Integration of Antennas at Microwave/mm-wave frequencies

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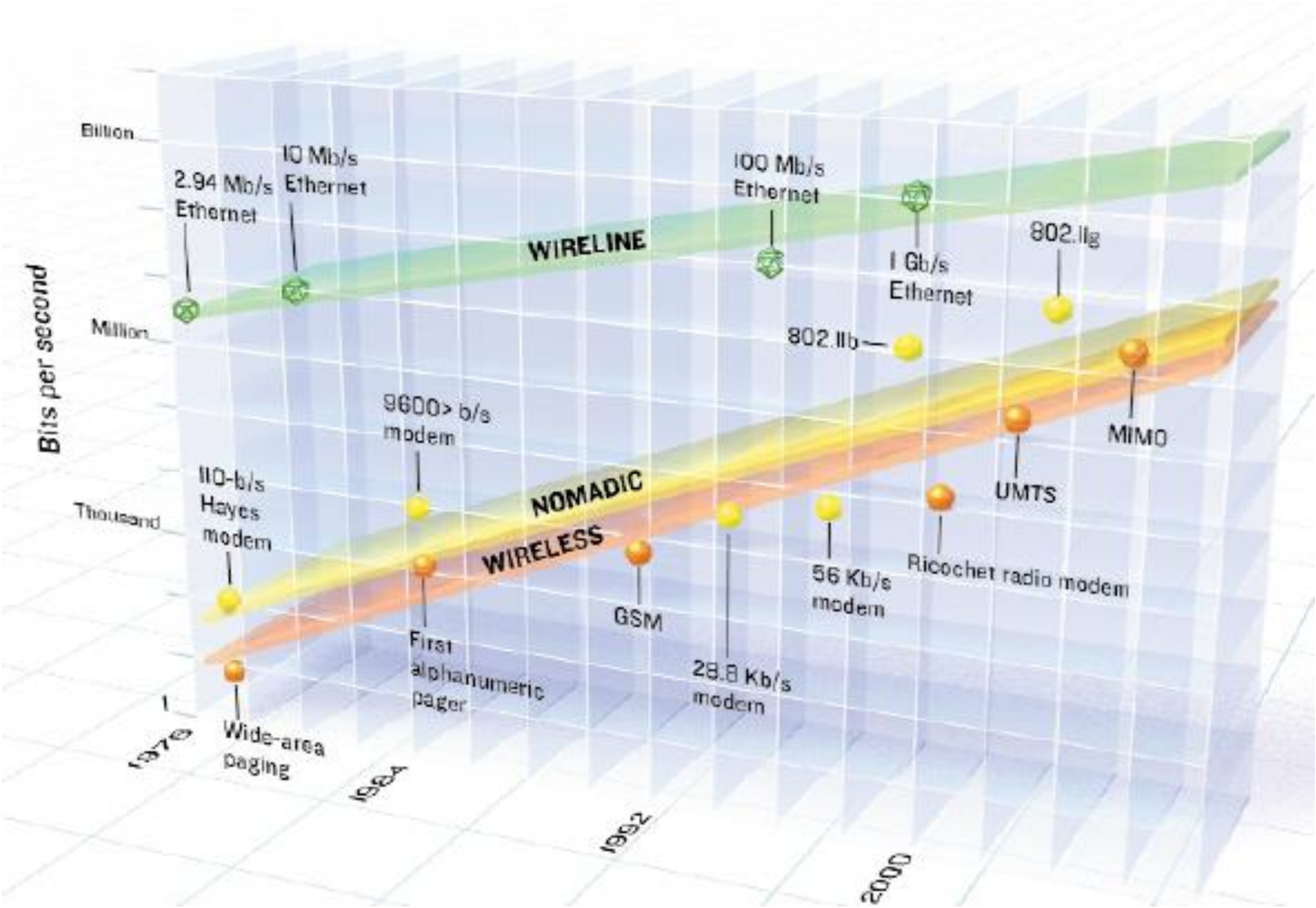
Where innovation starts

Content

- Why mm-waves?
- Antenna team at TU/e
- Antenna-on-Chip
- Reflect arrays for satellite TV/Internet
- Future research

Trend 1: Increase in bandwidth Edholm's Law

From IEEE spectrum July 2004



- Wireless growing faster than wired
-7 GHz available at 60 GHz

Required Bandwidth/datarate doubles each 18 months

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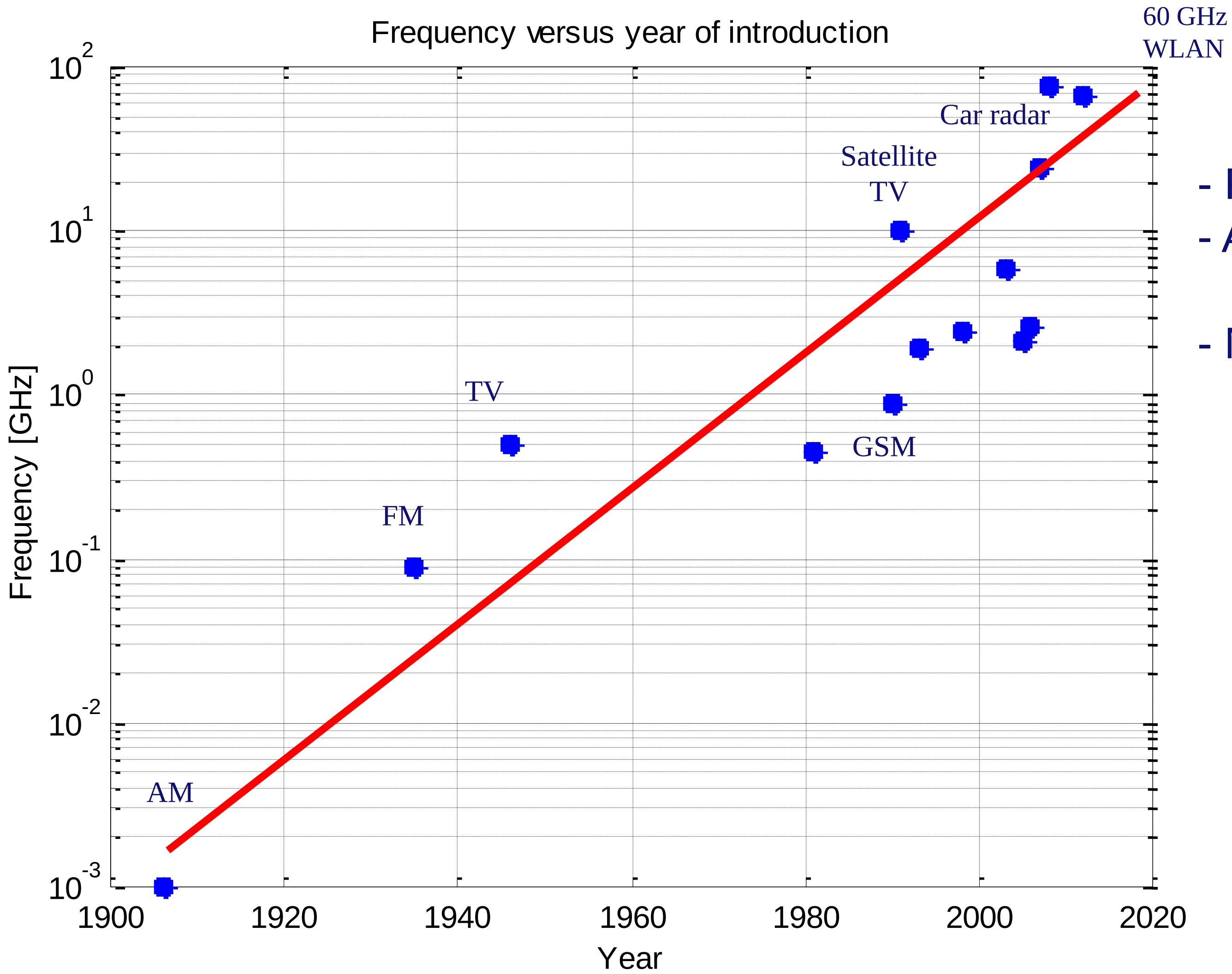
Trend 2: Increase of operational frequency



- Relative BW
- Availability of new bands
- Next step sub-THz?

