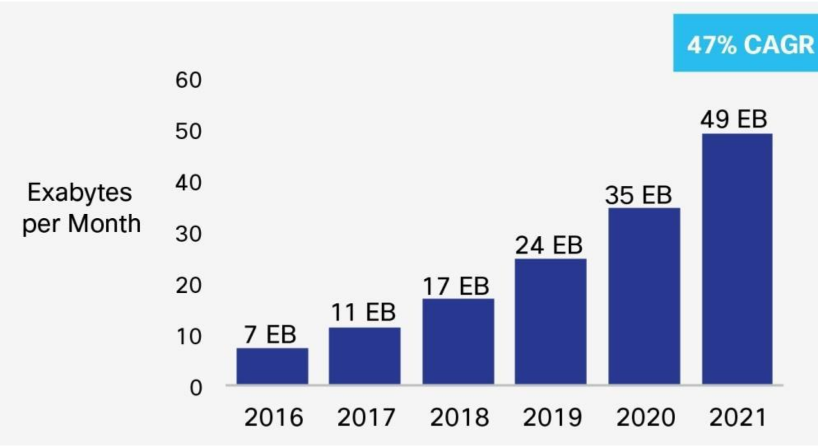
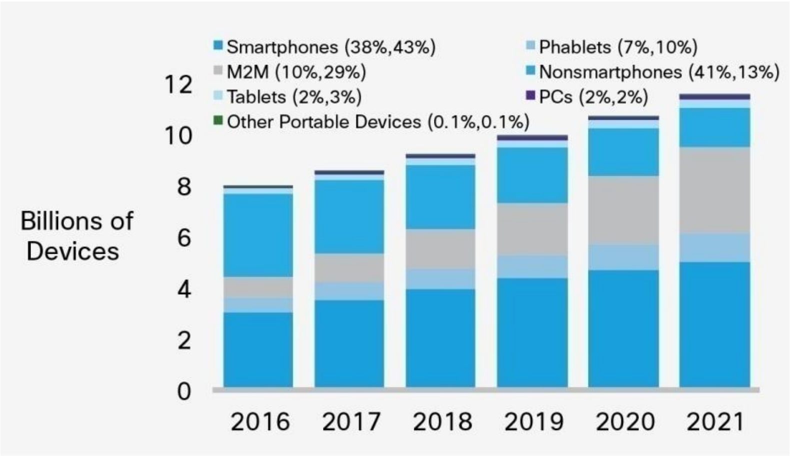
Towards 5G HetNet: trends, challenges end Key Enabling Technologies

cedric.dehos@cea.fr

Data traffic trends in cellular networks

- Mobile data traffic increased by 63% in 2016 to 7 hexabytes/month
  Mobile data traffic *18 over the past 5 years
- Driven by smartphones and tablets and huge growth expected in M2M/IoT
- 47% Compound Annual Growth Rate (CAGR) expected up to 2021
- Mobile video traffic accounted for 60 % of total mobile data traffic in 2016
- Wi-Fi access points and femtocells offload a great part (63%) of the mobile data traffic
- However this traffic offload mostly profits indoor → outdoor small cells needed

