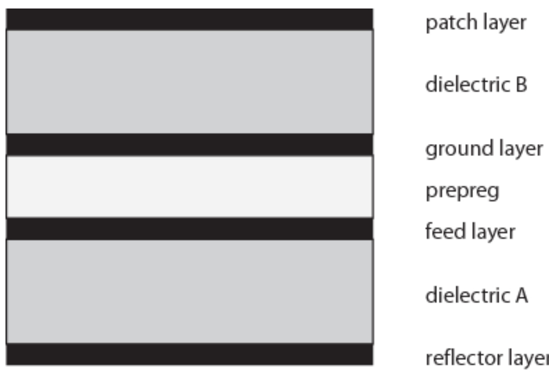


Antenna element
- Geometry

- Balanced-fed aperture-coupled patch antenna
  - realized in printed circuit-board
  - no vias
  - high radiation efficiency
    - >80%
  - bandwidth
    - 10-15 %



balanced-fed aperture-coupled patch antenna



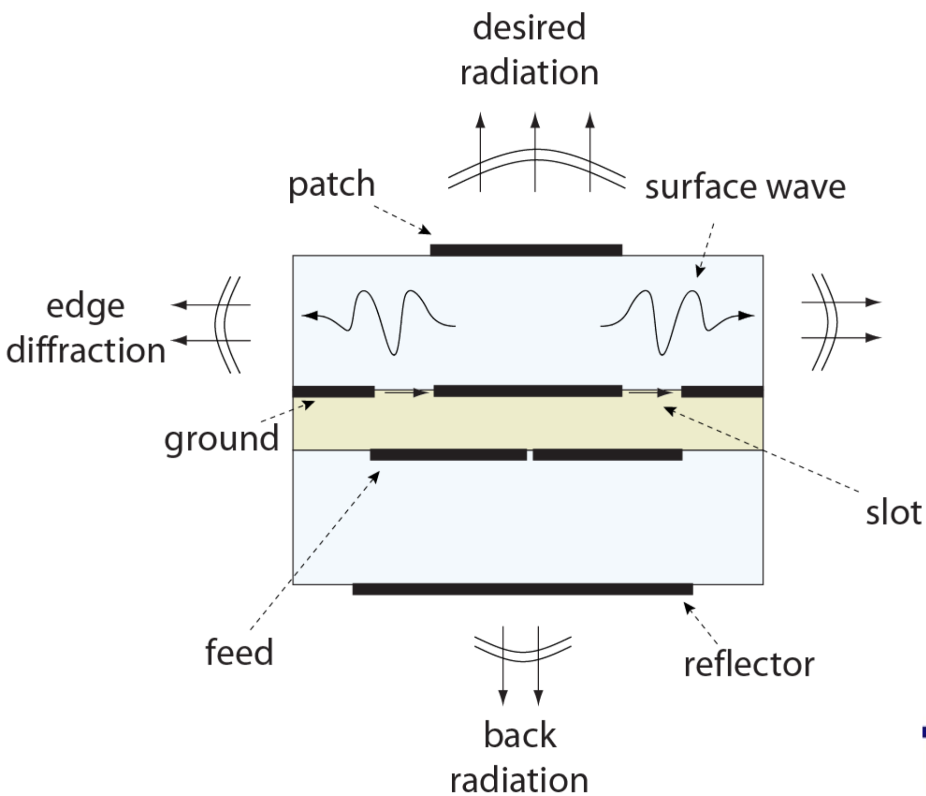
PCB stack

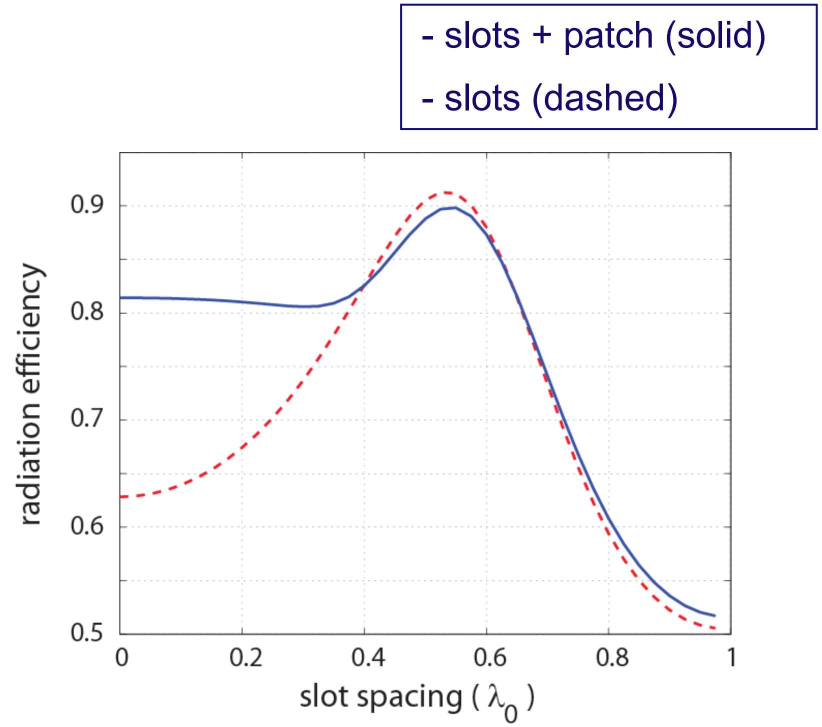
Antenna element
- Modelling

- Modelling
  - Green's functions for stratified media
  - Method of moments
    - spectral-domain representation
    - basis functions
      - entire-domain
      - rooftop
    - C++ implementation
- Sensitivity analysis and optimization

Antenna element
- Radiation efficiency

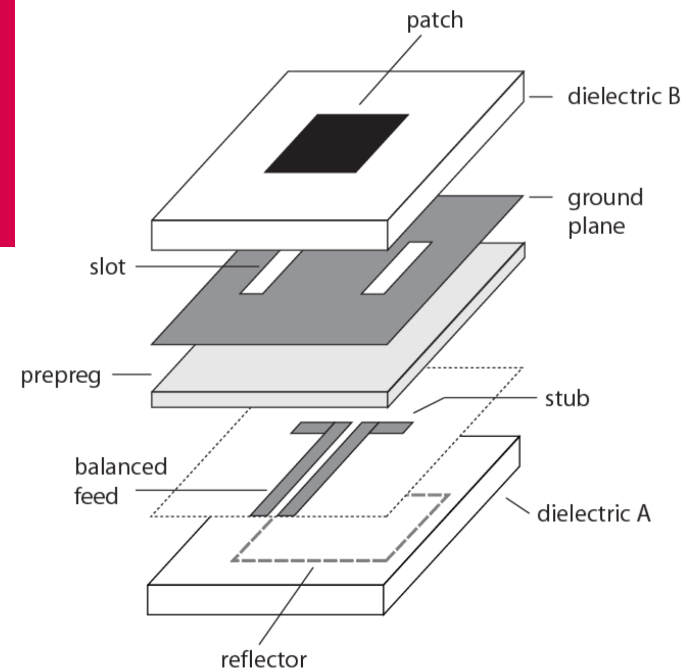
- slot spacing
  - cancel surface waves
  - efficiency > 80 %



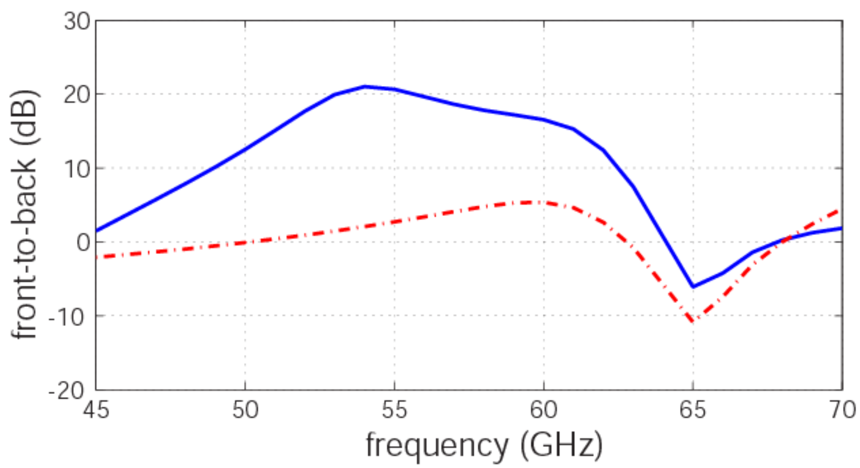


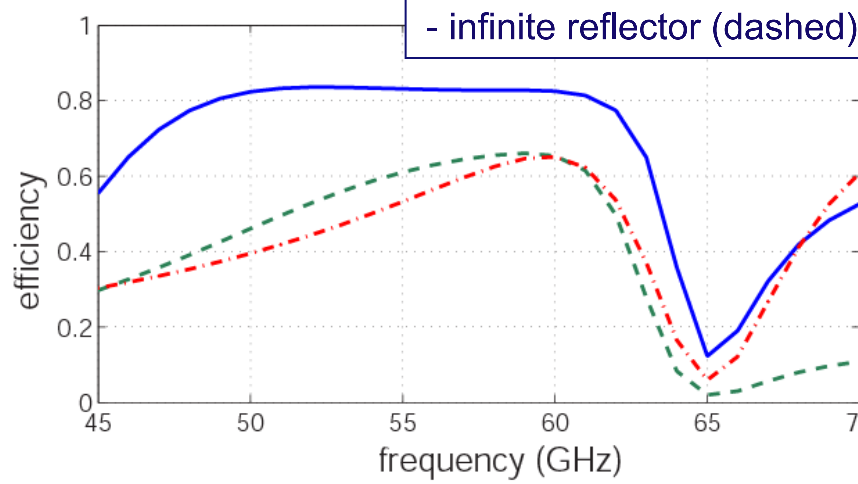
Antenna element
- Back radiation

- reflector element
  - comparison
    - no reflector
    - infinite metal plane
    - finite metal reflector