Antenna team at TU/e

- **Electromagnetics Group (EM)**
  - **Embedded in CWT/e.**
- **Focus is on phased-arrays and integrated antennas.**
- **Overall Chair: Prof.dr. Anton Tijhuis.**
- **Antenna team, status Jan. 2010:**
  - **Prof. Dr.ir. Bart Smolders**
  - **Dr.ir. Matti Herben**
  - **Dr.ir. Peter Smulders**
  - **Ing. Ad Reiniers and Ing. Reinier v. Dommele**
  - **Dr.ir. Huib Visser (part-time from IMEC-NL)**
  - **Prof. Dr. Giampiero Gerini (part-time from TNO D&V)**
  - **Dr.ir. Rob Mestrom (Post-doc)**
  - **Ulf Johannsen (PhD)**
  - **Mingda Huang (PhD)**
  - **Imran Kazim (PhD)**
  - **Sissy Papatheologou (TOIO)**
  - **Peng Guo (TOIO)**
  - **Mohadig Rousstia (TOIO)**
  - **Rob Maaskant (PhD at ASTRON)**
  - **Daniele Cavallo and Annalisa Iacona (PhDs at TNO)**
  - **+ Master students.**

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The ultimate solution: Integrating the antenna-on-chip

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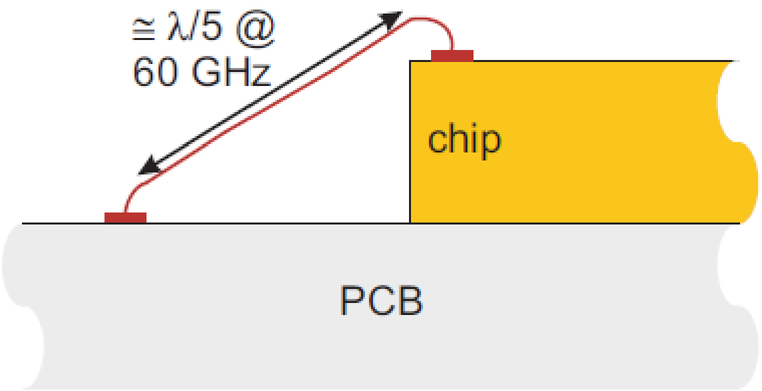
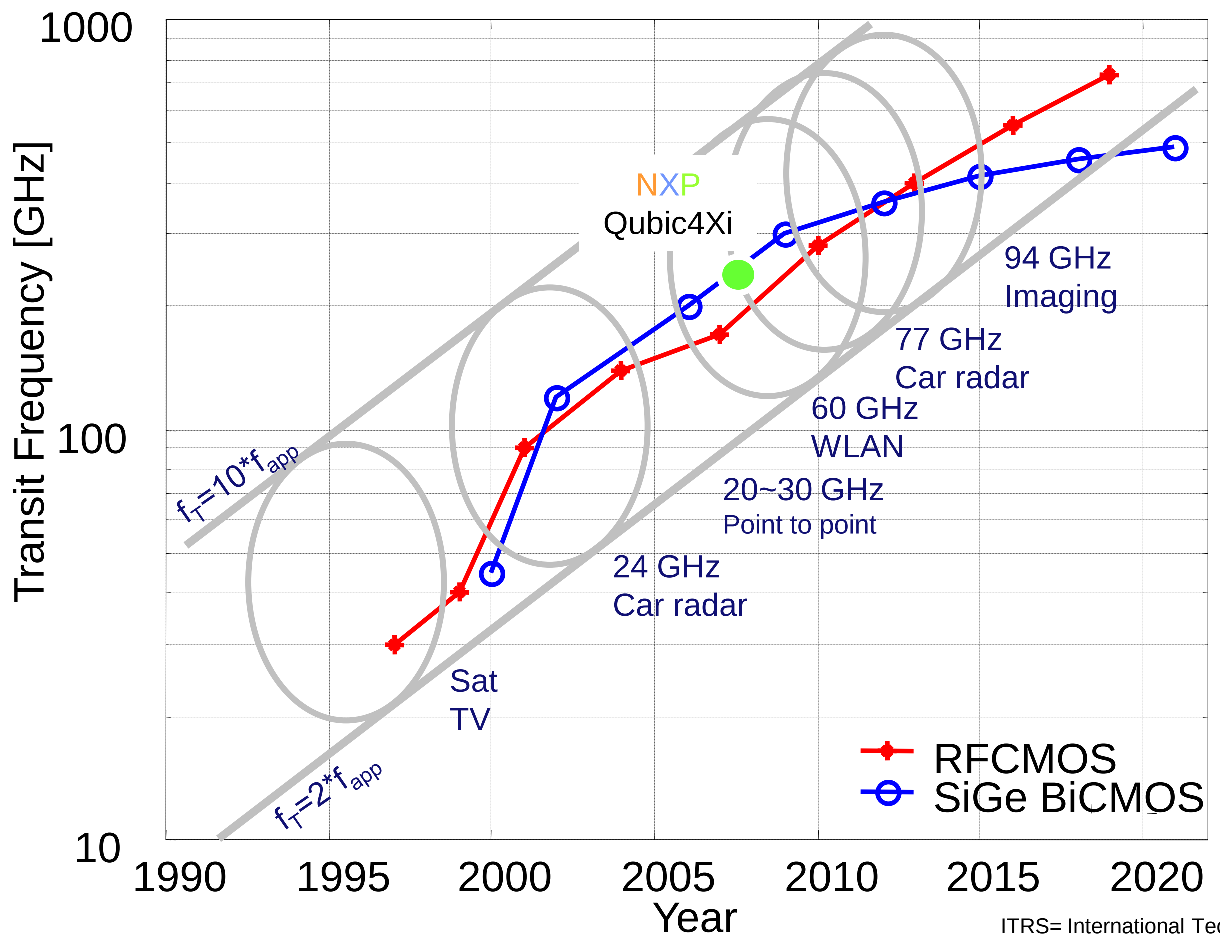
Where innovation starts

Why having an antenna on chip?

- **Avoid the “getting the signal on/off chip” problem**
- **Direct matching of the antenna and LNA/PA possible**
- **Antenna size at mm-waves (~ 1mm) makes it possible and cost-effective**