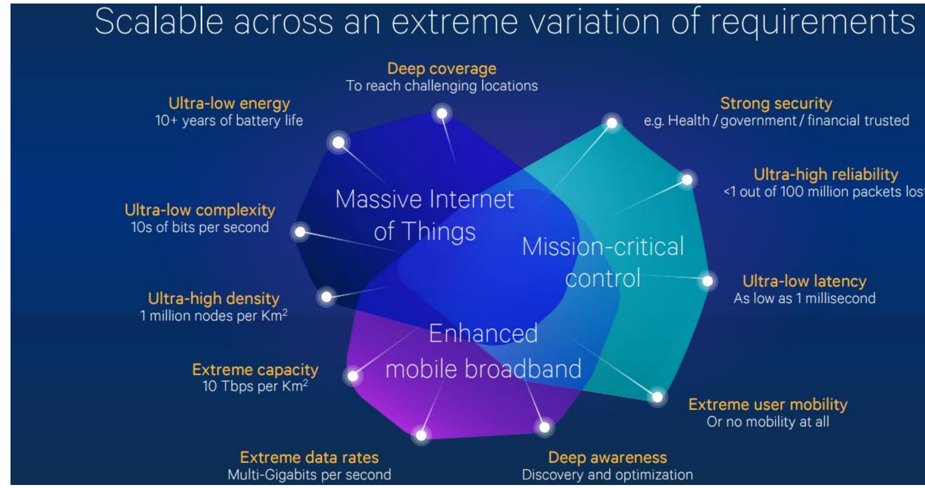




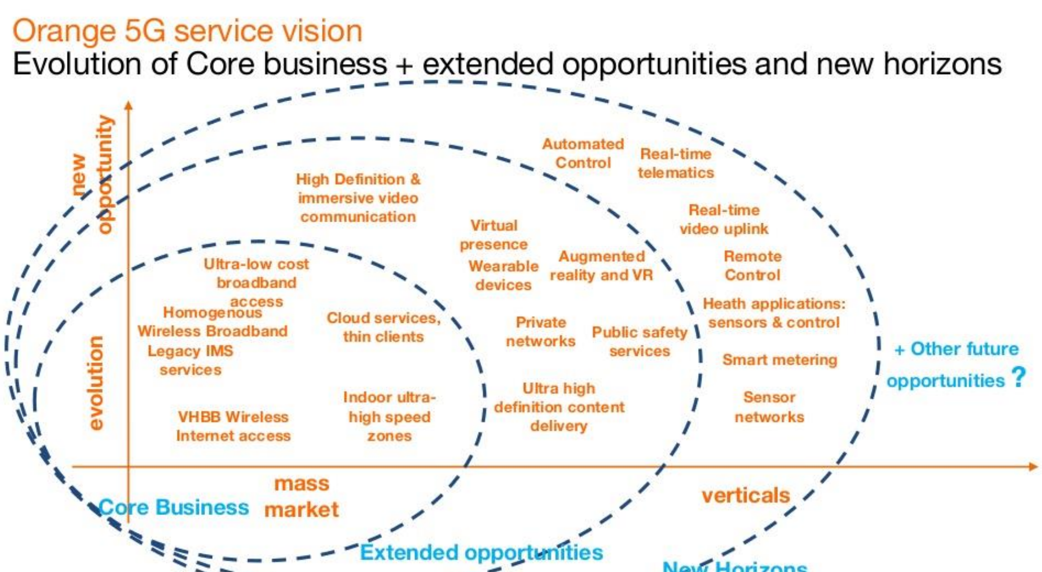
Source: Cisco VNI Mobile, 2017

5G market opportunities

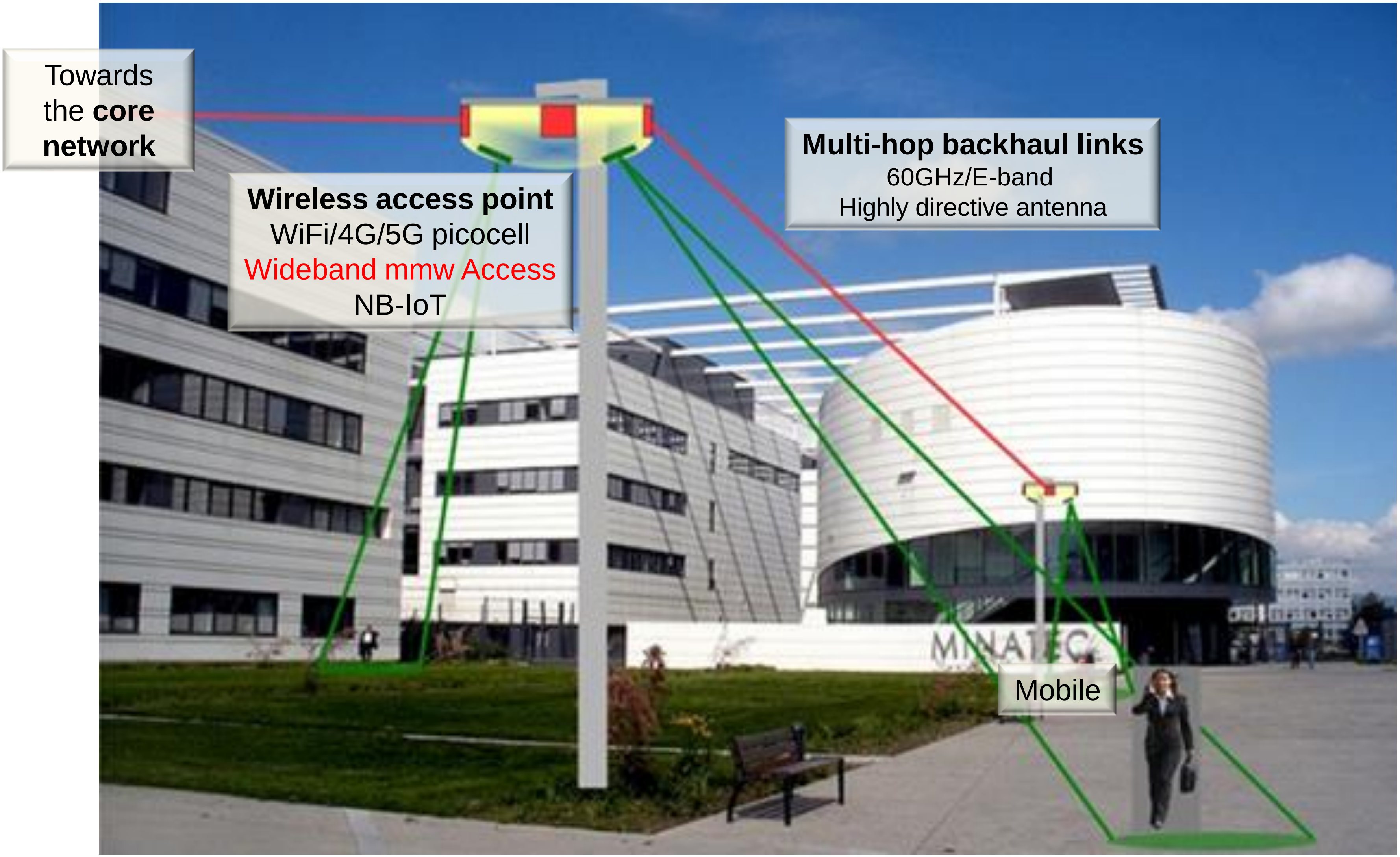
- Unclear vision on 5G
  - Profits decrease from 3G to 4G
  - 5G profitability not clear
  - Delays on 3GPP R15
    - Phase 1 Dec. 2017
    - Phase 2 Sept. 2018



- Research of new market opportunities
  - eMBB core business
  - MCC
  - NB-IOT

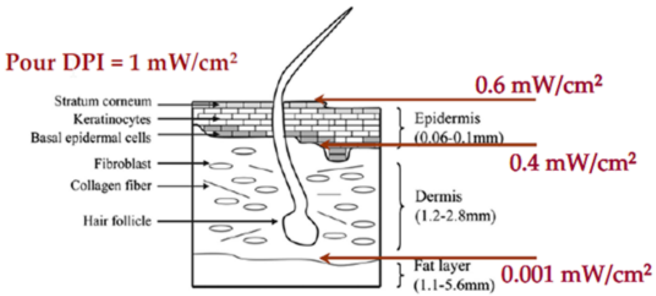


Proposition of **Het**erogeneous **Net**work at H2020

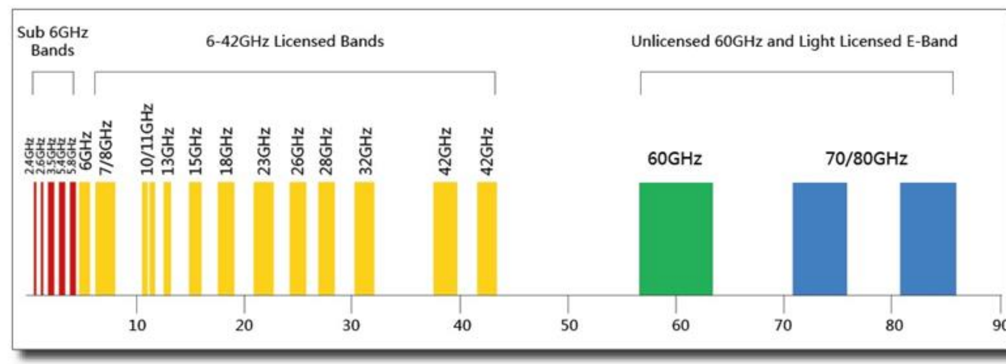


Proposition of **Het**erogeneous **Net**work at H2020

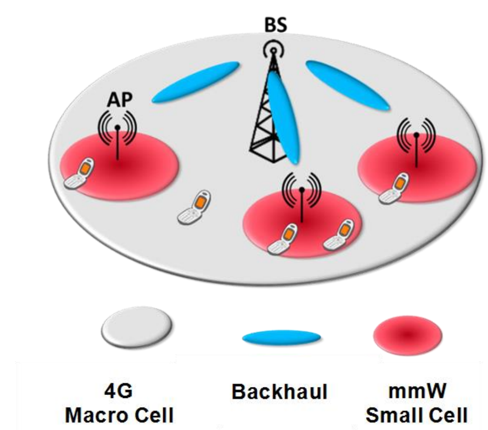
- Mmw access point and backhauling rationale
  - Huge available bandwidth
  - High frequency reuse
  - Natural immunity to interference
  - Low EMF (<1mW/cm²)



Skin penetration @60GHz (source: IETR/Inserm)



- Coexistence of 3 layers of wireless network coverage:
  - 3G/4G network: signaling, voice and high priority data at long range
  - mmw small cells: short range directive high data rate access point
  - 60GHz/E-band backhauling: aggregation and routing of data between small cells up to the core network



Mmw Small Cell challenges

- Access Point
  - Provide Gbps experience and new services to <u>multiple users</u> in the cell
  - Local/Global radio resource management
  - Mobility and small cell handover
  - Electromagnetic field (EMF) exposure
  - Cost of dense small cell network

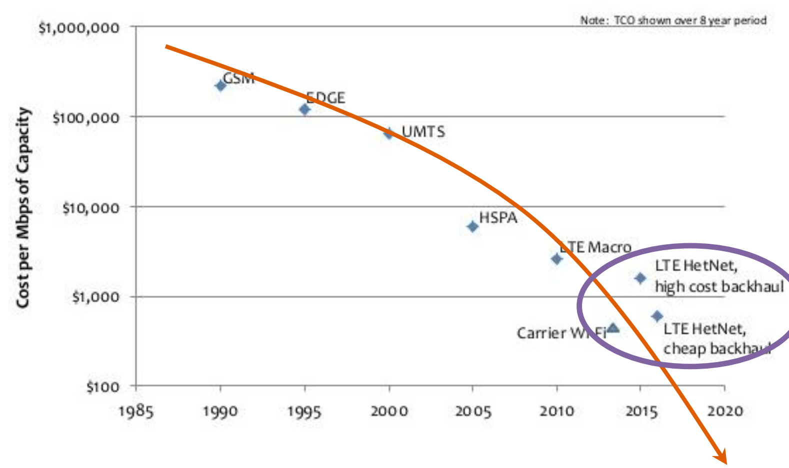
Source: JC Decaux

- Wireless backhauling
  - Aggregation and routing (latency)
  - Low cost and versatile