- finite reflector (solid)
- no reflector (dash-dot)
- infinite reflector (dashed)

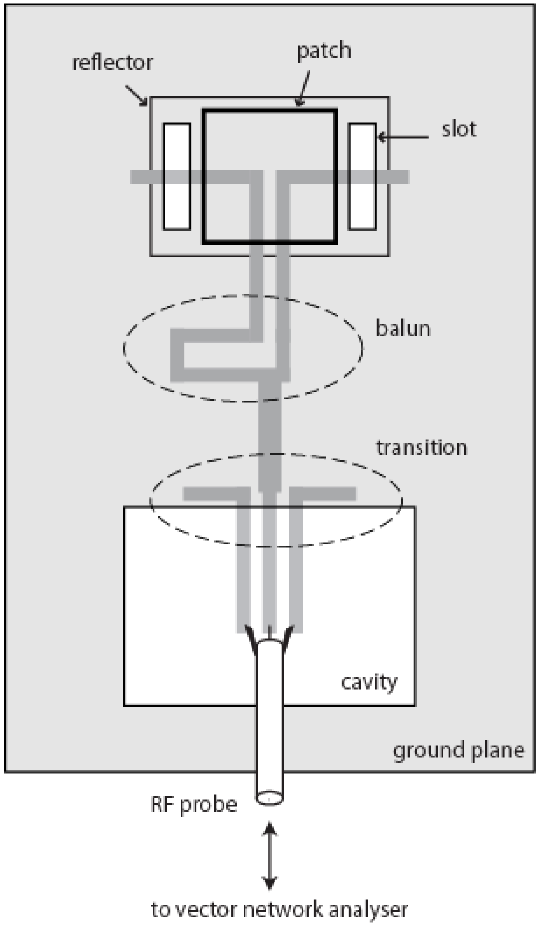


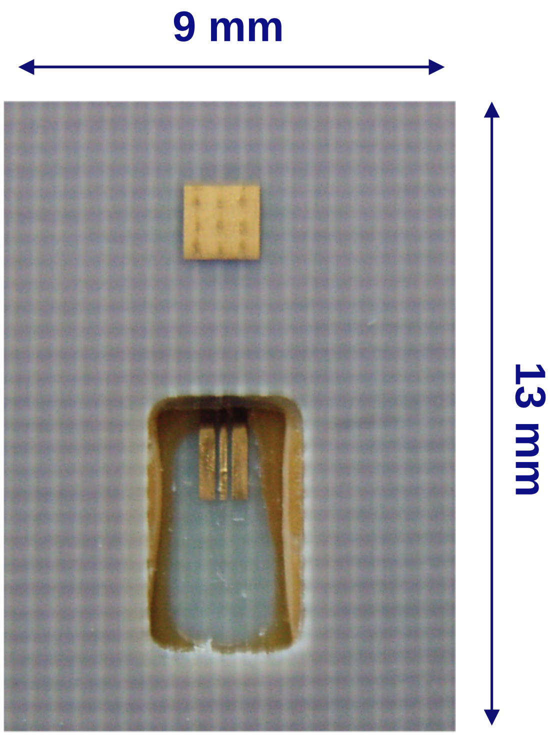


Measurements
- PCB layout

- GSG RF probe

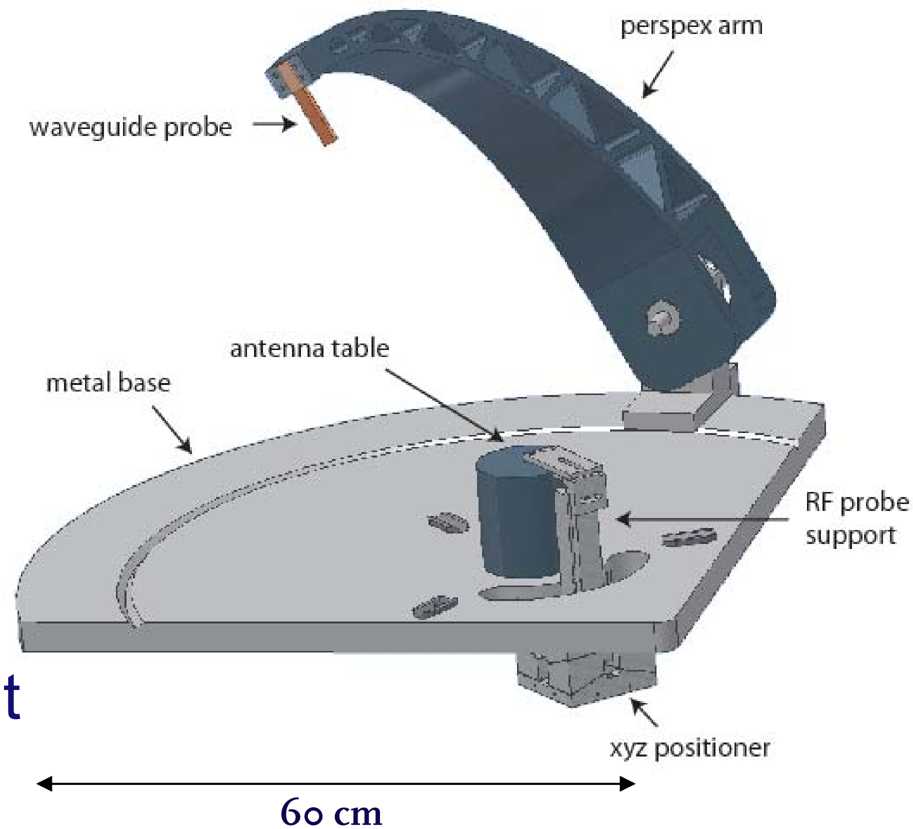
- transition
  - CPW - MS
- balun



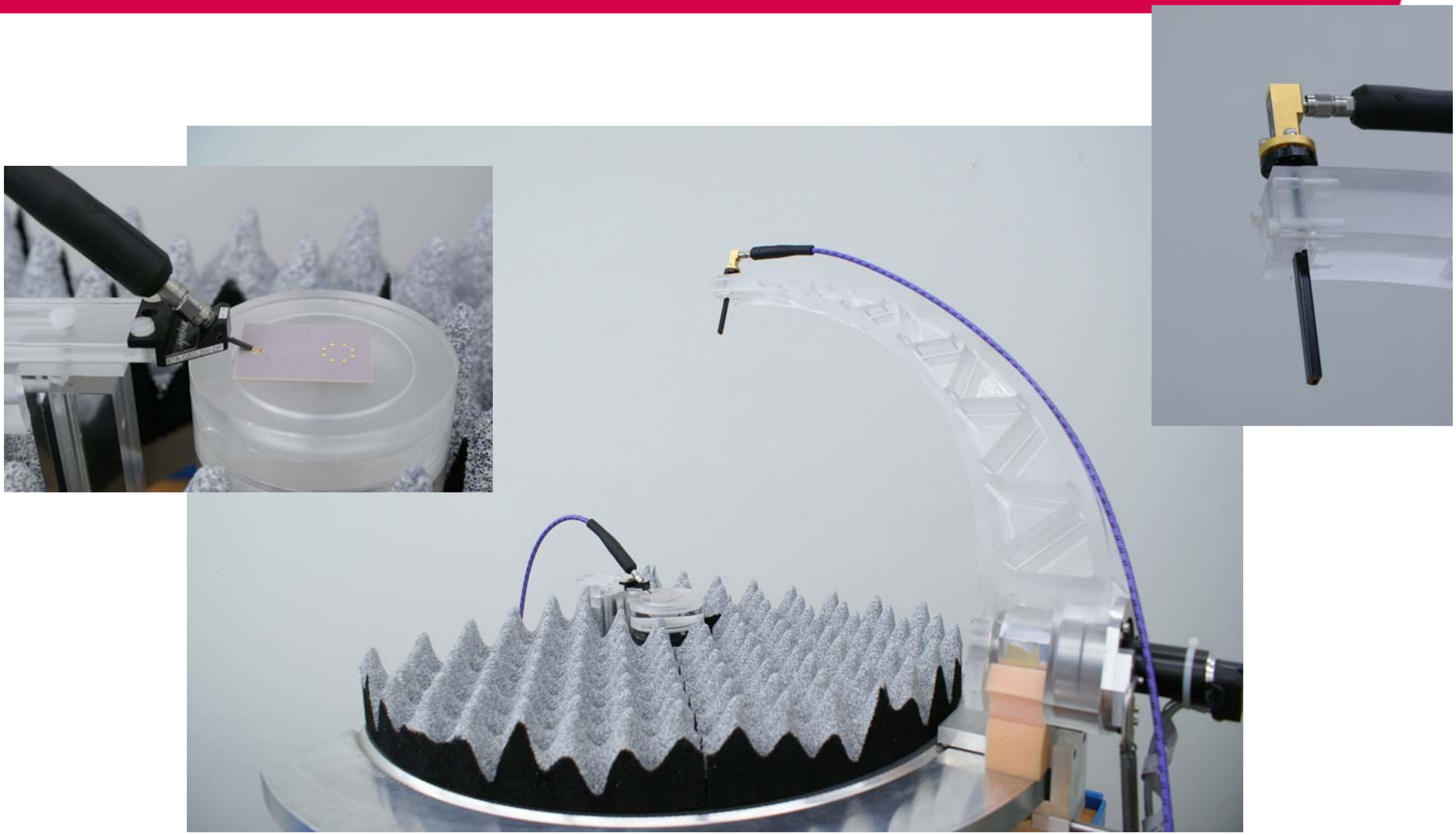


Measurements
- Radiation pattern

- Far-field radiation pattern measurement
  - measures hemisphere
  - designed to reduce unwanted scattering
  - features
    - RF probe support
    - open-ended waveguide
      - 0, 45, 90 degrees
    - automated measurement
      - labview