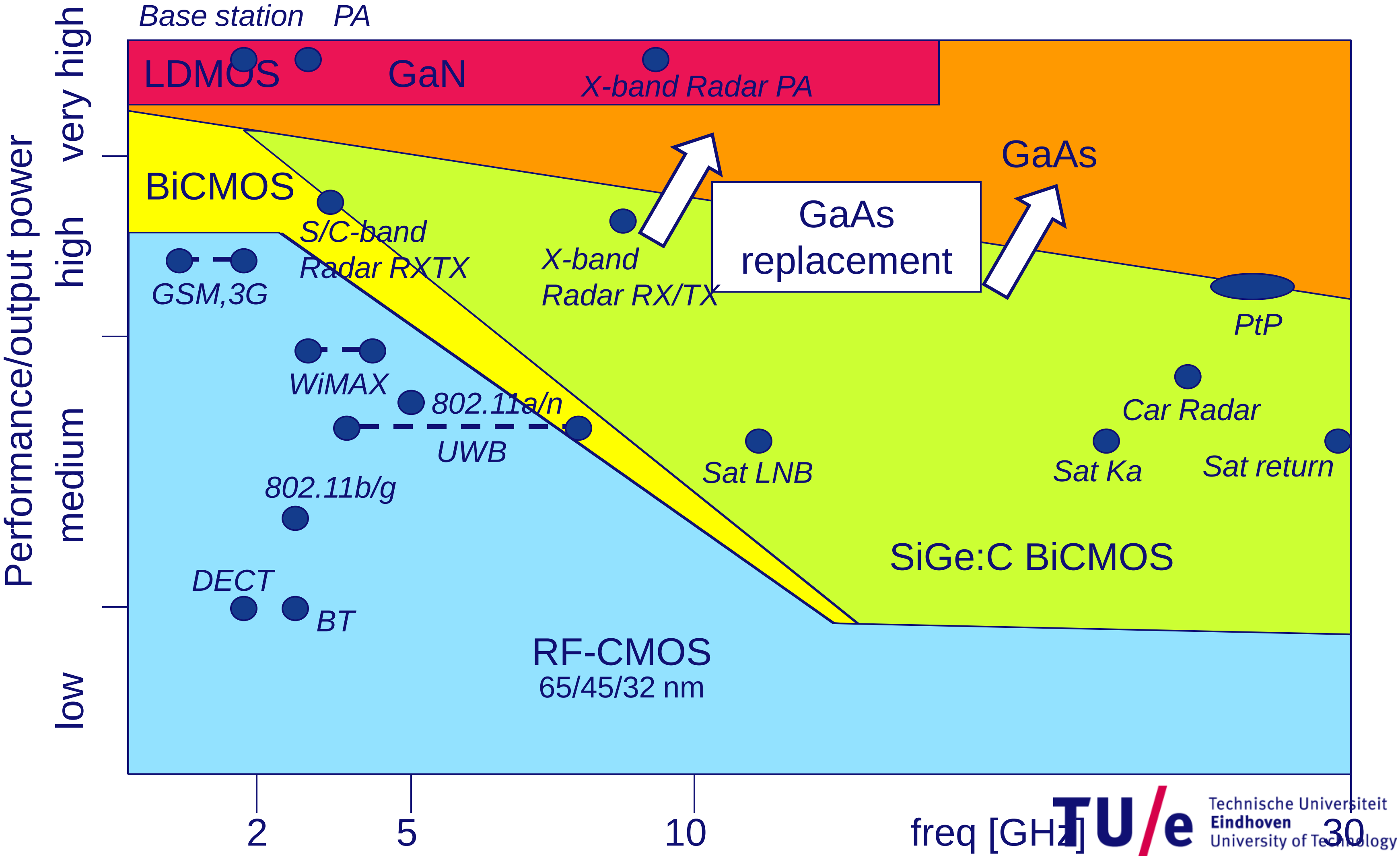


Ft of IC Technology vs Year [ITRS] & applications



ITRS= International Technology Roadmap for Semiconductors

RF Technology Partitioning 2010



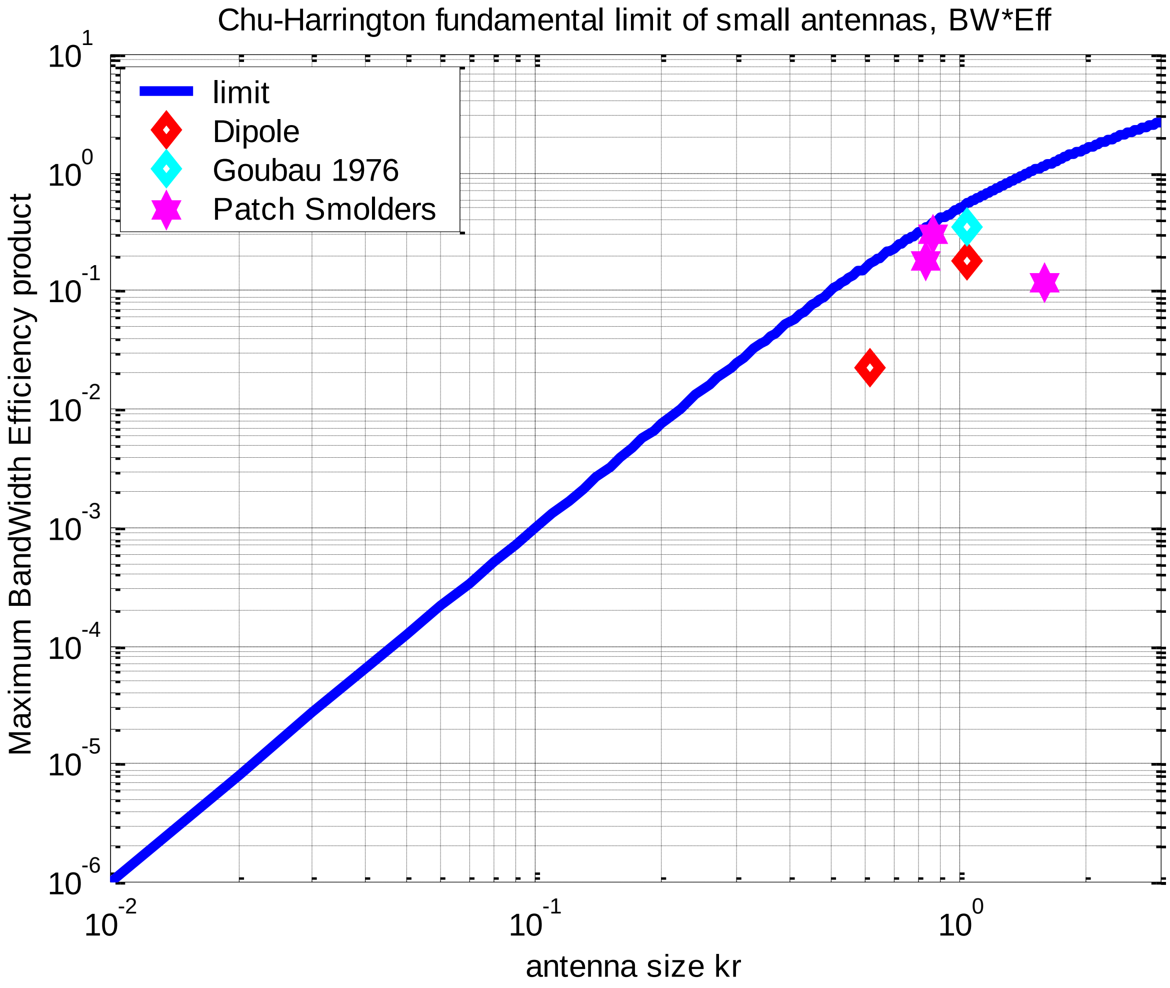
Cost is also important

- Typical case for RF building block (RF-IC)
  - Medium volume application 1-10 Mpcs
  - Digital interface required, low gate-count
  - 2 Silicon spins for final product
  - Die size 1.5 mm^2
- Relative price RFCMOS versus BICMOS
  - Based on wafer-price and Mask-cost

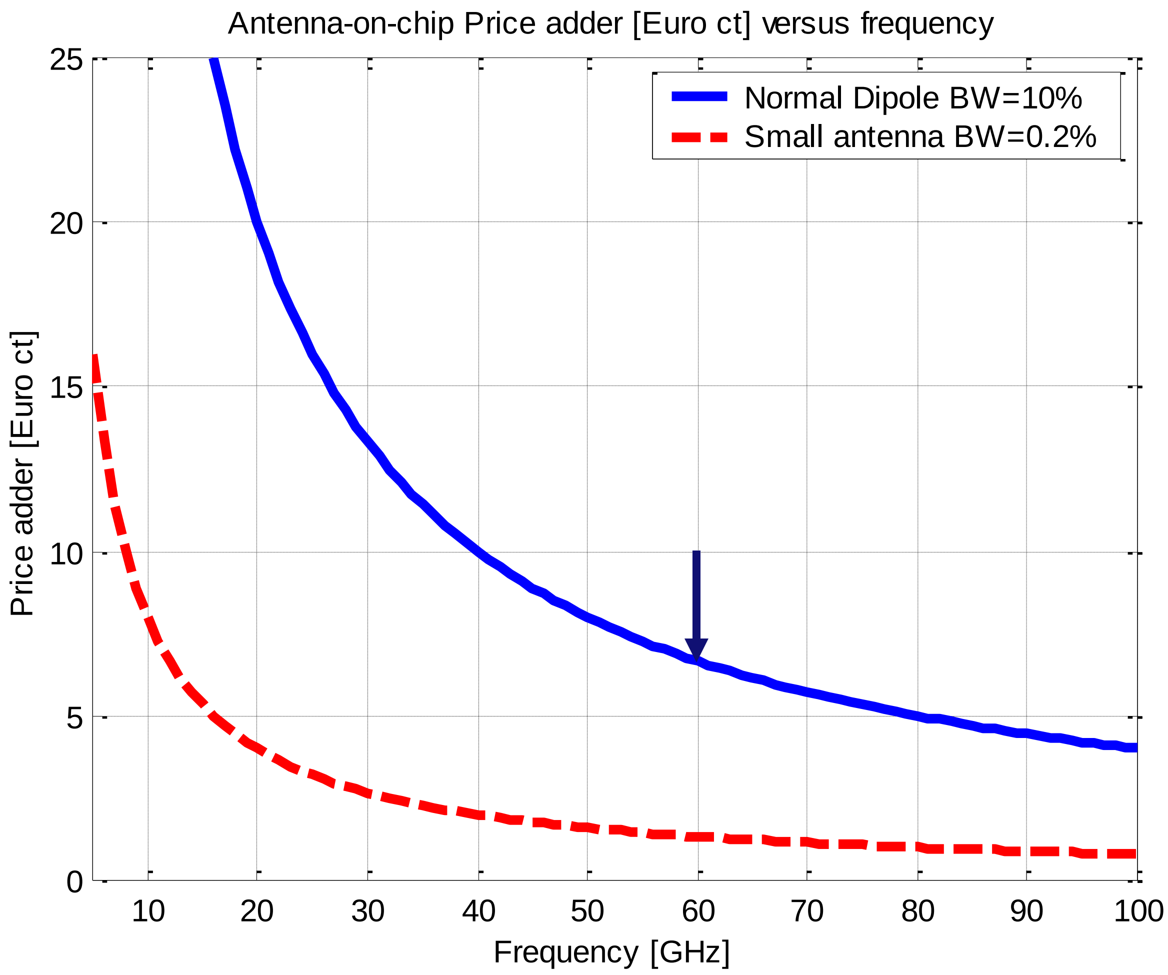
	BiCMOS	CMOS65	CMOS45
Total relative cost 1 Mpcs	1	5.2	10.9
Total relative cost 10 Mpcs	1	2.8	5.1

How small can we make an antenna?