- Reduction of Total Cost of Ownership (TCO)
  - Capex:

  Low cost CMOS technology, 3D package integration, reconfigurable planar antenna array
  - Opex:

  Low cost site rental, license-light/free bands, low power consumption, remote maintenance



Long range vs small cell backhaul

- **E-band Long Range specifications (SoA)**
- 250MHz channels, up to 2GHz BW
- Adaptive modulation up to 256QAM
- 1.2Gbps per channel, 10Gbps aggregated
- Power consumption >50W
- Volume >4l + antenna
- Range up to few km

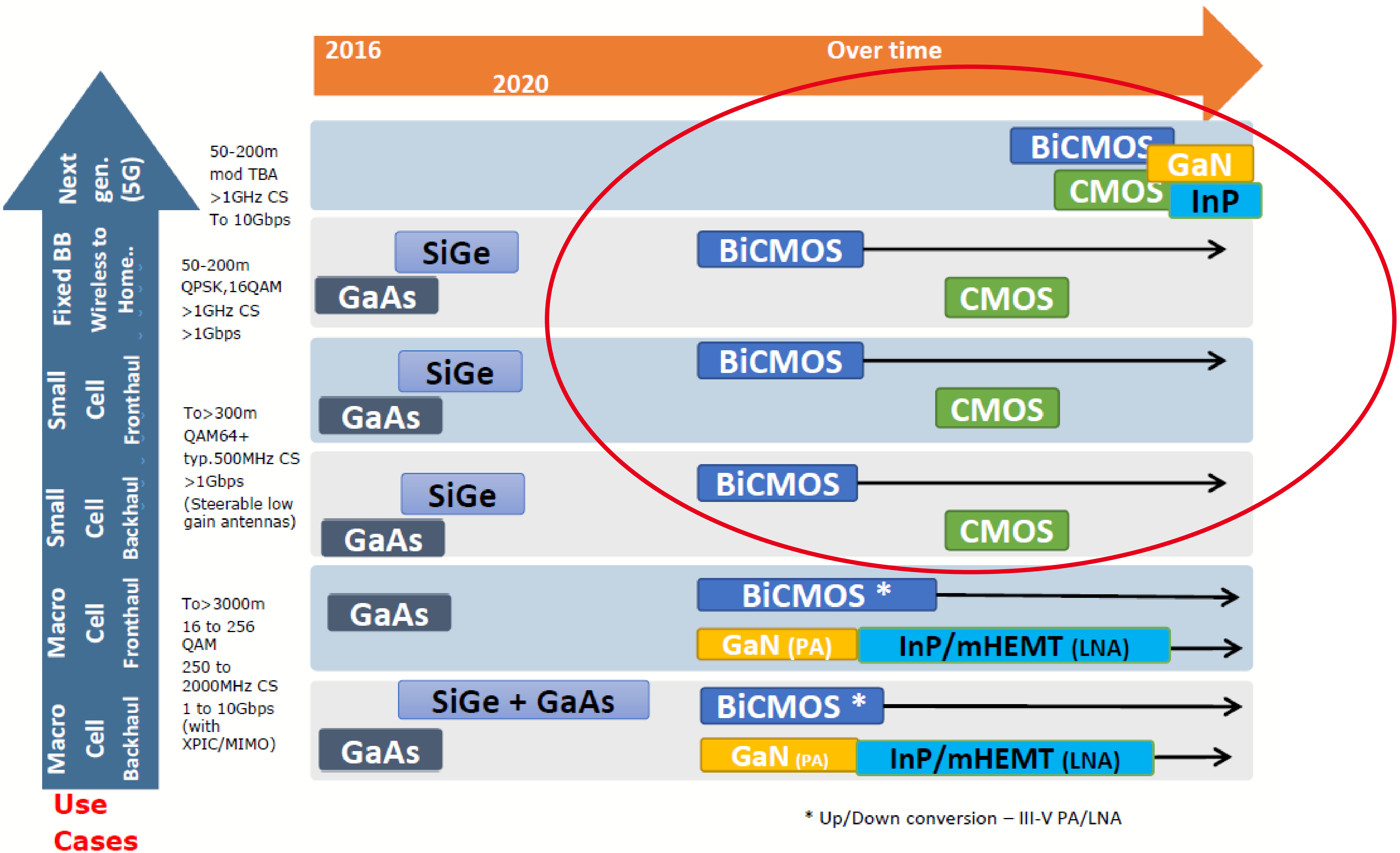
- III-V PA, Psat >25dBm
- ~50dBi 2 feet parabolic antenna
- <-110dBc/Hz@1MHz phase noise
- MMIC integration

V-band small cell specifications

- 1.76GHz channels
- Adaptive modulation up to 16QAM
- 4Gbps per channel, 16Gbps aggregated
- Power consumption <0.5W
- Volume <1l with antenna
- Range 50-200m

- Integrated CMOS PA 10dBm Psat
- ~32dBi planar antenna array
- -90dBc/Hz@1MHz phase noise
- Monolithic CMOS RFIC

Backhaul technology trends: RF front-end

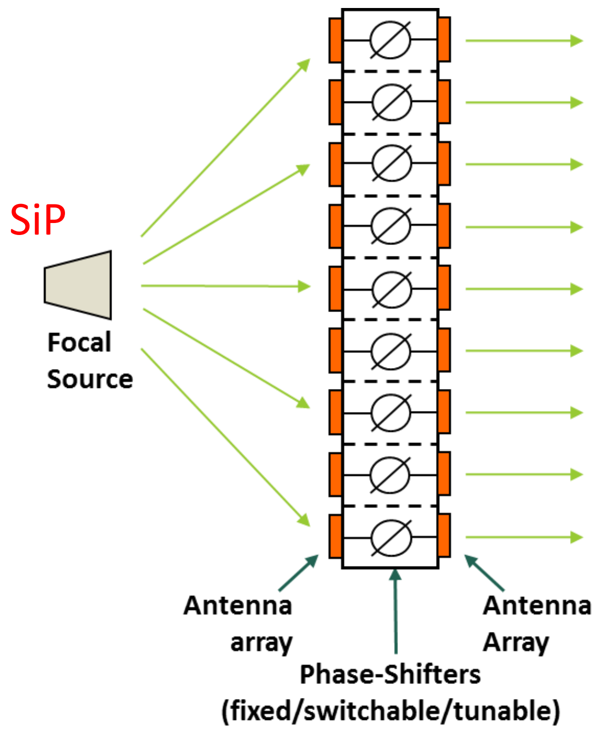


Source: Filtronic

Backhaul technology trends

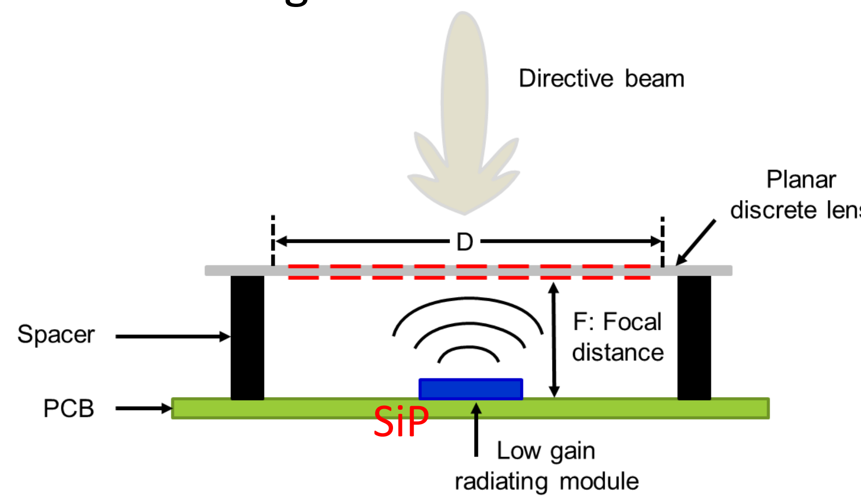
Planar discrete lens (transmit array)