Measurements
- Radiation pattern



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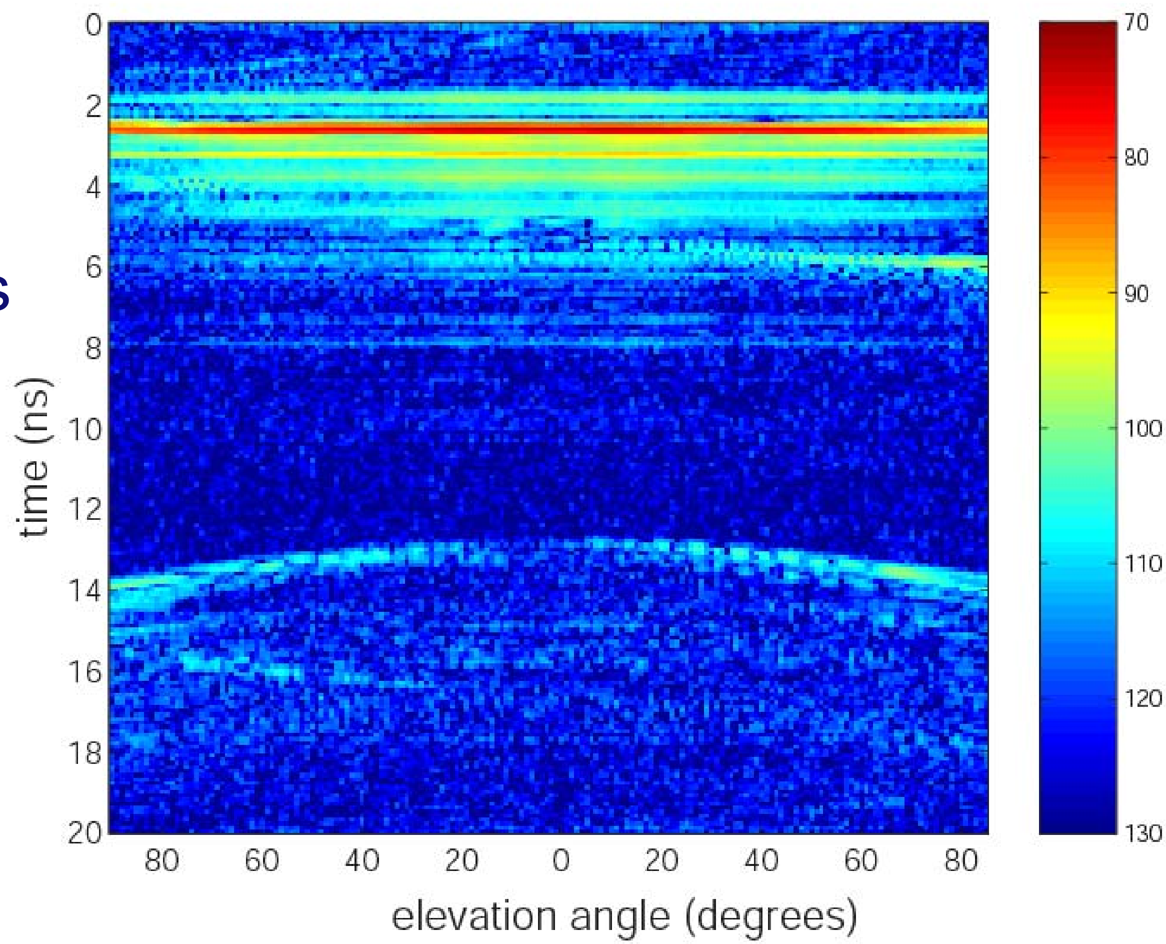
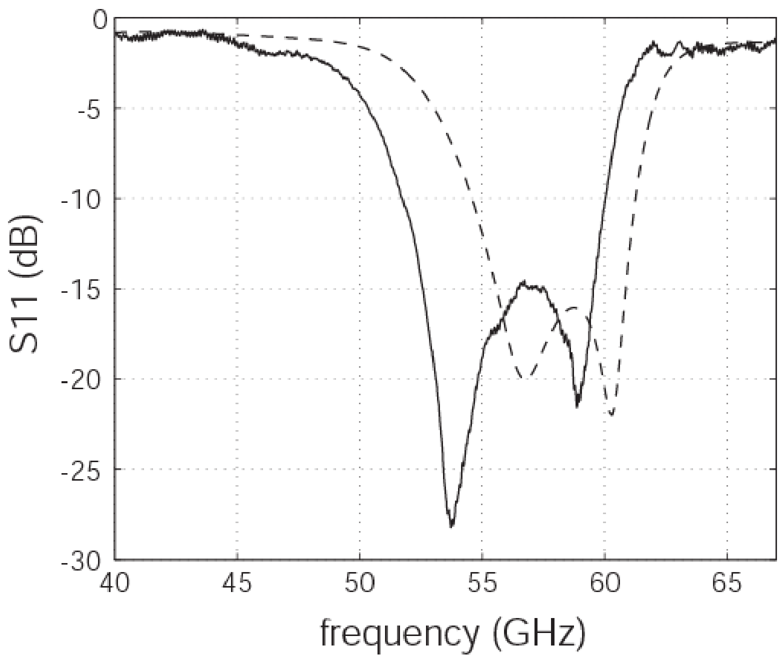
Measurements
- Time gating

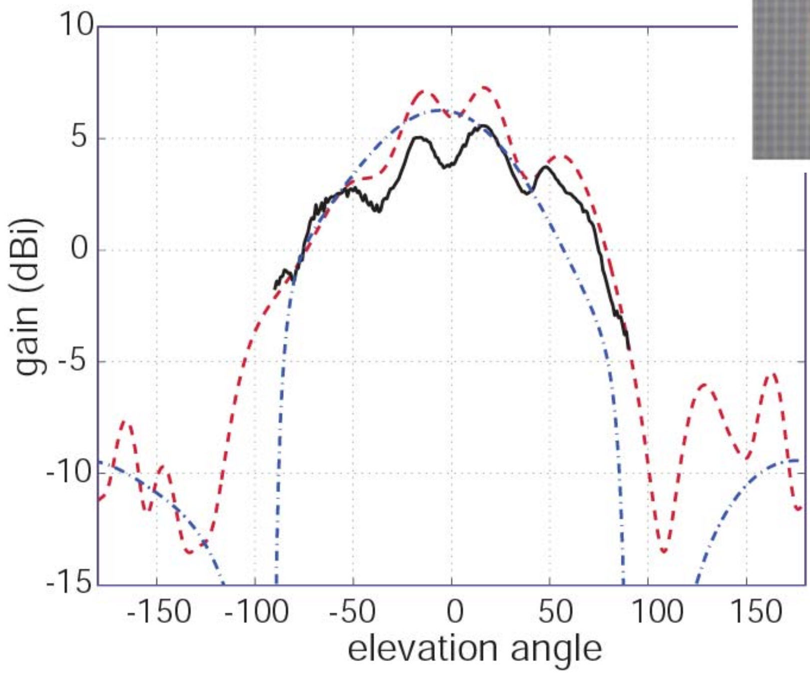
- Measurements
  in lab environment
- Time gating applied
  gate: t = 1.8 - 4.9 ns