Chu-Harrington fundamental limit

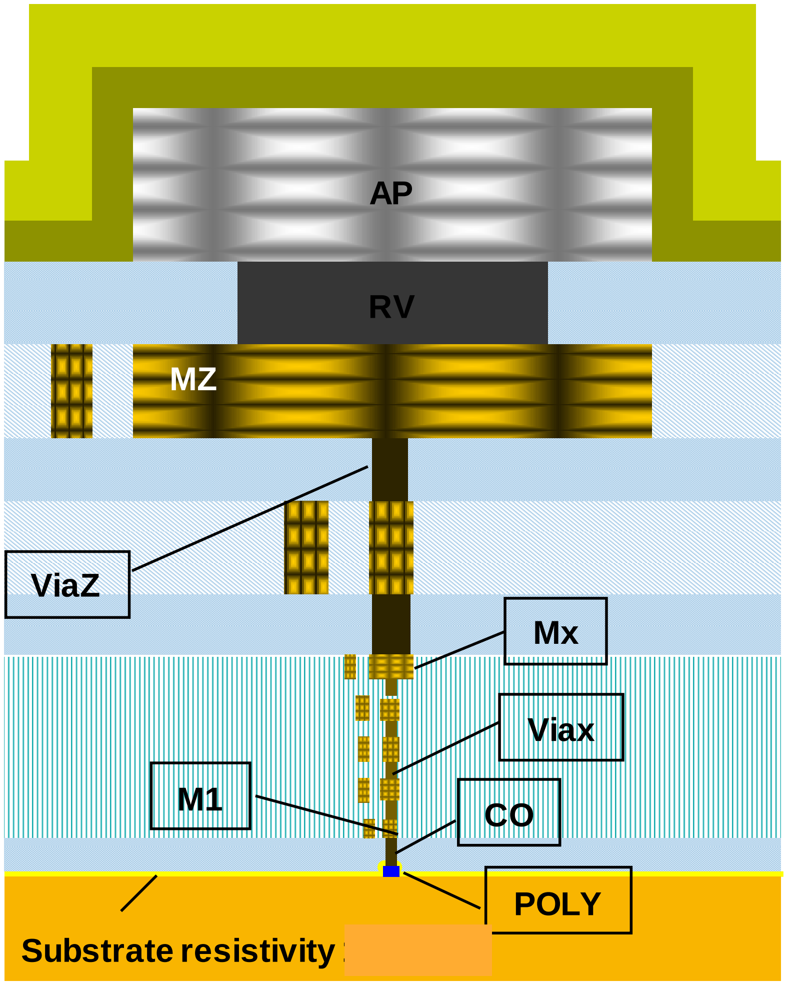


Cost of Antenna-on-Chip (AoC)



+ Lower test cost
+ Lower package cost

Silicon (Bi-)CMOS Technology stack
Typical example



- Typical 6-8 Metal layers
- Thick metal 1-3 μm (top layers)
- Substrate Res 10-200 Ohmcm
- Wafer thickness 200-700 μm
- Substrate modes are main issue to address for efficiency and mutual coupling

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Passives are key at mm-waves
Transmission lines and loss requirement

- Three essential functions:

Loss spec:

  – Signal transport — Relaxed (20 dB/cm)
    2 dB loss in 1 mm
  – Impedance matching — Demanding (12 dB/cm)
    ~ 0.5 dB loss in LNA match
  – Frequency selection (filtering) — Critical (6 dB/cm)
    Q_{line}=25

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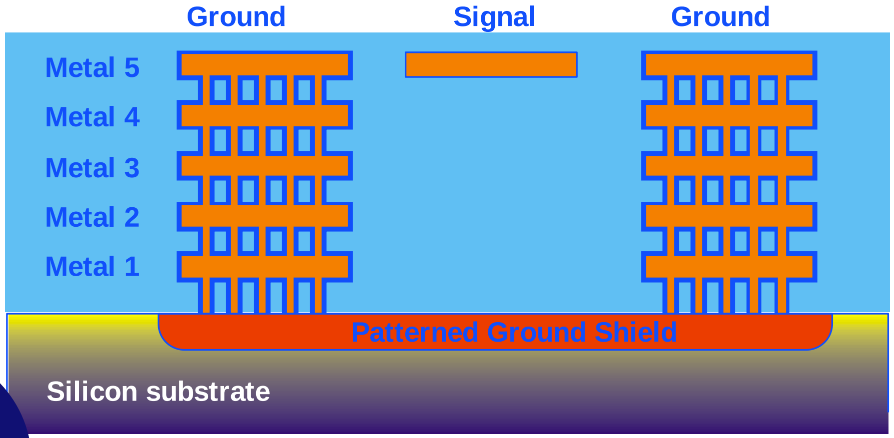
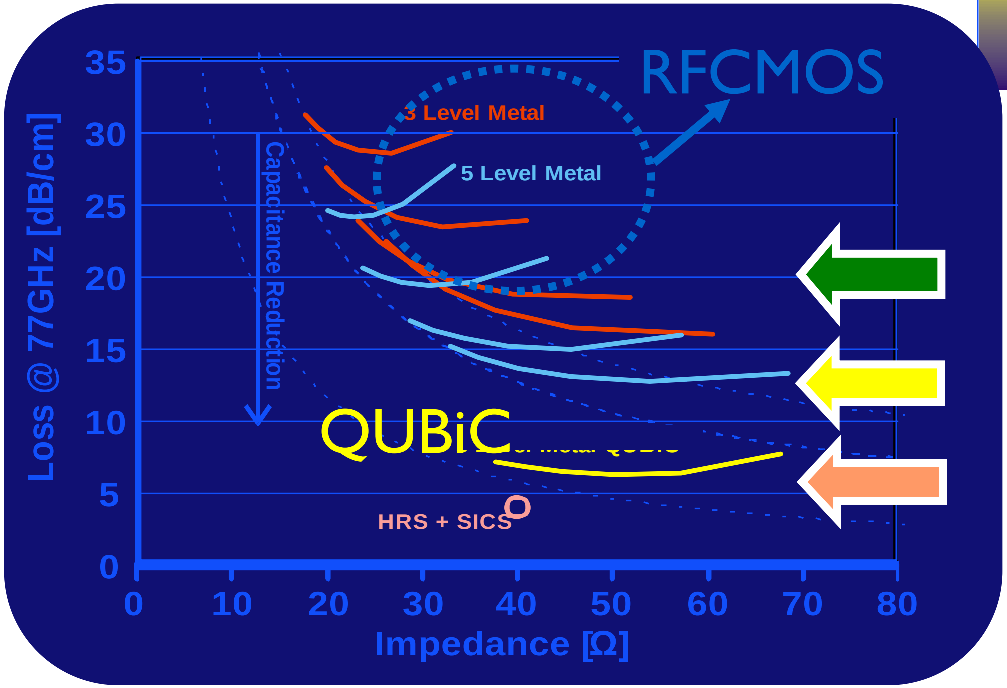
Transmission Line performance @ 77 GHz

- Cross-section:



- Standard technology



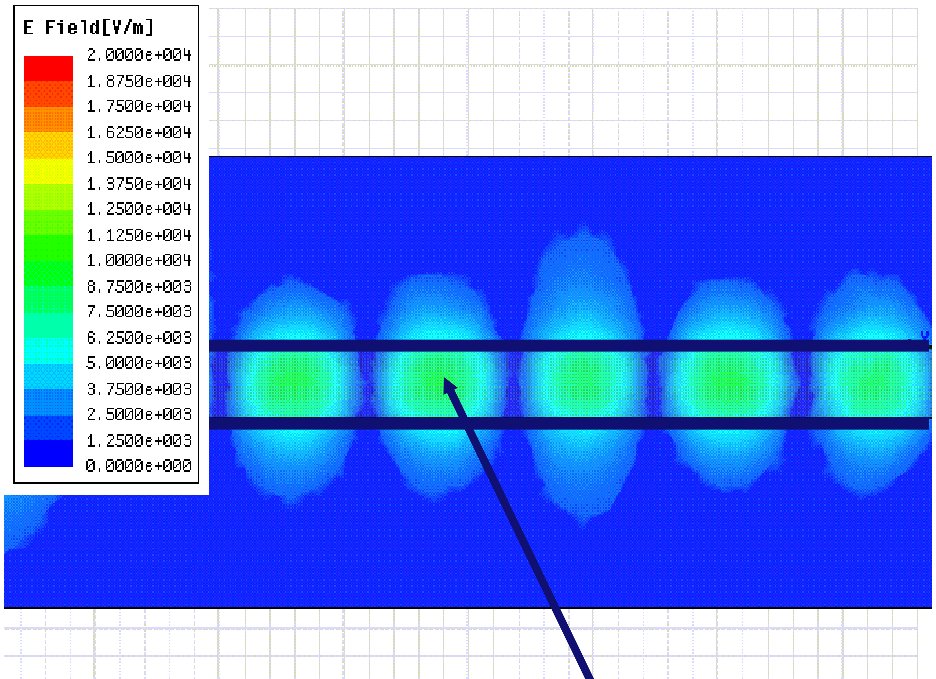
*Tiemeijer et. al. IEEE-T-MTT 2009

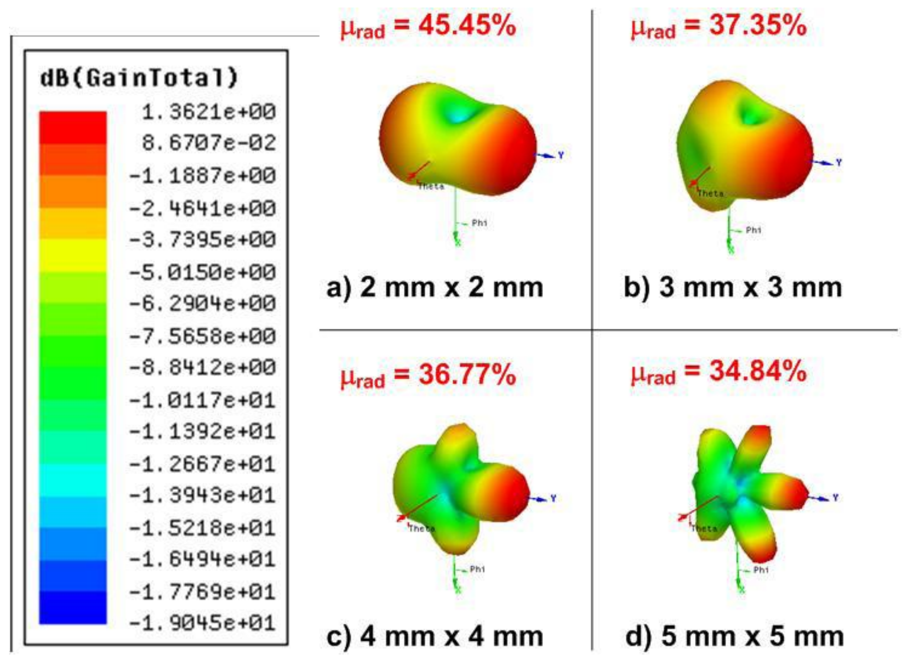
*van Noort et. al. BCTM 2007

Fundamental problem for AoC: Substrate modes

EM simulation of physical structure

Effect on radiation characteristics

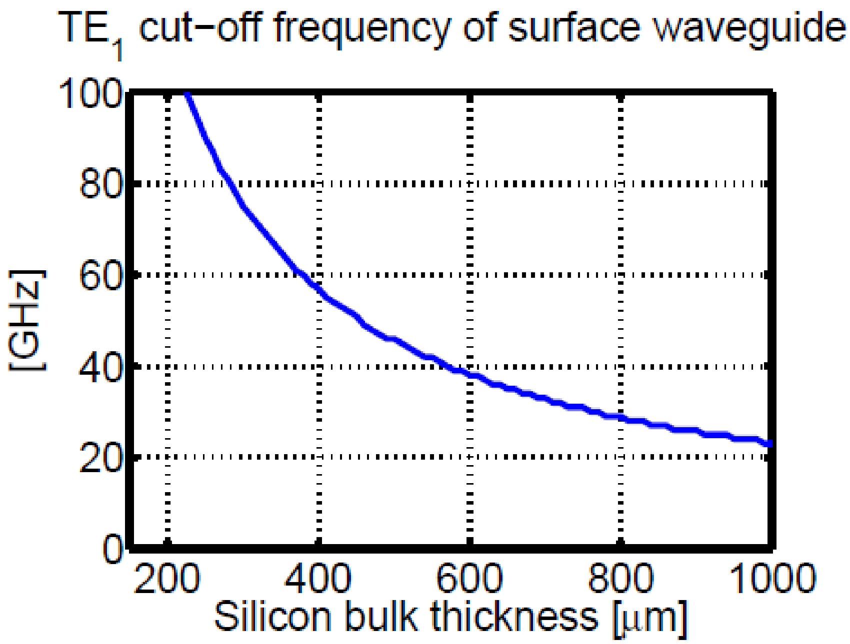




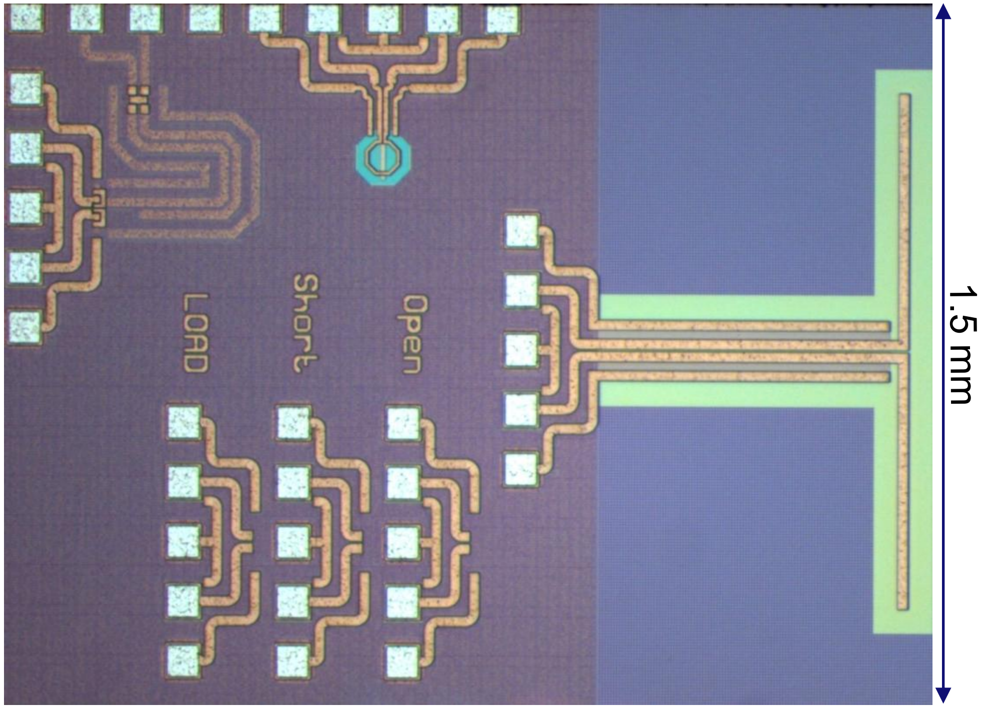
Slab waveguide TE mode of a 500 um IC at 60 GHz

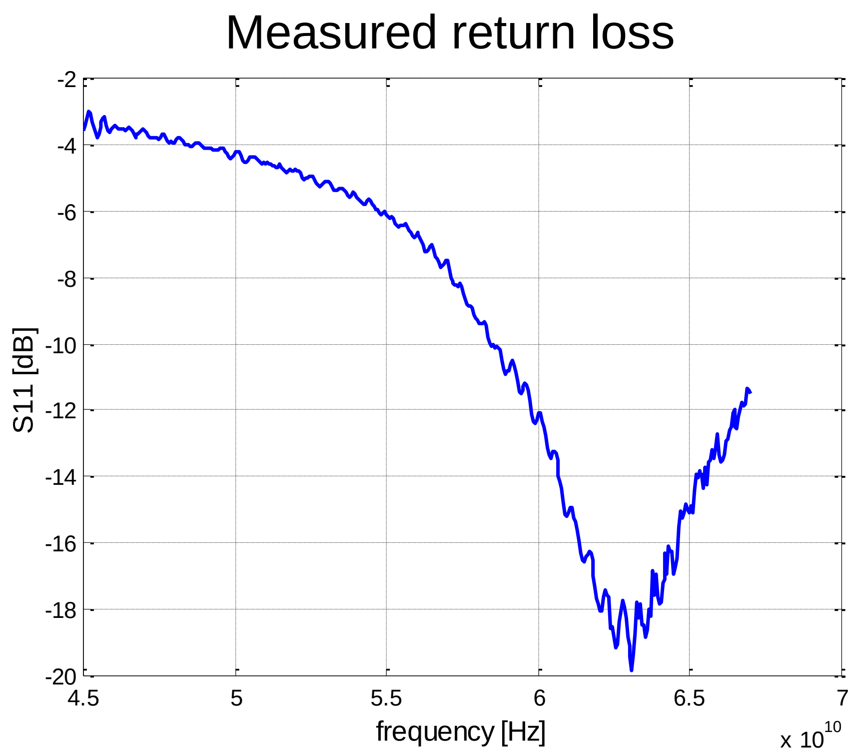
Mitigation strategy

- Implement a metal plate in the lowest metal layer at λ/4 distance from the dipole.
  - Quasi Yagi structure
  - Suppression of the TE_1 mode
- Thinning of the high-Resistive Silicon substrate back to 200 μm
- Place the dipole close to the edge of the chip (50 μm).
- Works also for standard CMOS65/45 Technologies.