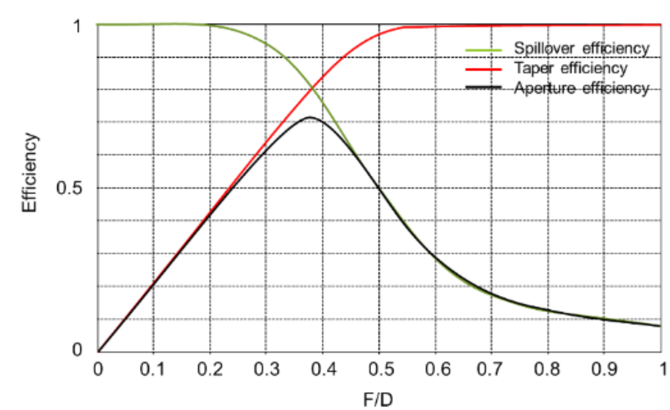
- Cost, complexity and power consumption effective solutions
- Use of planar technologies for potential full integration



Typical implementation

Light integration

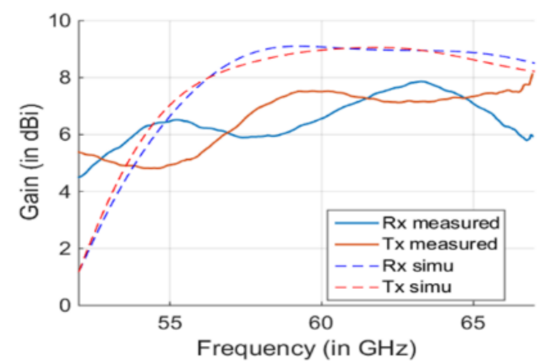




Backhaul technology trends: SiP module

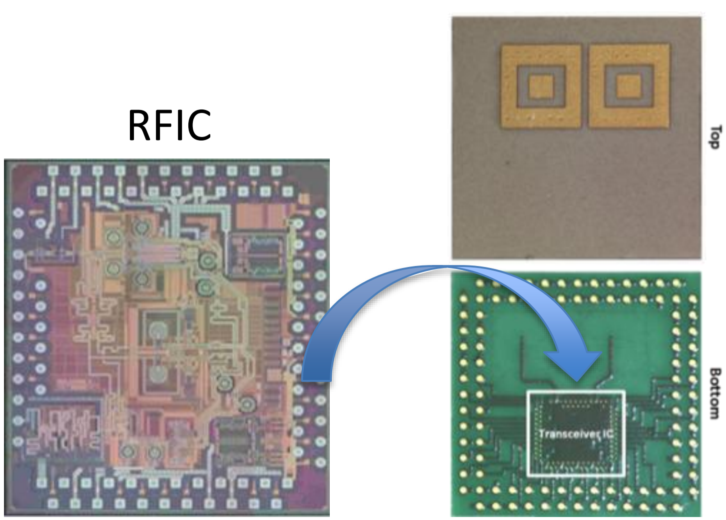
10*10mm² System In Package module with mmw transceiver and antennas

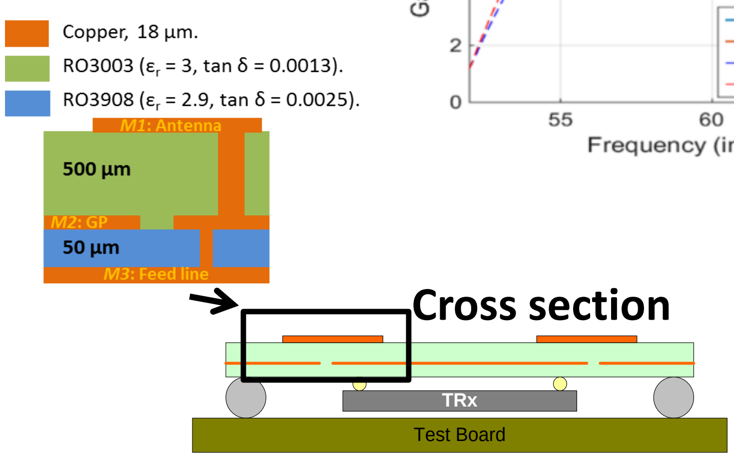
- 4 channels 60GHz transceiver
- Liquid Crystal Polymer interposer
- 3-metal layer back-end: antennas, interconnects
- TSV for shielding and vertical interconnects
- transceiver RFIC flip-chipped on the bottom side of the interposer
- through polymer vias
- BGA connection of the interposer on the PCB



SiP

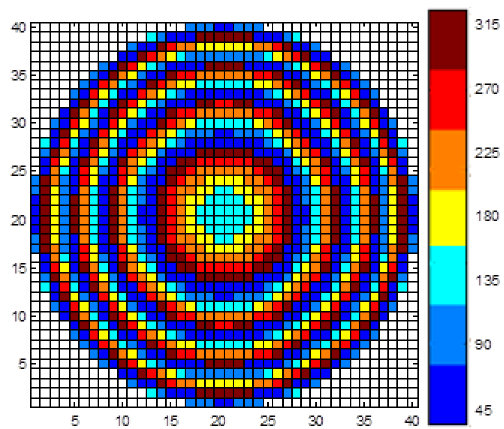
RFIC



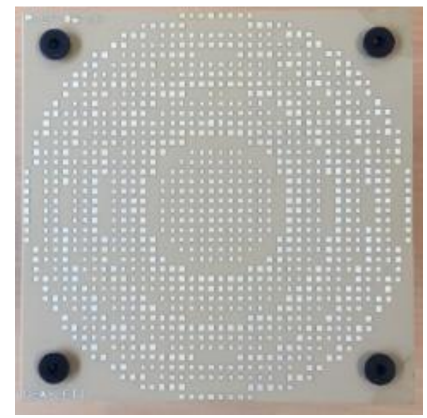


Backhaul technology trends: transmit array antenna

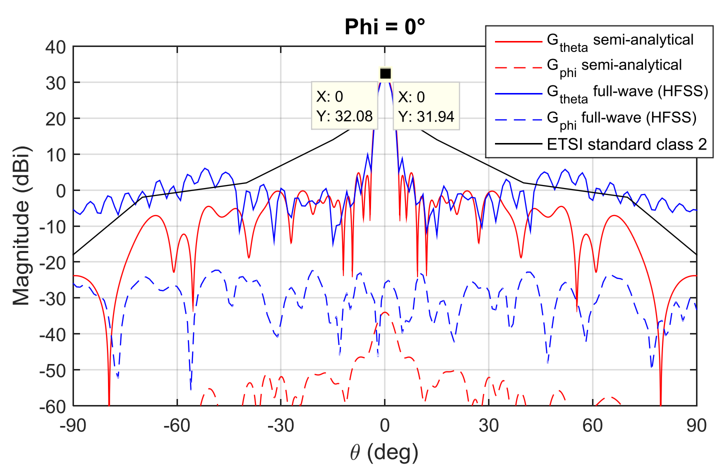
3bit Phase shifting matrix

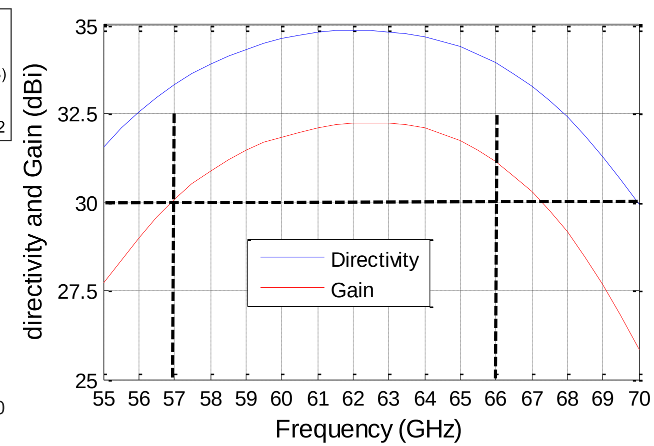


Realization on low cost PCB



- Lens: 100x100 mm
- Focal distance: 55 mm
- Gain @61GHz : 32 dBi
- Beamwidth : 3.2°
- Secondary lobe : 5 dBi
- 3dB Gain Bandwidth : 20%
- Max cross polar : -25dBi