Measurements
- Results

- Measurement results



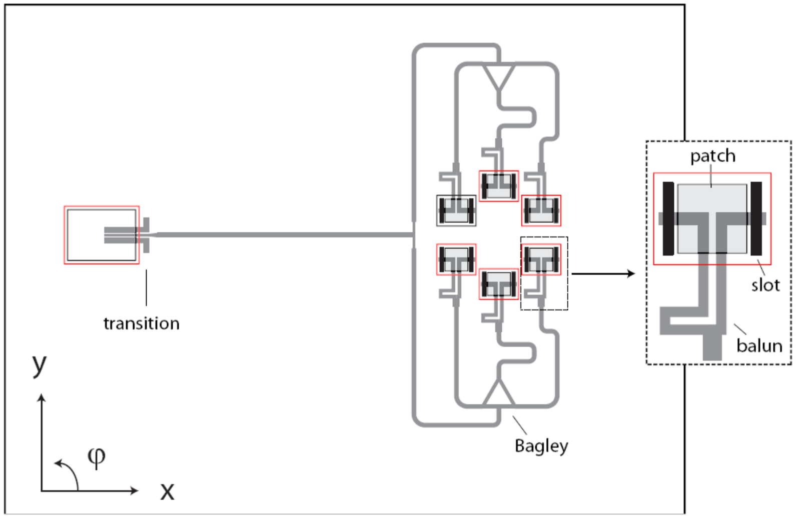


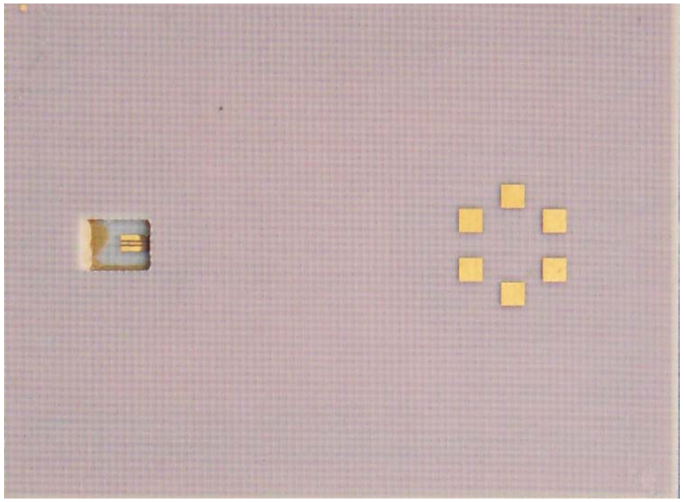
- measurements (solid)
- simulation [Spark] (dashed)

- measurements (solid)
- simulation [CST] (dashed)
- simulation [Spark] (dash-dot)

Antenna array

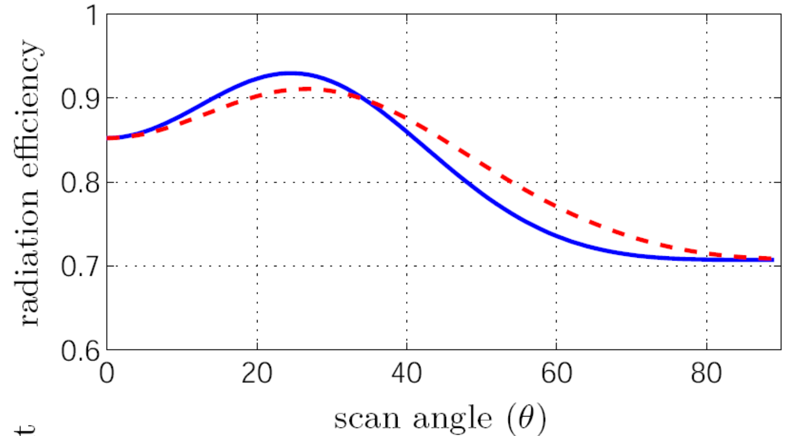
- Beam-forming antenna array
  - 6-element circular array
  - feed network designed for scan to θ = 0, 30, 45 degrees
  - problem: large feed-line losses (1.3 dB/cm)

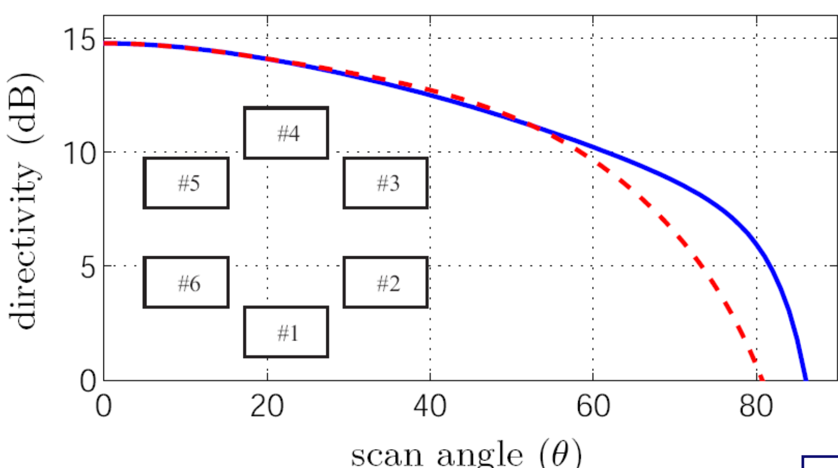


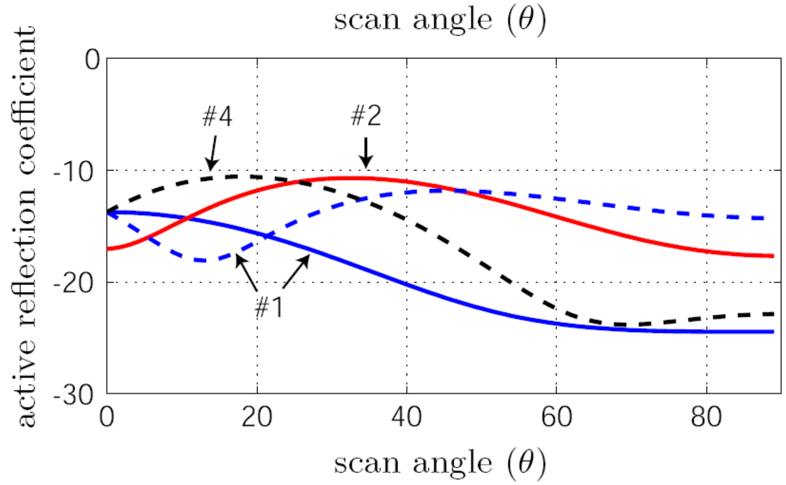


Antenna array
- performance

- Performance as function of scan angle
  - no feed network
  - directivity
  - radiation efficiency
  - reflection coefficient





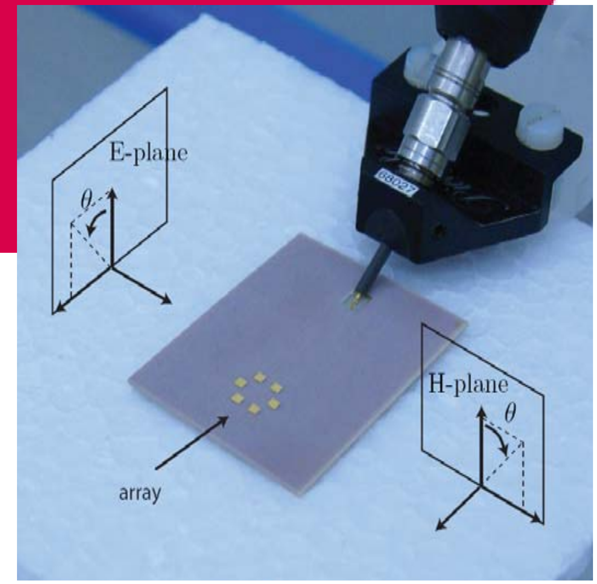


E-plane: φ = 0º (solid)

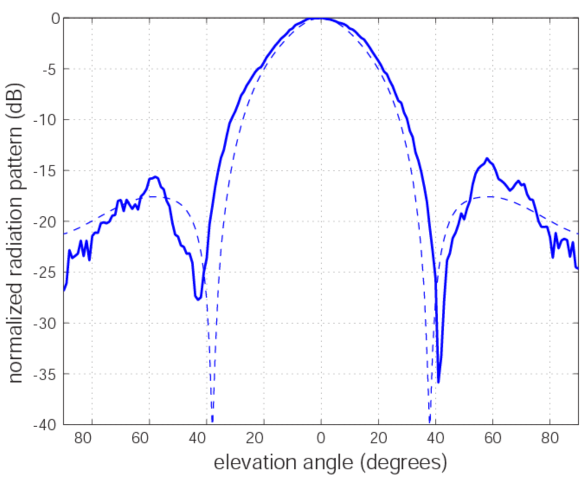
H-plane: φ = 90º (dashed)

Antenna array
- Results

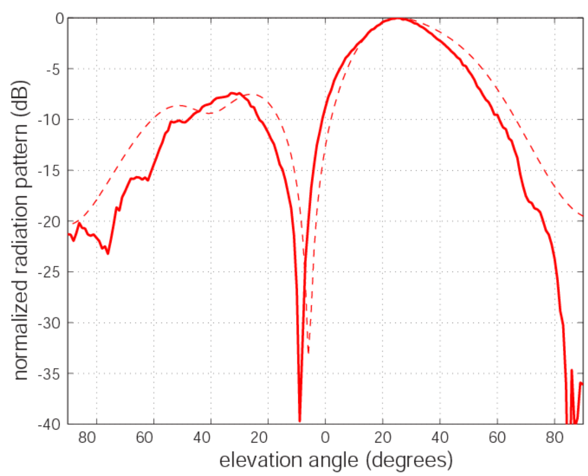
- Measurement results
  - beam-forming to 0, 30, 45 degrees