60 GHz AoC prototype in QuBiC4Xi
Overall Gain ~ 0 dBi





Advantages:
- Reduced package, test and application cost
- Higher performance due to direct matching antenna and electronics

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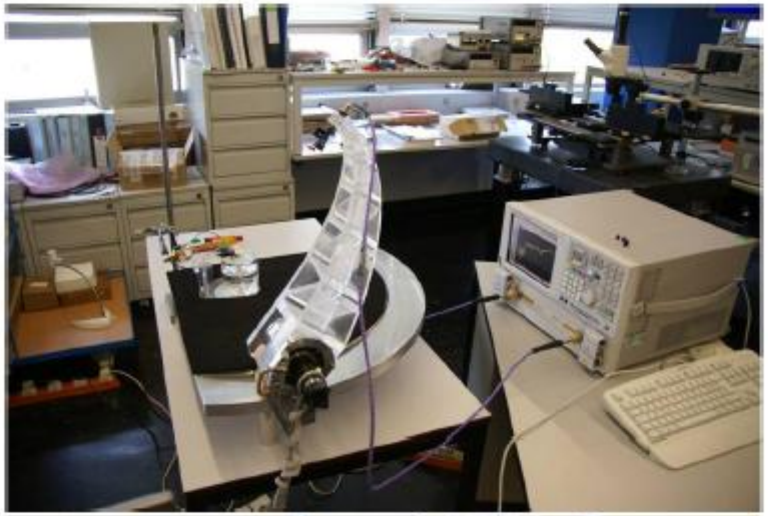
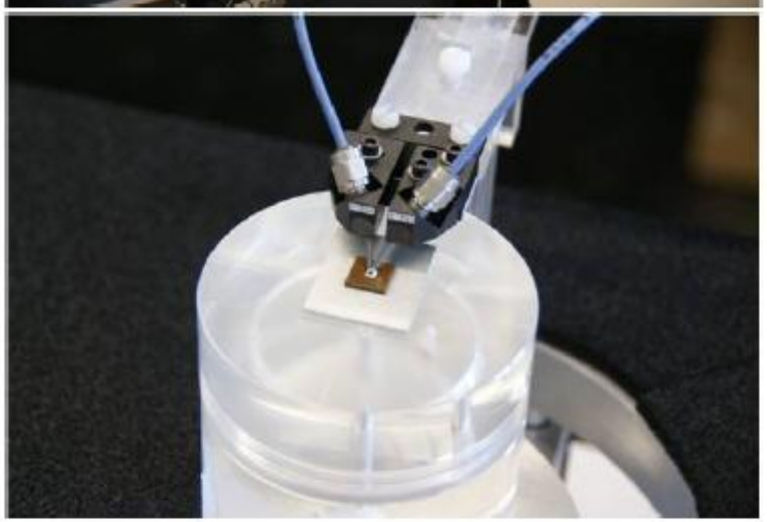
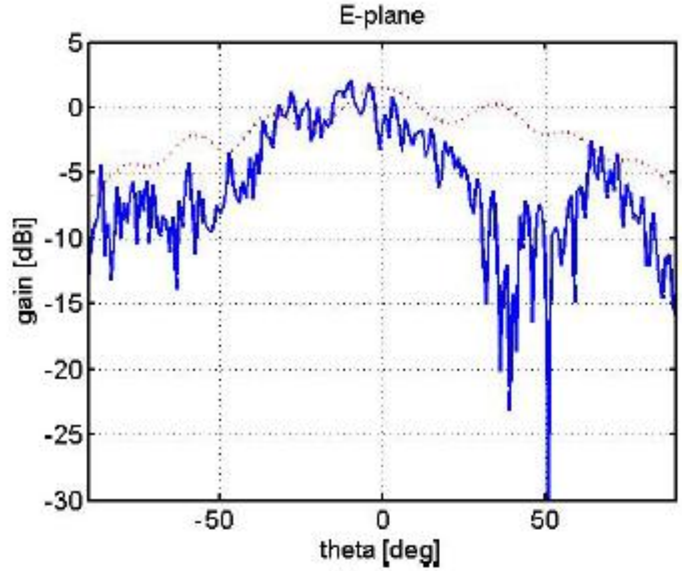
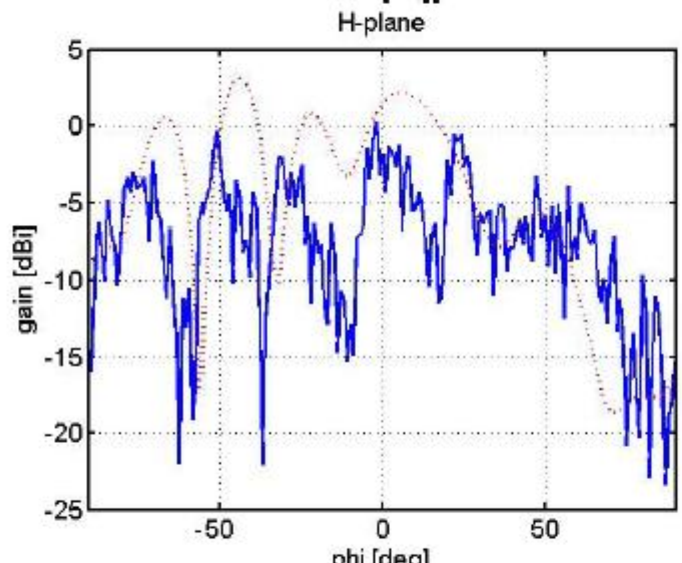
Measurement results





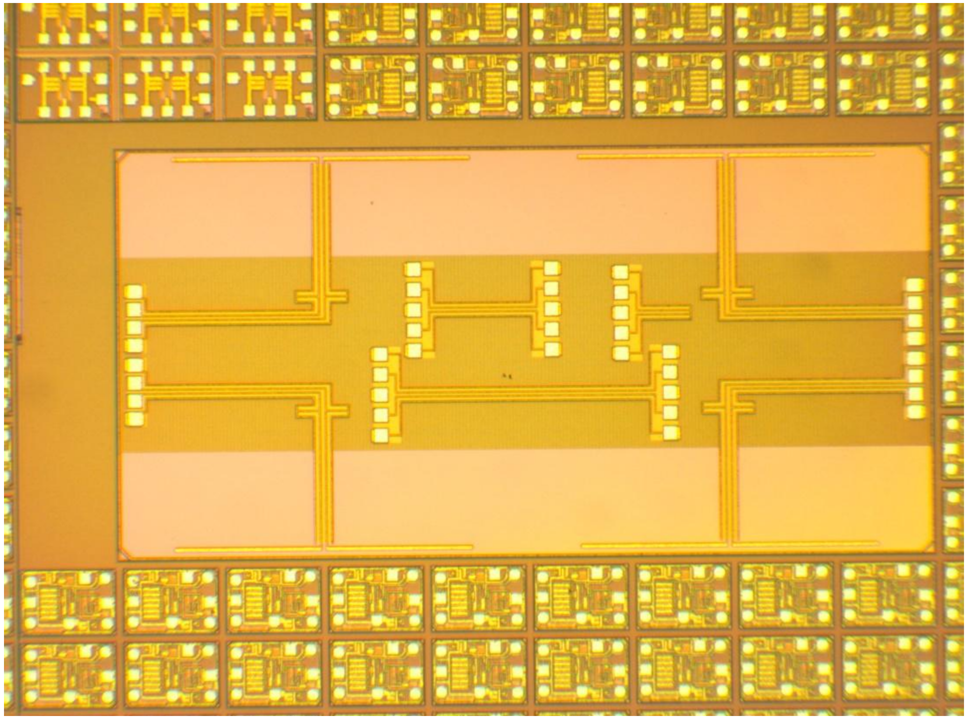




Work-in-progress/next steps

- **Improvement of antenna measurement set-up.**
- **Array-on-chip**
- **Circular polarisation**
- **Integration with electronics**

Photograph of 2x2 array in BiCMOS



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Phased-arrays in Satellite reception: Reflect-arrays

Current situation in Direct-to-Home (DTH) Satellite TV

Drive for innovation in antenna concepts

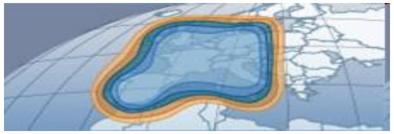
- Less “visible” antennas, especially in urban areas
- Multi-beam requirements, reception of multiple satellite positions simultaneously.
- Interference suppression by using beam-nulling techniques.
- Most promising (low-cost) concepts:
  - Focal-plane arrays
  - Reflect-arrays