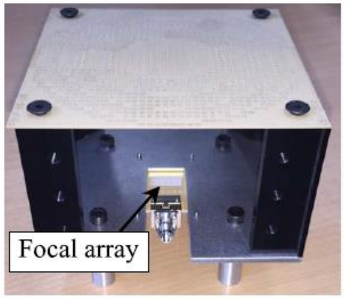
Small cell backhaul proof of concept

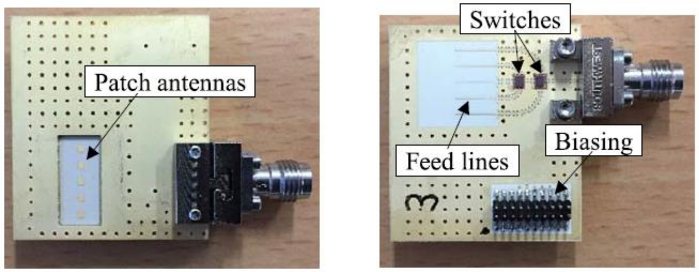
- 60GHz transceiver on organic interposer module
- Module on BGA card with power supply, Xtal
- Transmit array on front
- Indoor/outdoor measurement:
  - 3Gbps (QPSK) at 100m range
  - 7Gbps (16QAM) at 30m range
- Manual antenna alignment

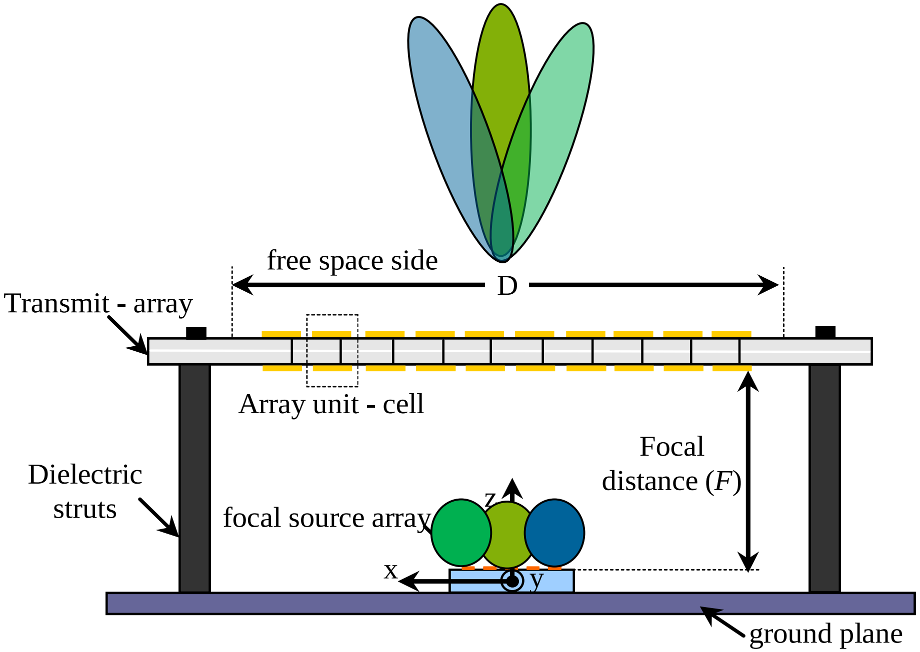
Small cell backhaul proof of concept

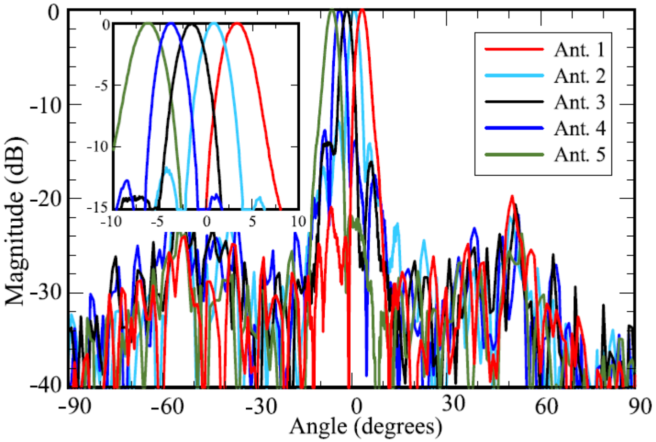
Beam-switching steerable transmit array antenna
Principle

- Selection of antenna source (antenna array)
  for beam switch over +/-10-20° (electronic beam alignment)
- 20-35dBi gain function of lens area
- Proof of concept: 5 beam switched antenna array