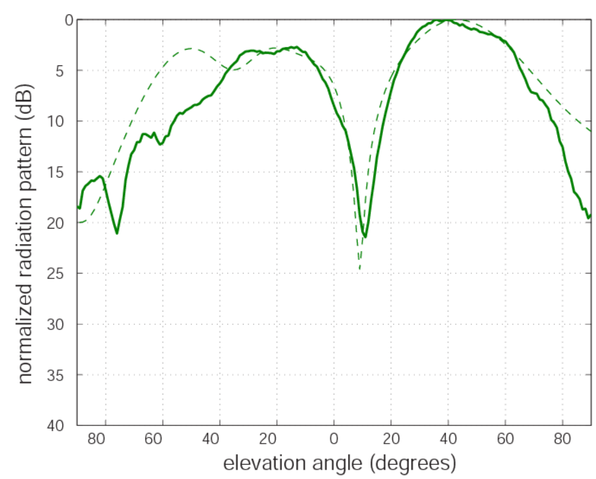
broadside



30 degrees

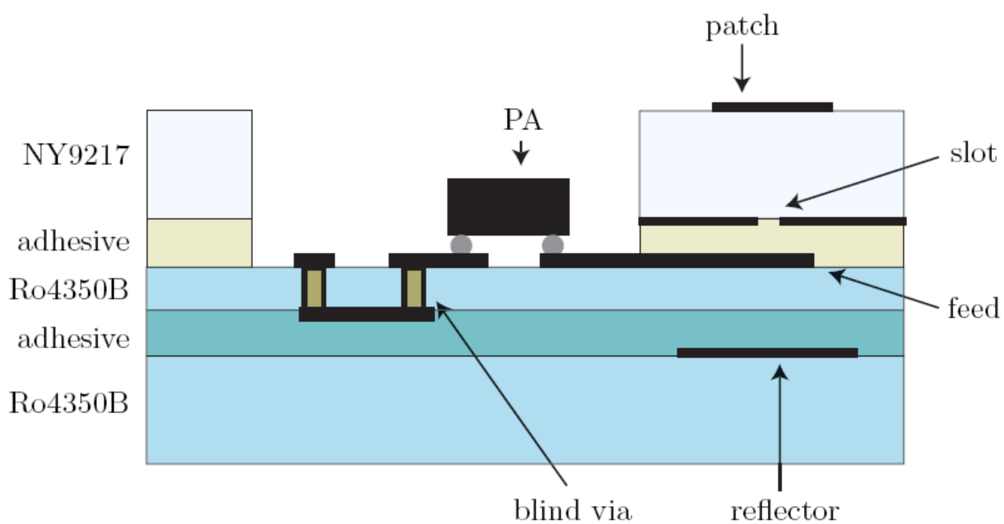


45 degrees

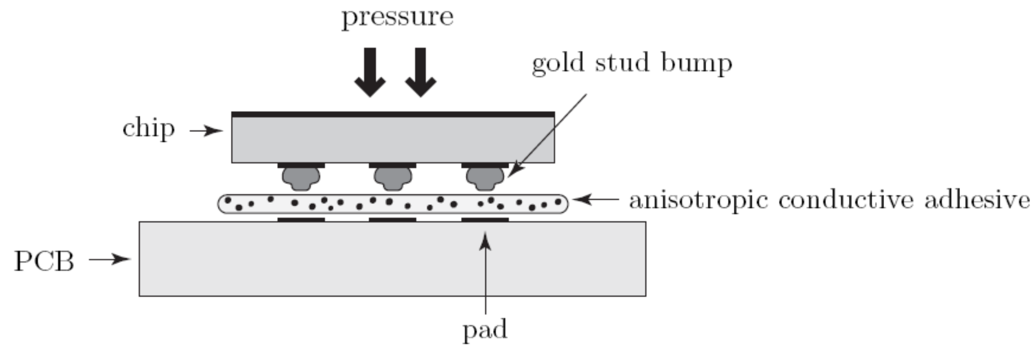


- simulation (dashed)
- measurement (solid)

Packaging
- PCB stack

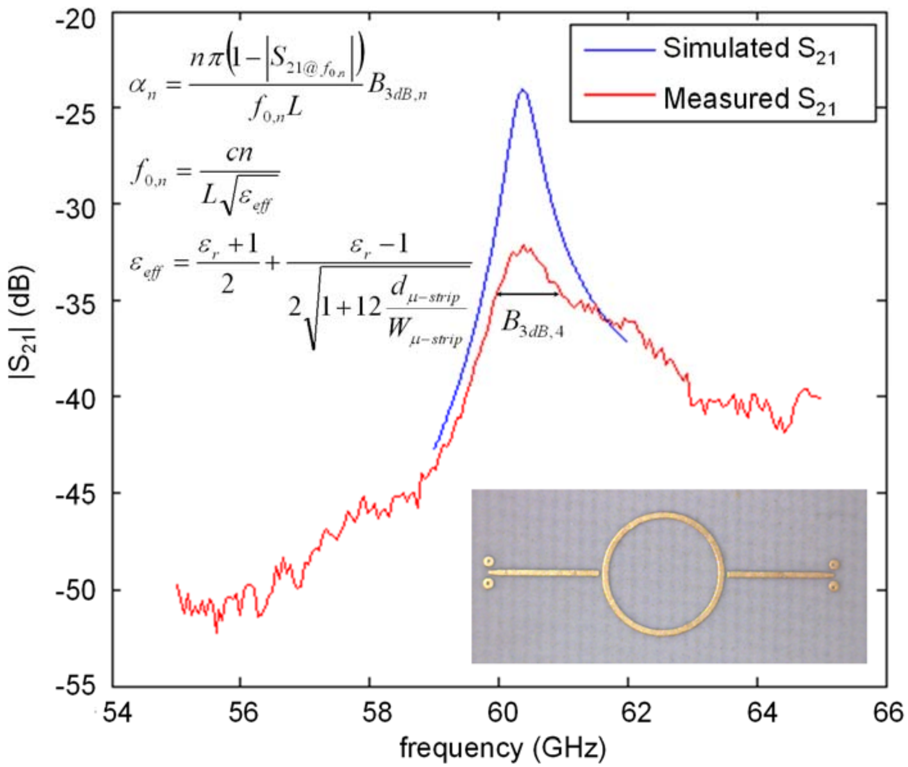


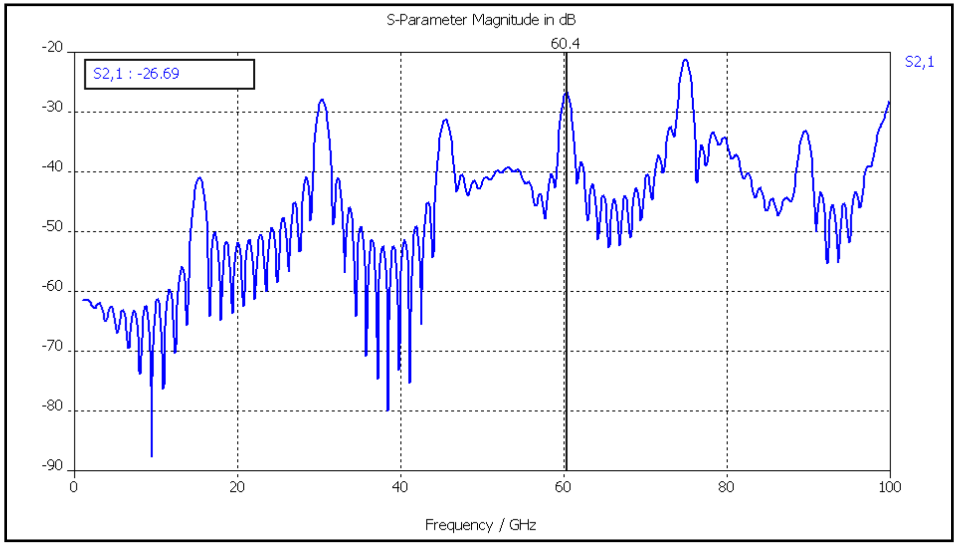
- Teflon-based materials
- ceramic materials
- vias



Packaging
- Material characterization

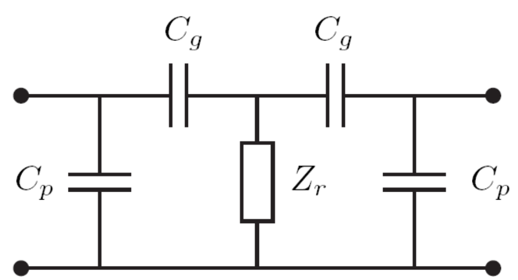
Microstrip Ring Resonator



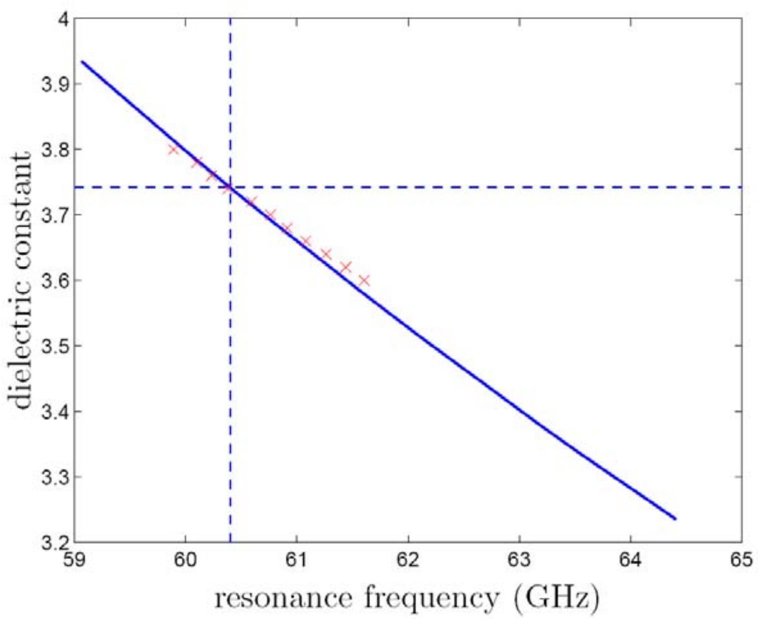


Packaging
- Material characterisation

- Circuit model [1]
  - incorporate loading effect microstrip lines
  - determine dielectric constant



$$Z_r = \frac{Z_0}{2}\coth\left(\frac{\gamma L}{2}\right)$$



[1] J. Bray and L. Roy, "Microwave characterization of a microstrip line using a two-port ring resonator with an improved lumped-element model," IEEE MTT, May 2003