ASTRA satellites and services

Specifications

16 Satellites – 5 Orbital Positions

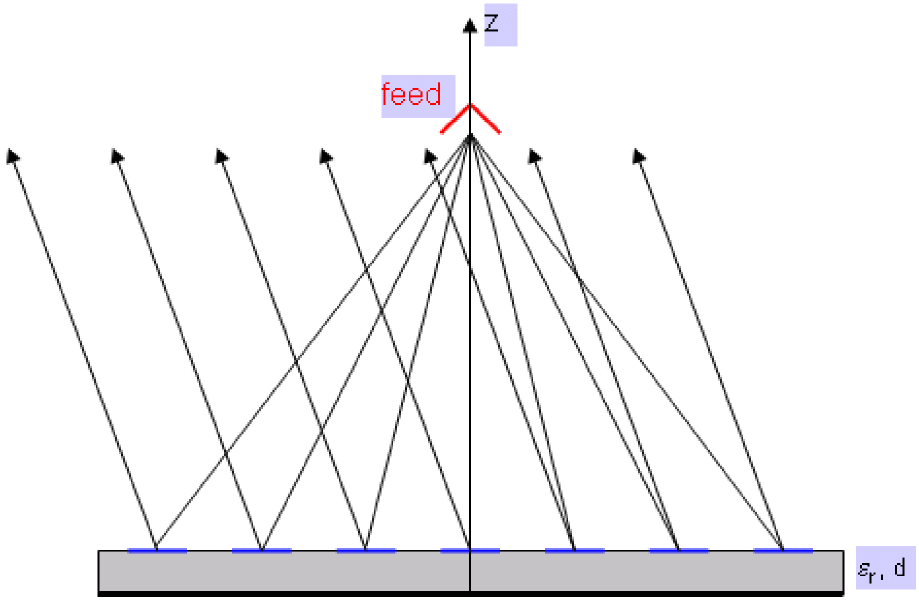
ASTRA The Quality Link.

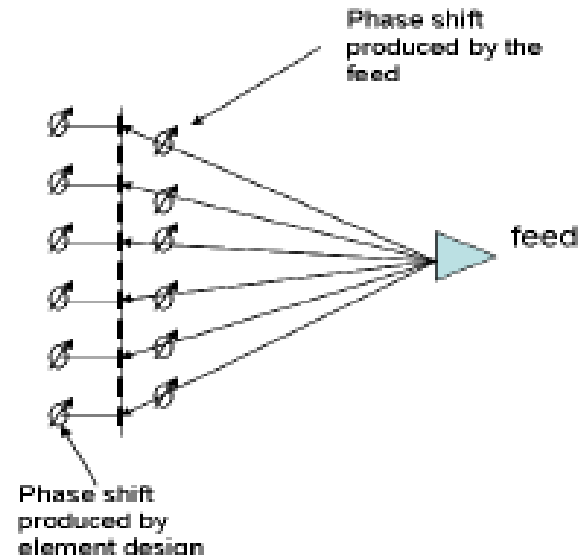


Orbital Position	Satellite	Use
5^{0} E	**ASTRA 4A** **ASTRA 1C**	**DTH services to Nordic countries and the Baltic, Eastern Europe, Ukraine, Russia.**
19.2^{0} E	**ASTRA 1F** **ASTRA 1G** **ASTRA 1H** **ASTRA 1KR** **ASTRA 1L** **ASTRA 1M**	**DTH services to large audiences markets, e.g. Germany, France, Spain.**
23.5^{0} E	**ASTRA 3A** **ASTRA 1E**	**DTH services for dynamic markets, e.g. Italy, Benelux, Central and Eastern Europe. ASTRA2Connect – Broadband Internet and VoIP.**
28.2^{0} E	**ASTRA 2A** **ASTRA 2B** **ASTRA 2C** **ASTRA 2D**	**DTH services to UK and Ireland.**
31.5^{0} E	**ASTRA 1D**	**Cable TV distribution, Digital Terrestrial TV (DTT) and other terrestrial feeds throughout Europe.**

Reflect array

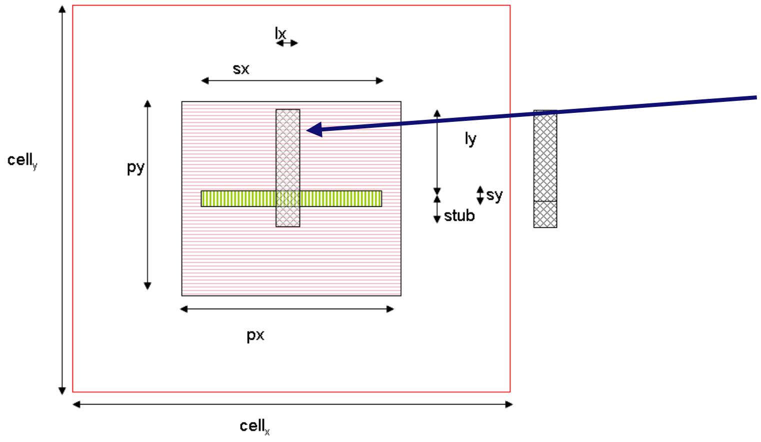
Low-cost solution for multi-beam/beamsteering



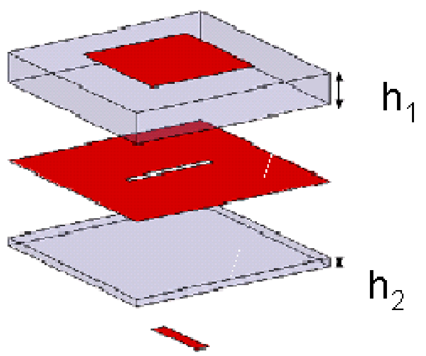


- **A Ku-band demonstrator for Satellite DVB-TV was developed at the TU/e, using fixed beams**
- **Next step to include MEMS phase-shifter for dynamic beam steering**

Reflect array, element design using low-cost patch antennas



Microstrip stub-length determines phase-shift.



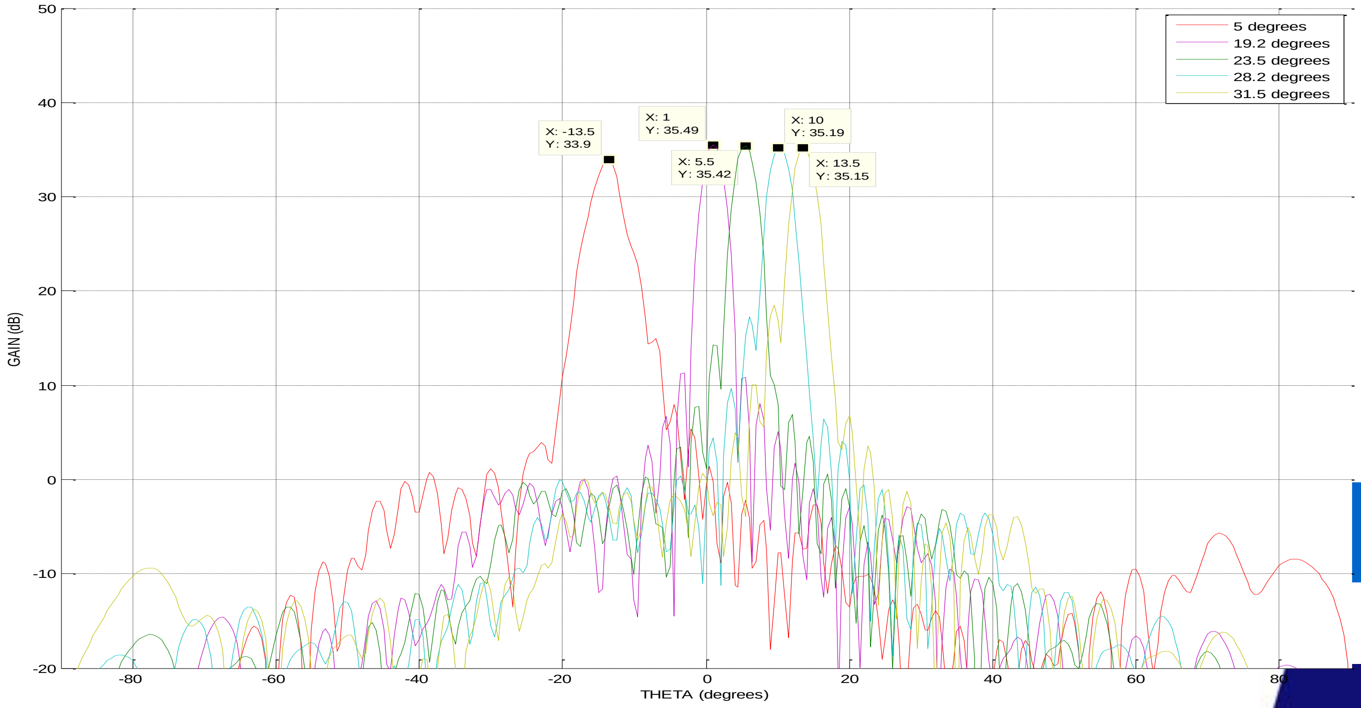
Aperture Coupled Microstrip Antennas (ACMA)

- High Bandwidth
- Space for microstrip line
- Many degrees of freedom

Antenna patterns

Table 5.2 Radiation characteristics for multiple beams.