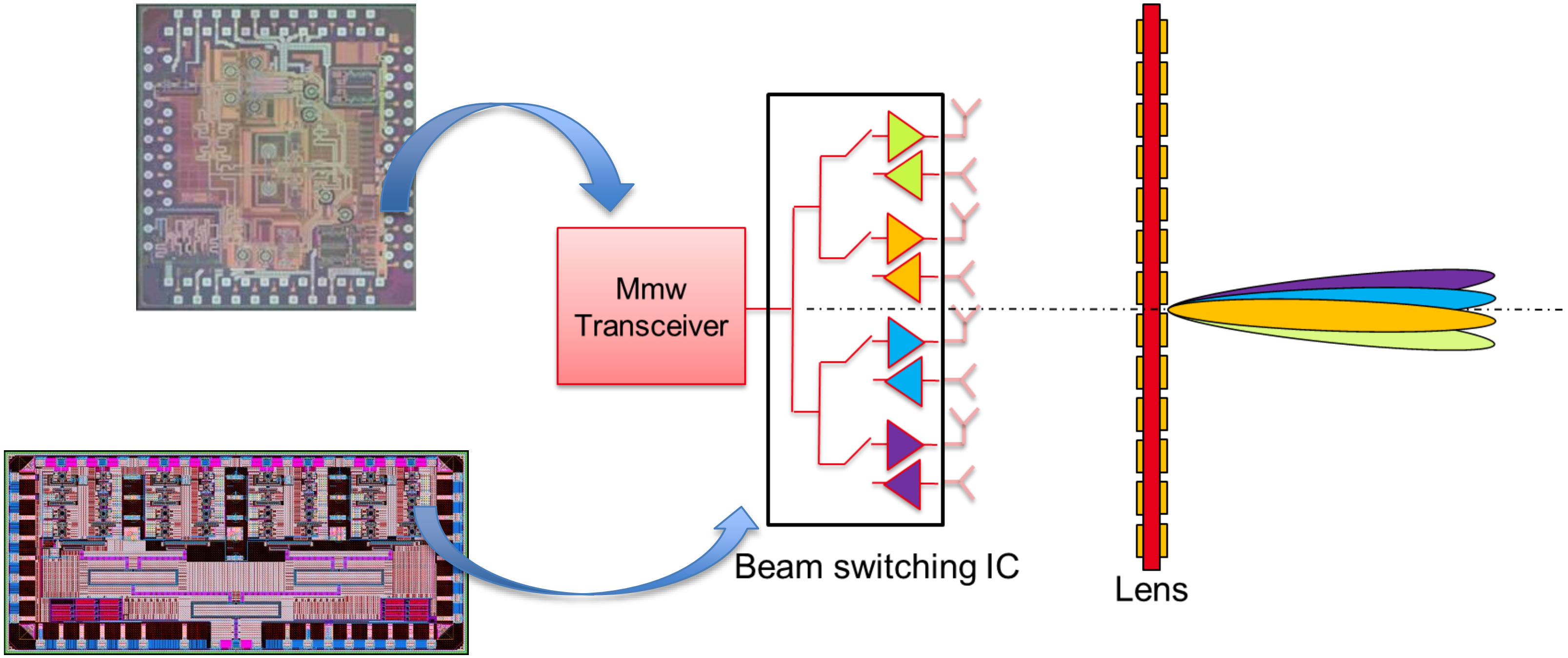






Small cell backhaul perspective

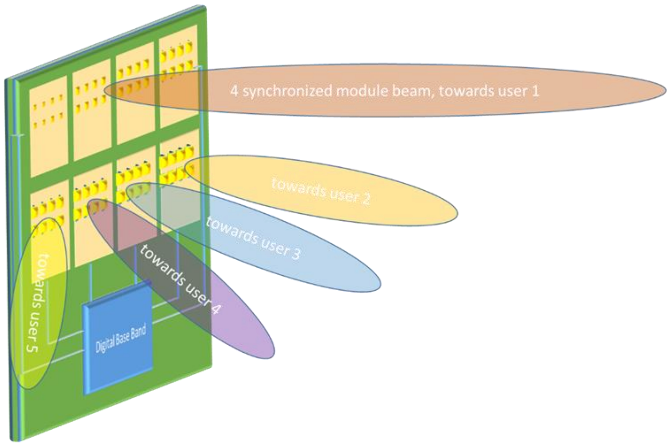
- Beam-switching steerable transmit array antenna
- Active feeding switch IC
- Bidirectional active feeding network for beam switching
- Compensation of the feeding network losses thanks to PA/LNA
- Possible integration of phase shifters for fine beam alignment

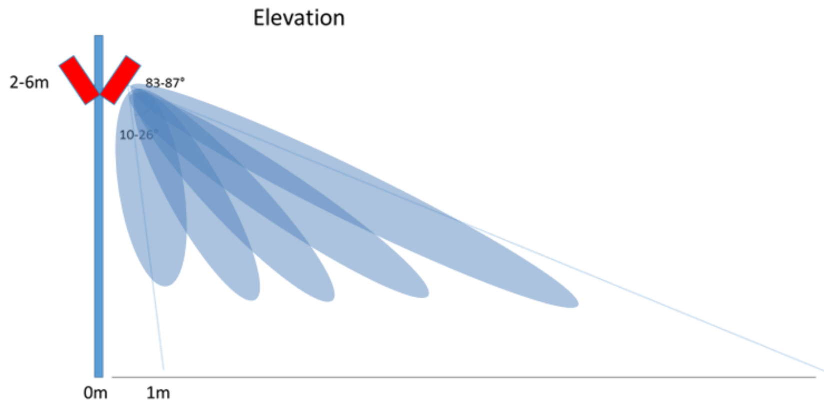


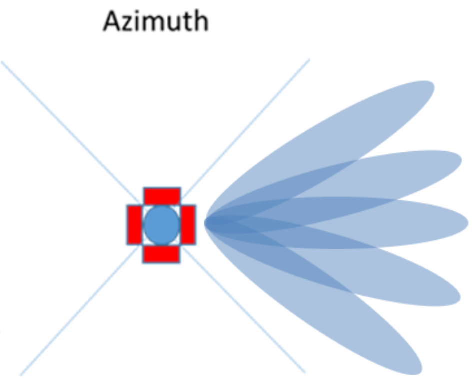
MmW Multi User Access Point

Proposed architecture

- Sectorization of the azimuthal plan
- 50m-200m range
- 0.3 to 7Gbps DL per user
- Multiple array modules per sector
- Multi-user access (Time/Frequency/Space)



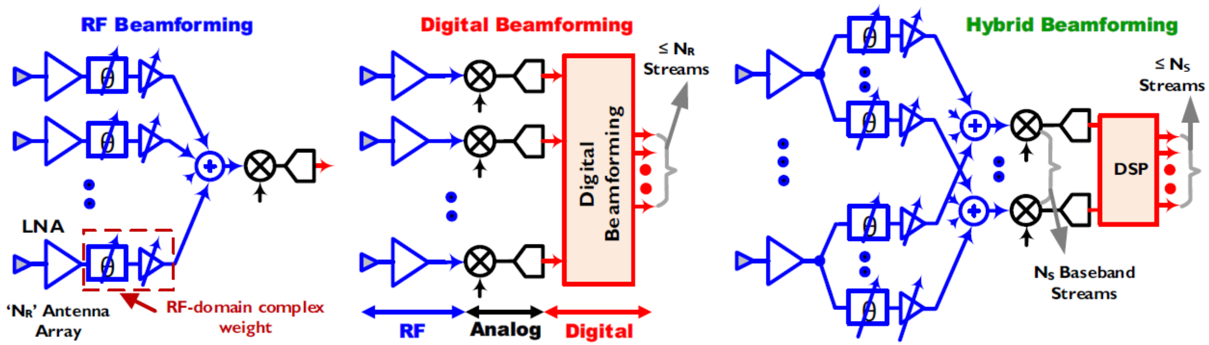




MmW Access Point: beamforming architectures

Beamforming approaches

- Beam switching
- RF beamforming: single IC with integrated phase shifters
- RF beamforming: satellite phase shifters (active antenna array)
- Massive MIMO (digital beamforming) → hybrid beamforming



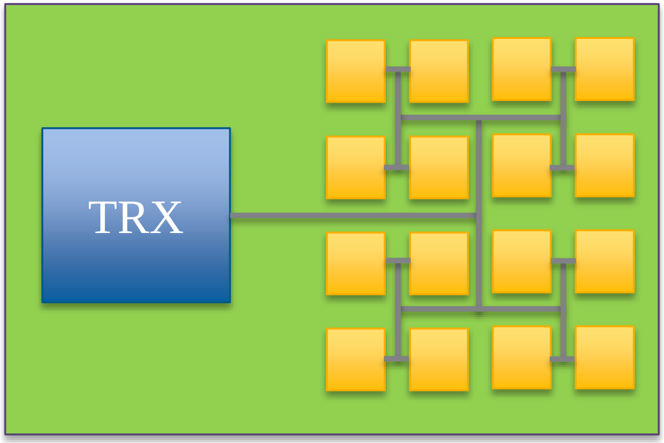
RF Beamforming	Digital Beamforming	Hybrid Beamforming
✓ Power Efficient	× Power Hungry	✓ Power Efficient
✓ Area Efficient	× Area Hungry	✓ Area Efficient
× Single-stream	✓ Multi-stream	✓ Multi-stream
× Less Flexible	✓ Most Flexible	✓ More Flexible