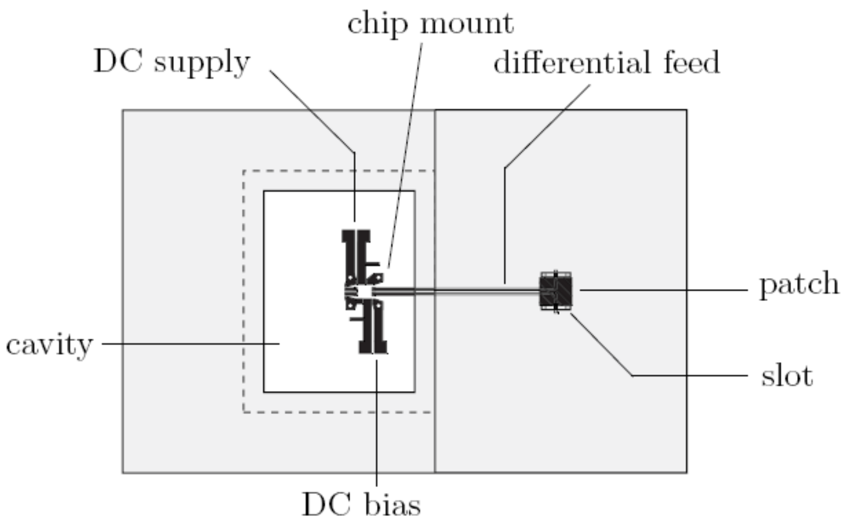
Packaging
- Material characterisation

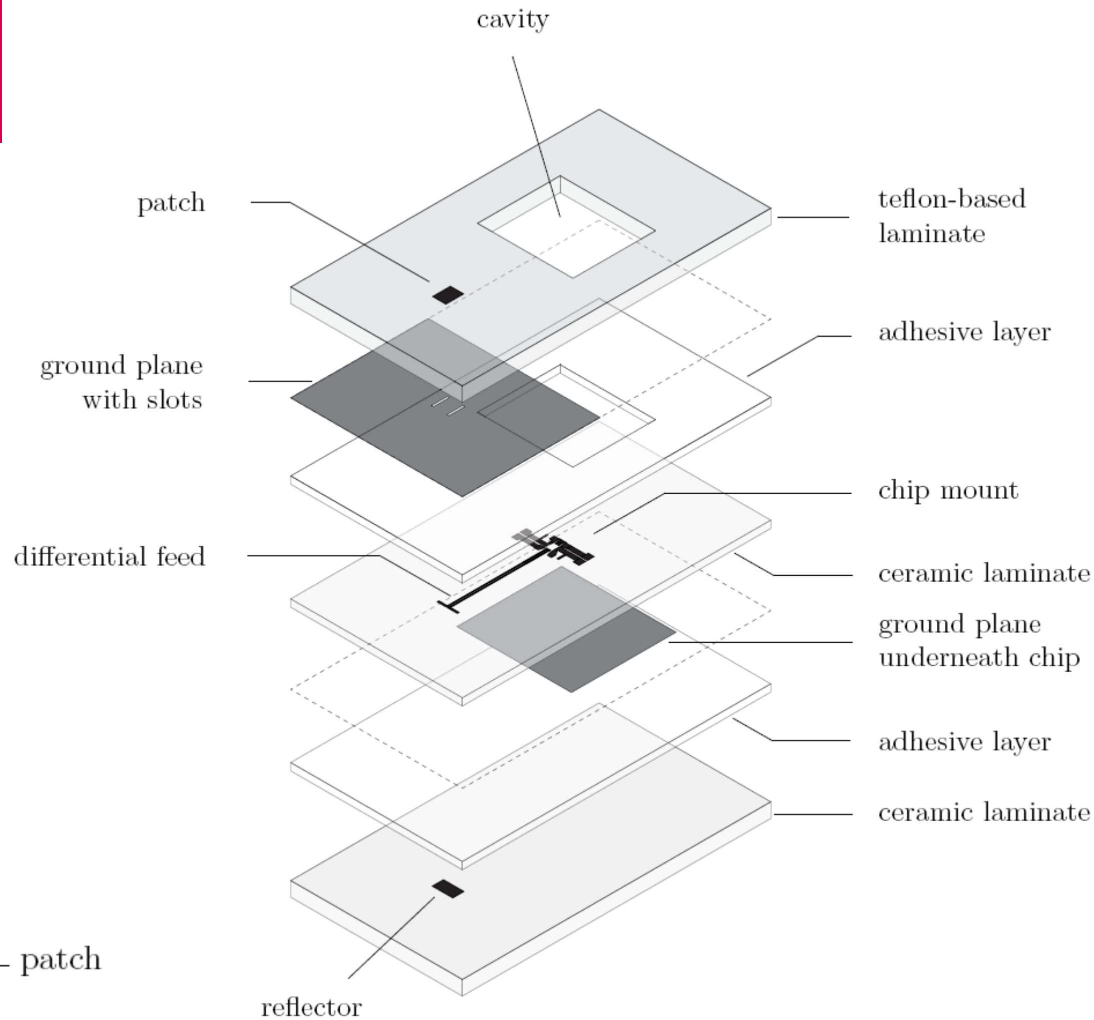
- RO4350B
- data sheet (10 GHz)
  - $\varepsilon_r = 3.66$

n	$f_{0,n}$ [GHz]	$B_{3dB,n}$ [GHz]	ε_r	attenuation [dB/cm]
1	15.24	0.49	3.67	0.38
2	30.46	0.69	3.66	0.53
3	45.55	1.0	3.69	0.77
4	60.42	1.3	3.74	1.0

Packaging
- Layout

- Single-element antenna
- CMOS power amplifier





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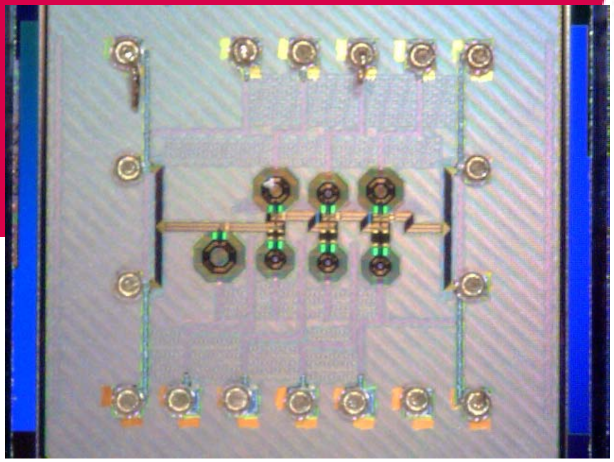
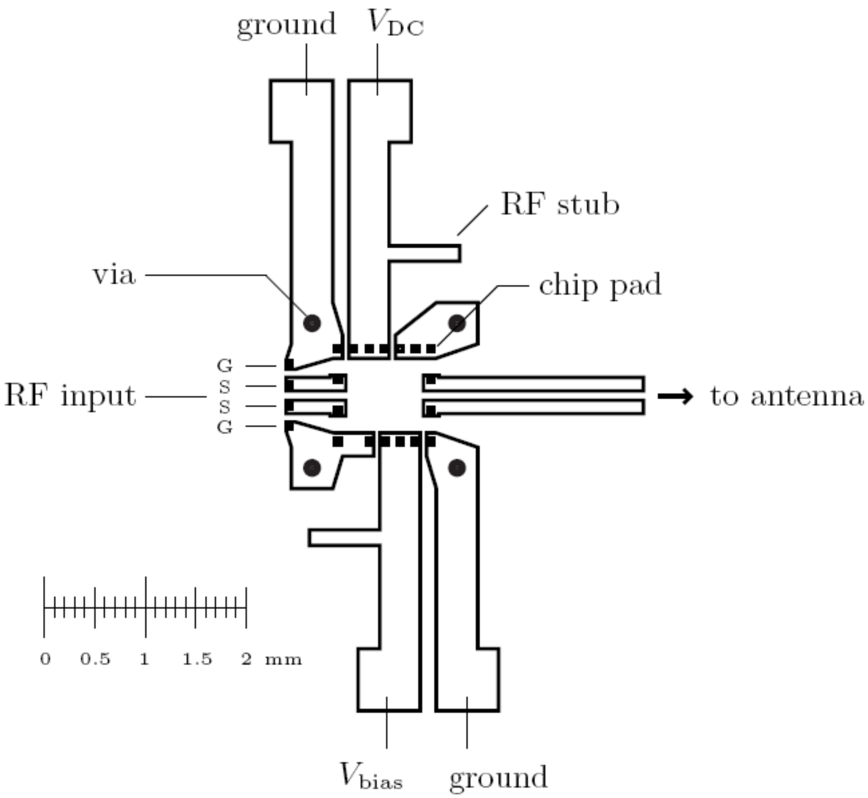
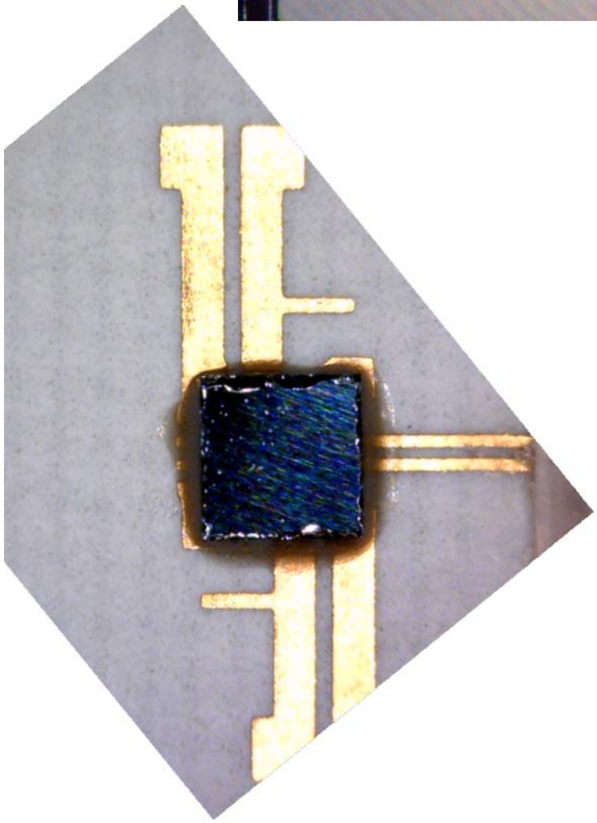
Packaging
- Chip mount