Beam	Maximum Gain (dB)	Peak Sidelobe Level (dB)	Average Sidelobe Level (dB)
Reference beam	35.56	-24.33	-45.04
5^0	33.9	-18.96	-41.96
19.2^0	35.49	-24.27	-42.8
23.5^0	35.42	-21.14	-43.32
28.2^0	35.19	-17.96	-42.56
31.5^0	35.15	-16.69	-41.95



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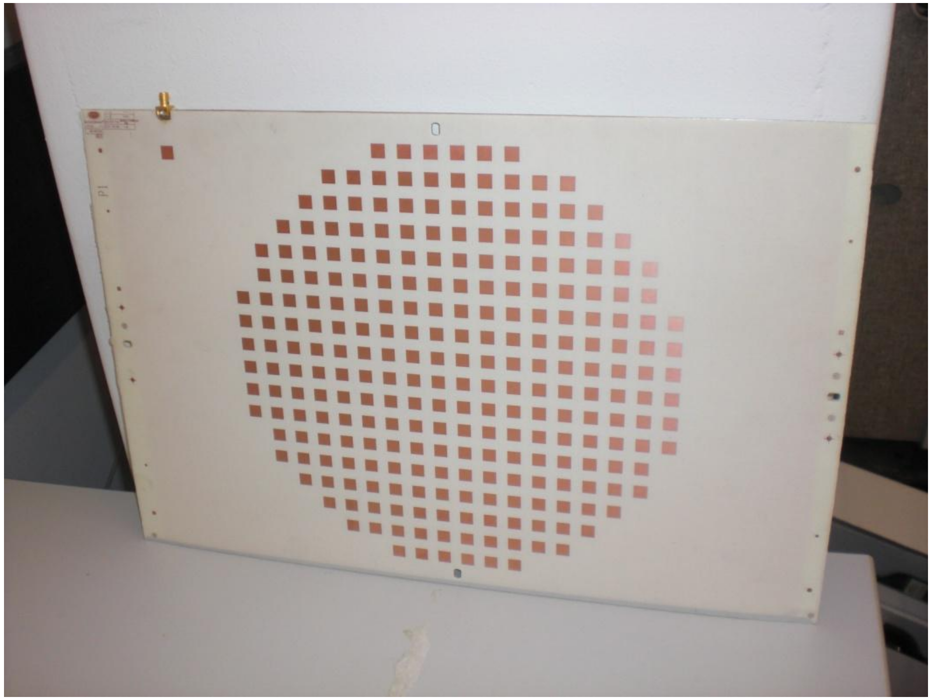
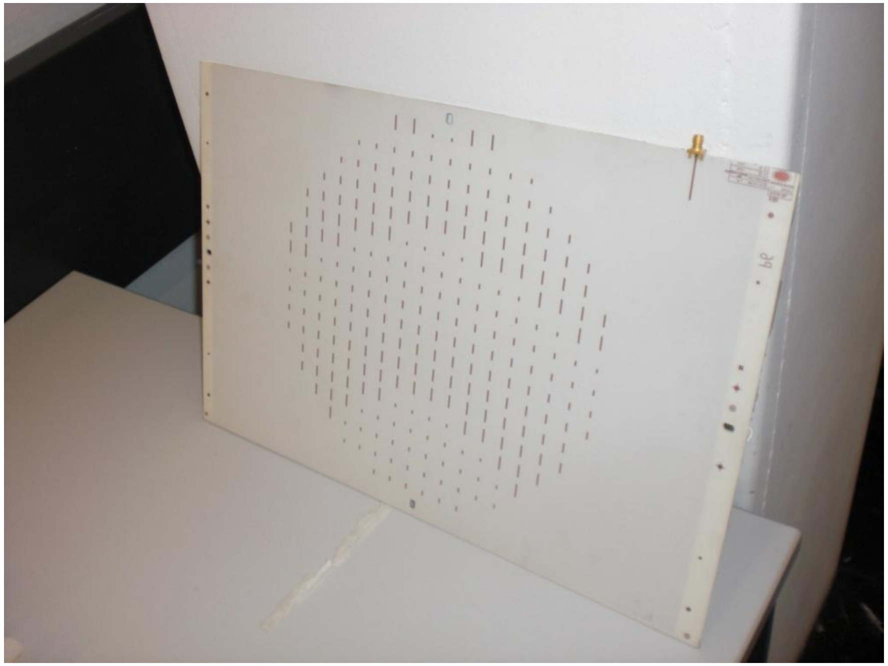
Reflect-array prototype with fixed beams





- Frequency band 10.7-12.75 GHz
- Scaled version with diameter ~ 30 cm.

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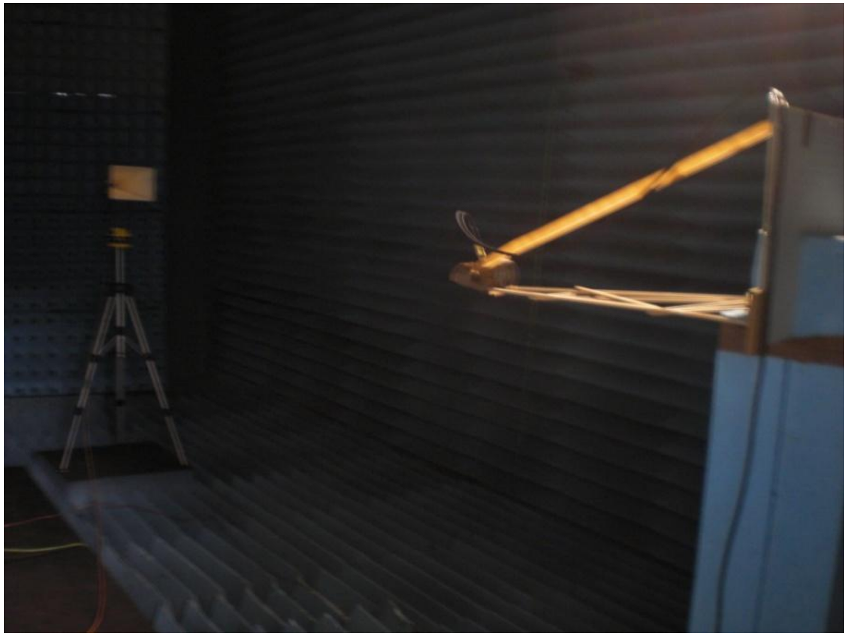
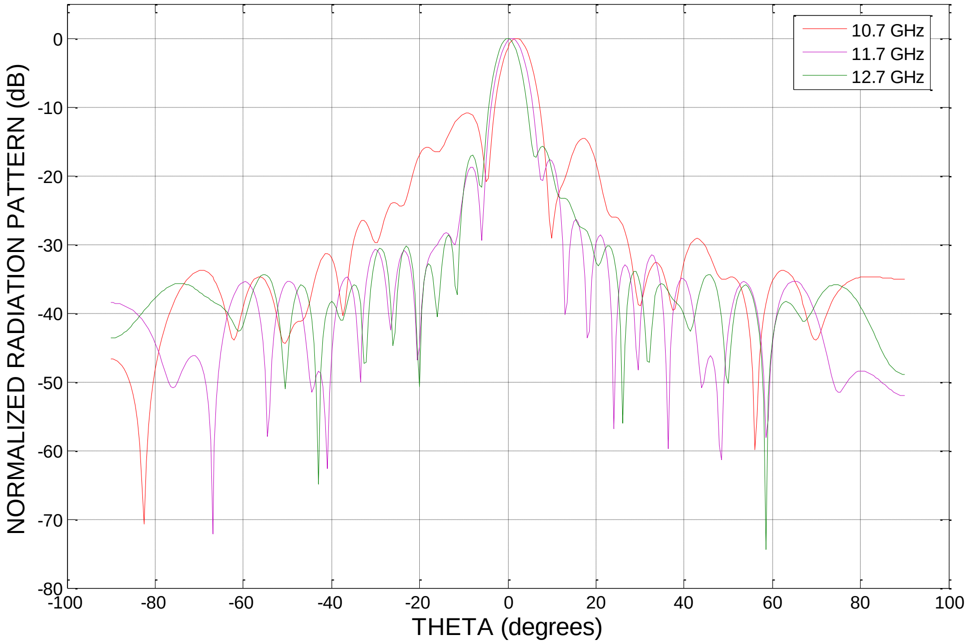
Measurement in TU/e Anchoic room



Measured beam versus frequency



Behaviour at low frequencies (10.7 GHz) not good.

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Conclusions

- **Integration of antennas into main-stream silicon (Bi-)CMOS is possible from a cost and performance point-of-view.**
- **Next step is integration of sub-arrays with electronics as key-building blocks for phased-arrays.**
- **Satellite communication is interesting application domain for electronic beamsteering. Cost is key.**

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