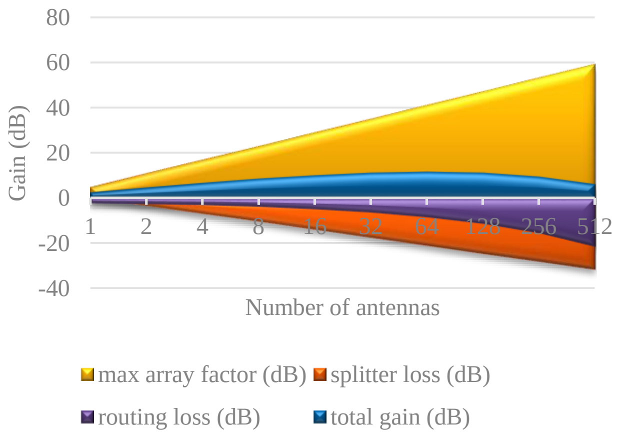
Source: Carnegie Mellon Univ. IMS 2018

MmW Access Point: beamforming architectures

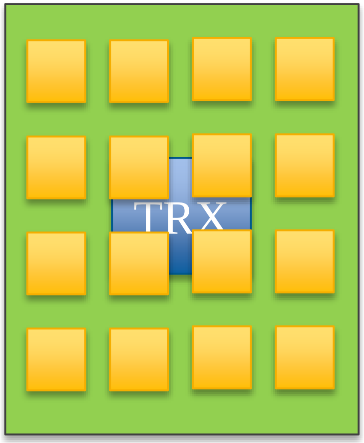
RF Beamforming approaches

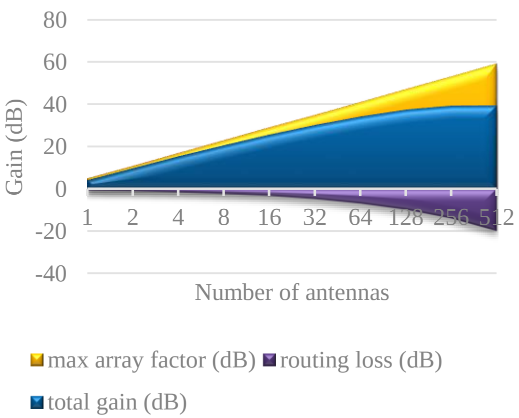
Fixed beam antenna array



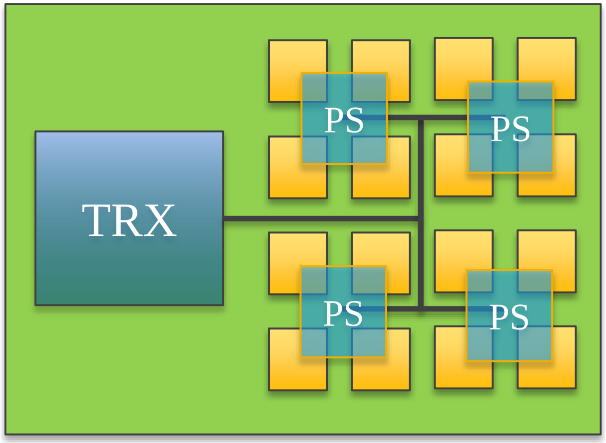


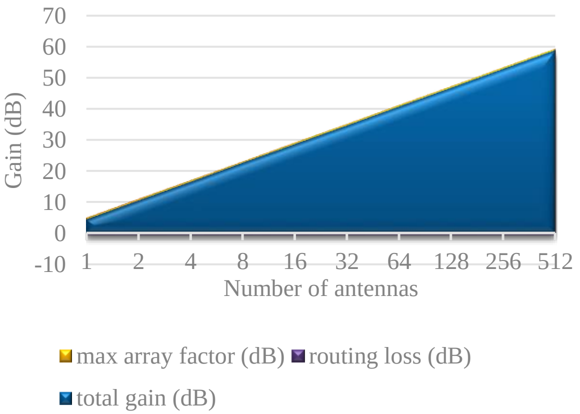
Compact monochip





Satellite phase shifters

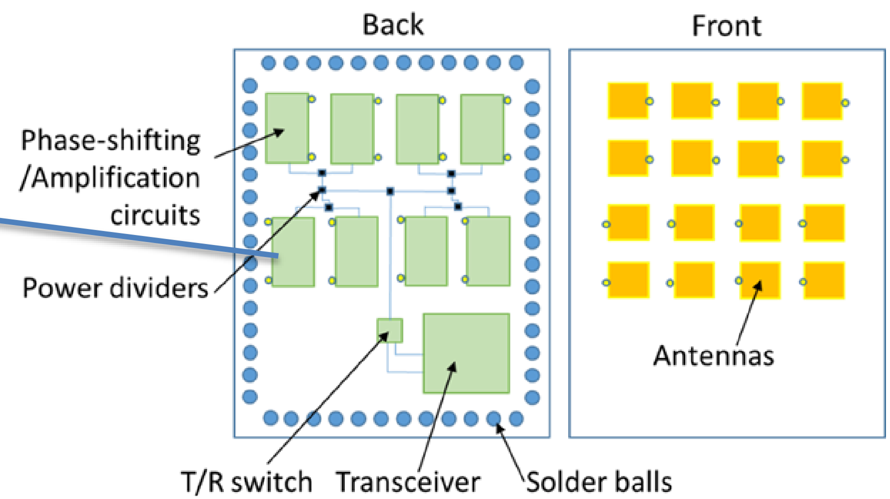


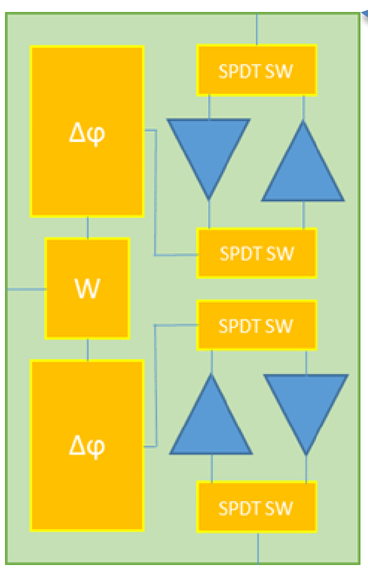


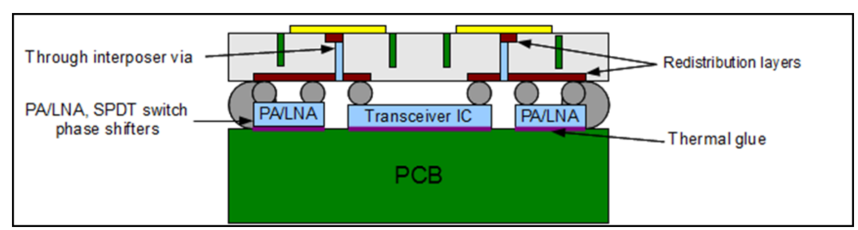
MmW Access Point: satellite active phase shifter

Satellite phase shifter architecture

- BICMOS 55nm active antenna array module
- {PA, LNA, phase shifter} circuit flip-chipped at antenna back with transceiver IC
- Compensation of the power splitter and phase shifter losses
- Vector modulator phase shifter
- 3D multi-layer organic module (LCP)



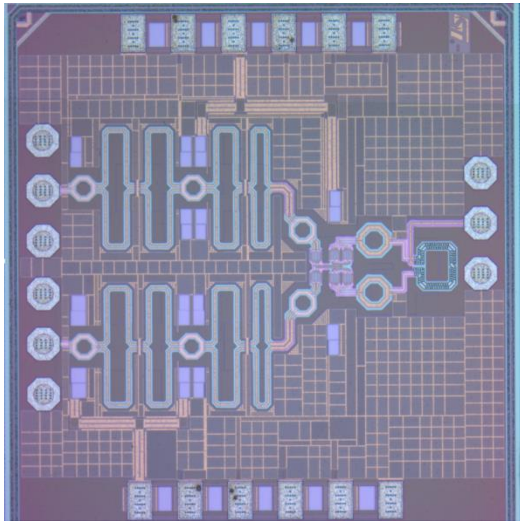




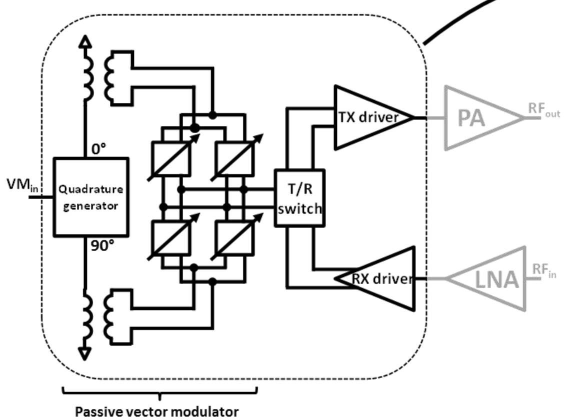
MmW Access Point: satellite active phase shifter