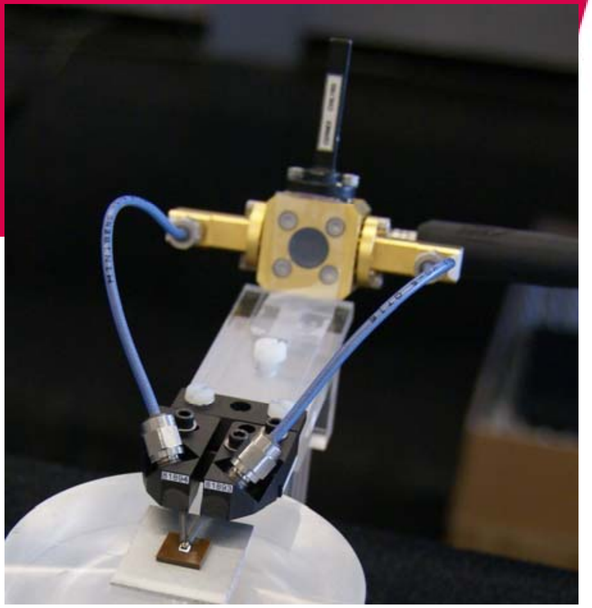


- chip mount PA
- flip-chip interconnection

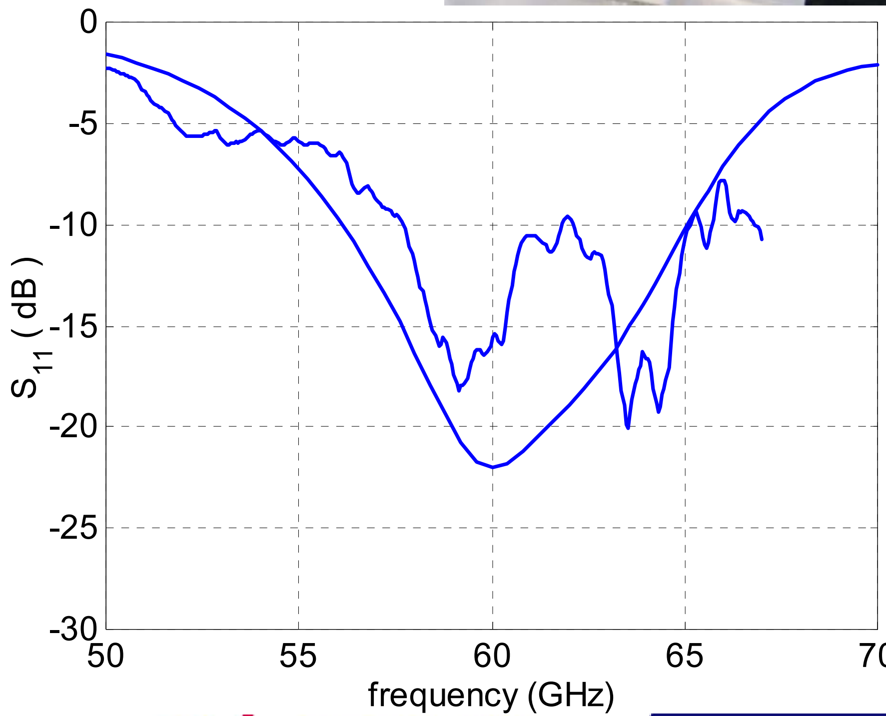




Packaging
- Antenna performance

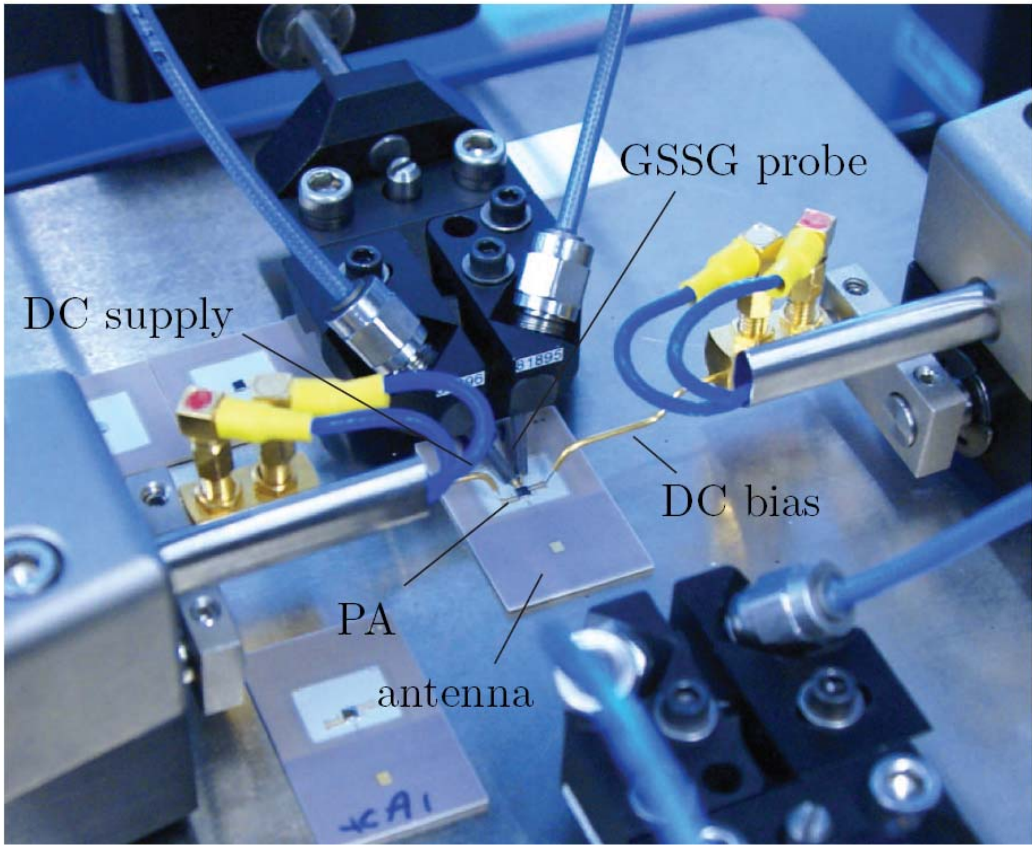


- Antenna measurement
  - balanced measurement
  - bandwidth
    - − 57.7 - 65.1 GHz



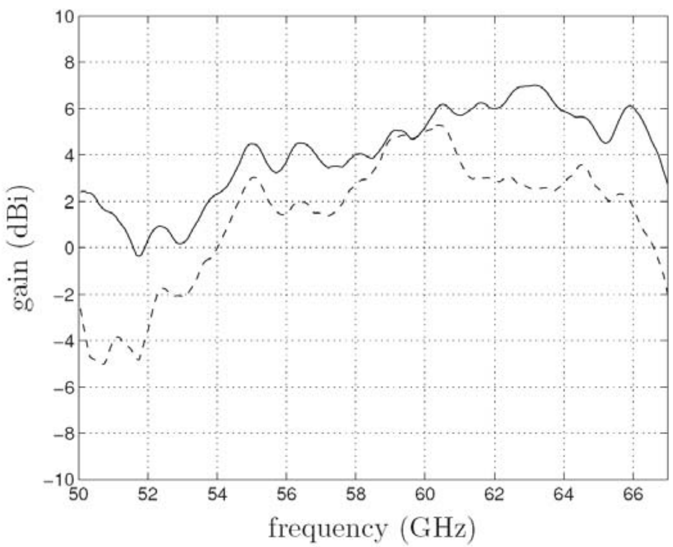
Packaging
- PA + antenna

- Probe station
  - MsM group



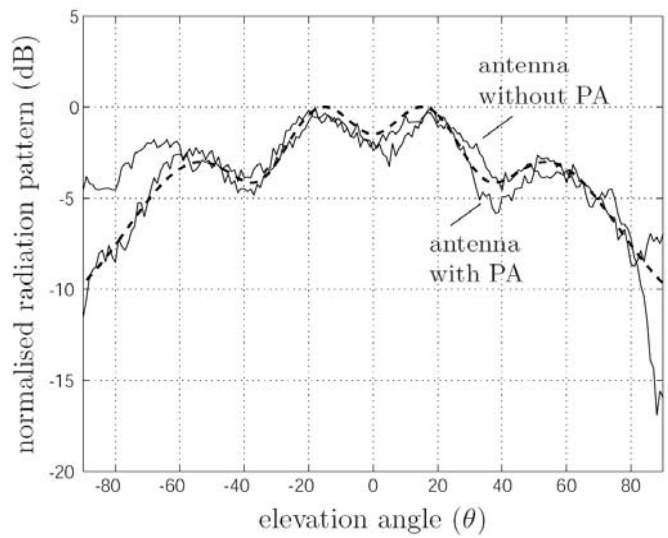
Packaging
- PA + antenna

gain measurement



- antenna (solid)
- PA + antenna (dashed)

pattern measurement

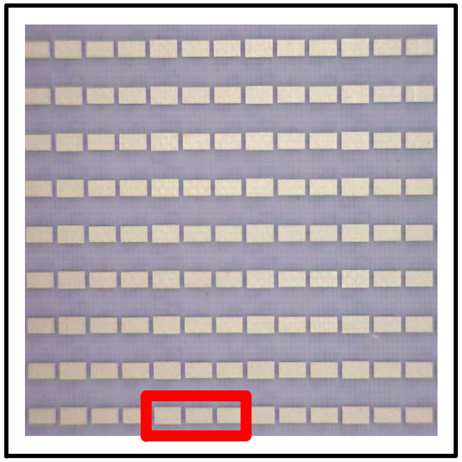


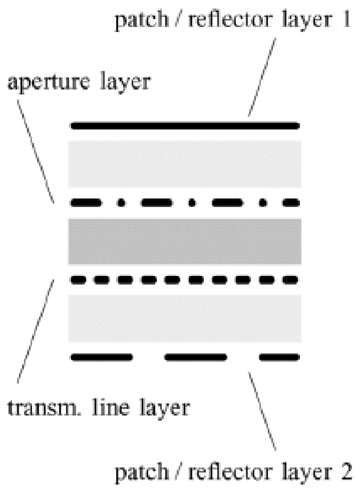
- measurements (solid)
- simulation (dashed)

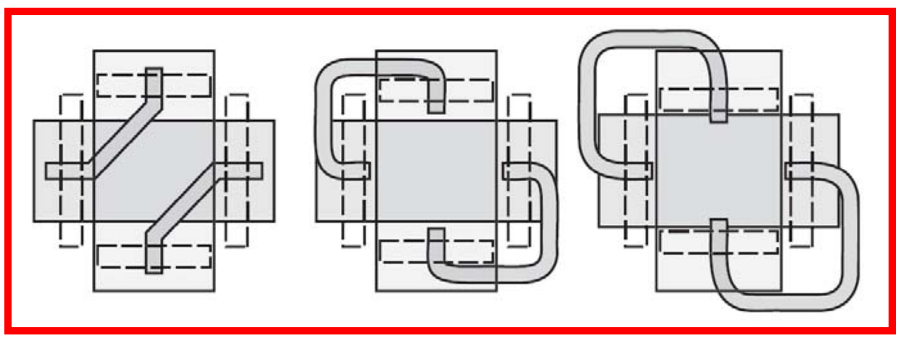
- Flip-chip considerations
  - On-chip inductor
  - Extra plating layer on aluminium pads of the CMOS chip

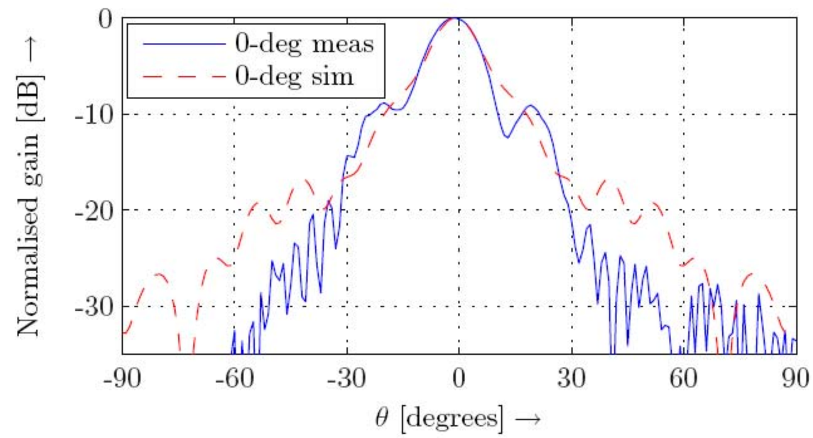
3D/Conformal antenna array

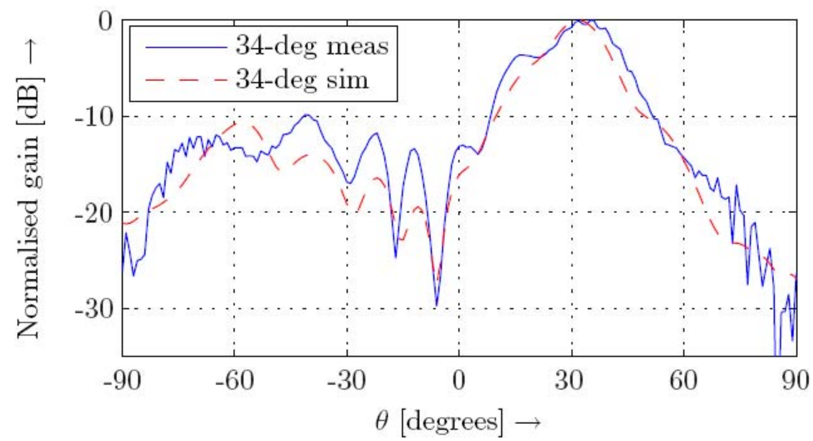
Passive Electromagnetic Deflector



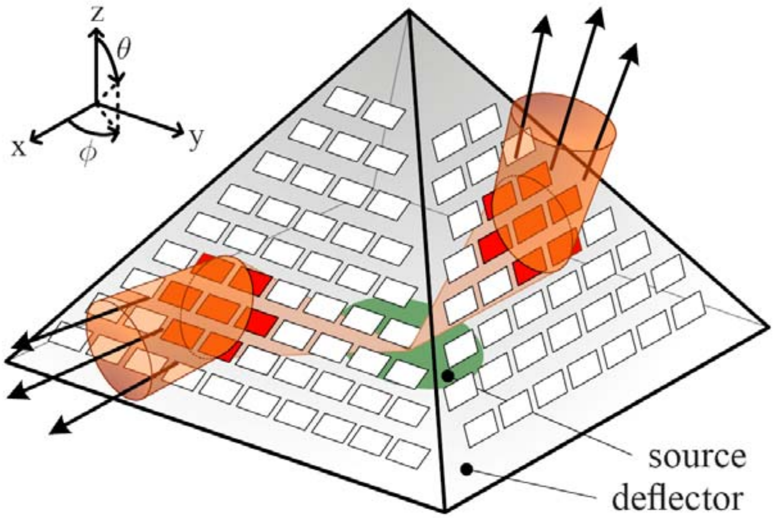




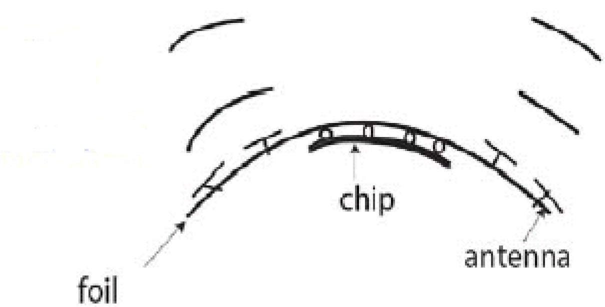




3D/Conformal antenna arrays



Flex PCB technology



Trade-off between directivity, steerability and size of the deflector

Conclusions

- Antenna element
  - high efficiency, large bandwidth
  - MoM model
    - limited number of basis function
  - Optimisation
    - simple, efficient method
- Measurement setup
  - RF probes
    - avoid interconnection problems
  - radiation pattern setup

Conclusions

- Antenna array
  - beam-forming demonstrated
- Packaging
  - integration with PA
  - flip-chip interconnect
  - realization of 7 GHz bandwidth (57.5 to 65.0 GHz) using the packaged PA-antenna
- 3D/Conformal antenna arrays

Almost there...