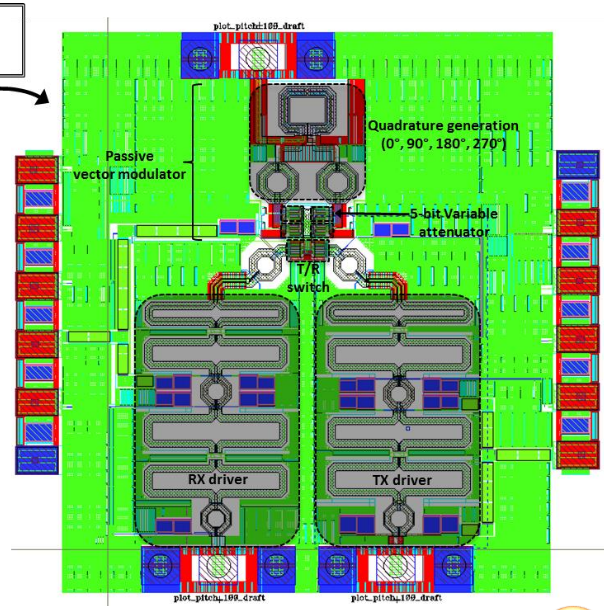
Key Enabling Technology: Vector modulator phase shifter

- Bidirectional phase shifter (small area: 400*700µm²)
- Quadrature generation and passive vector modulator
  0.5dB amplitude and 2.5° phase precision with 6bits DAC
- Tx/Rx driver to compensate for losses (~4dB)

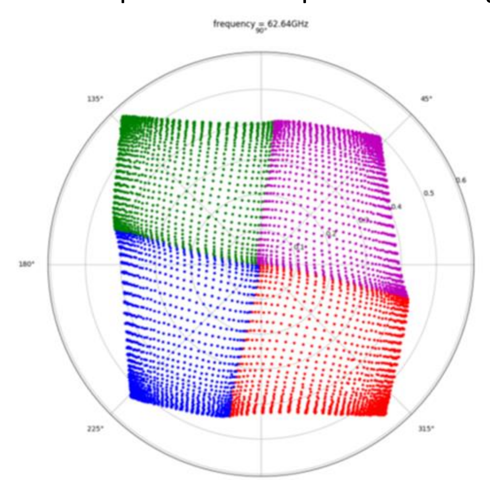


Operations of vector generation and amplification are split





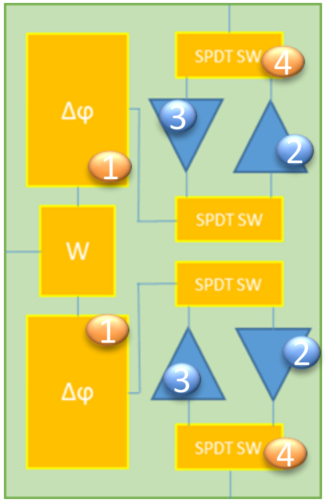
Measured phase and amplitude coverage



IMS' 2017

1

MmW Access Point: satellite phase shifter

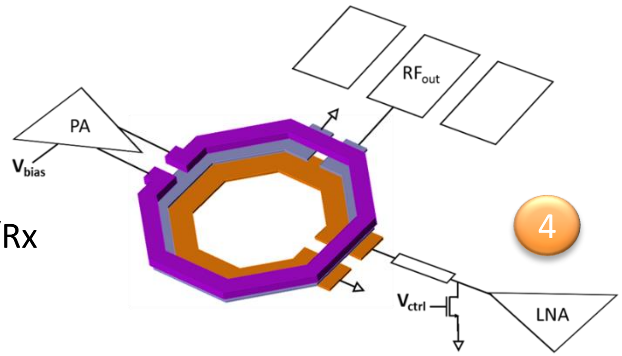


KET: Tx/Rx switch

Tx/Rx Balun and matching network

Extinction of Vbias/Vctrl to switch between Tx/Rx

<2dB loss; BW >12GHz; >15dBm ICP1dB



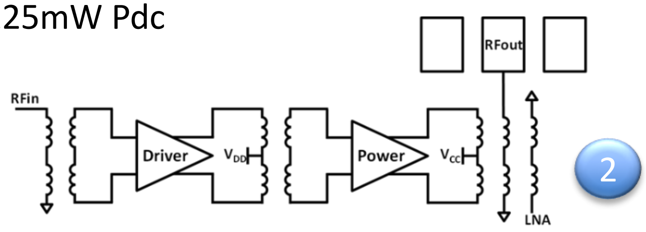
KET: Efficient Power Amplifier

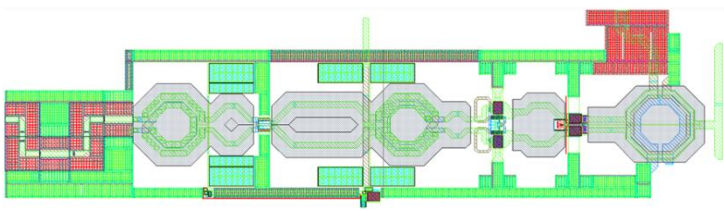
2 stages

Bipolar transistors in deep class AB

>30 dB gain, 15dBm OCP1dB

125mW Pdc



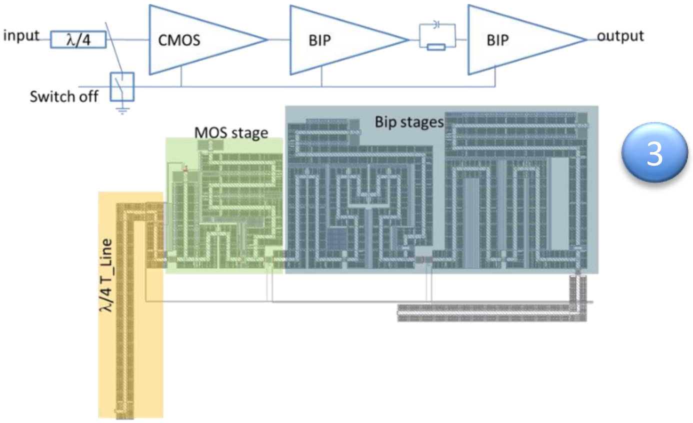


3 stages Low Noise Amplifier

1st stage CMOS Common Source

2nd and 3rd stage Bipolar Common Emitter

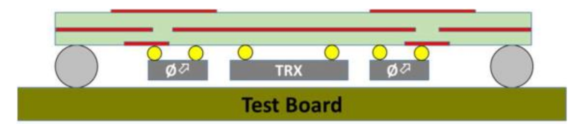
BW 15GHz; Gain 23 dB; NF 5.4dB

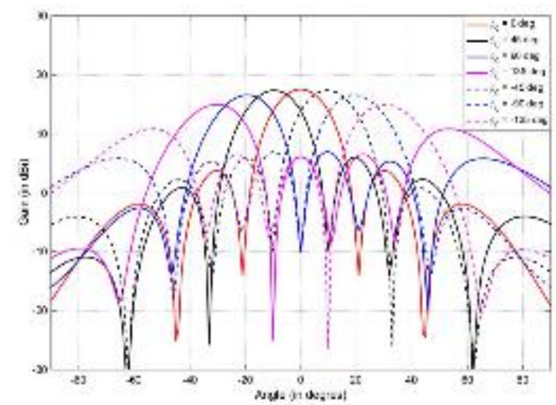


MmW Access Point: satellite phase shifter

Beamforming with satellite phase shifter

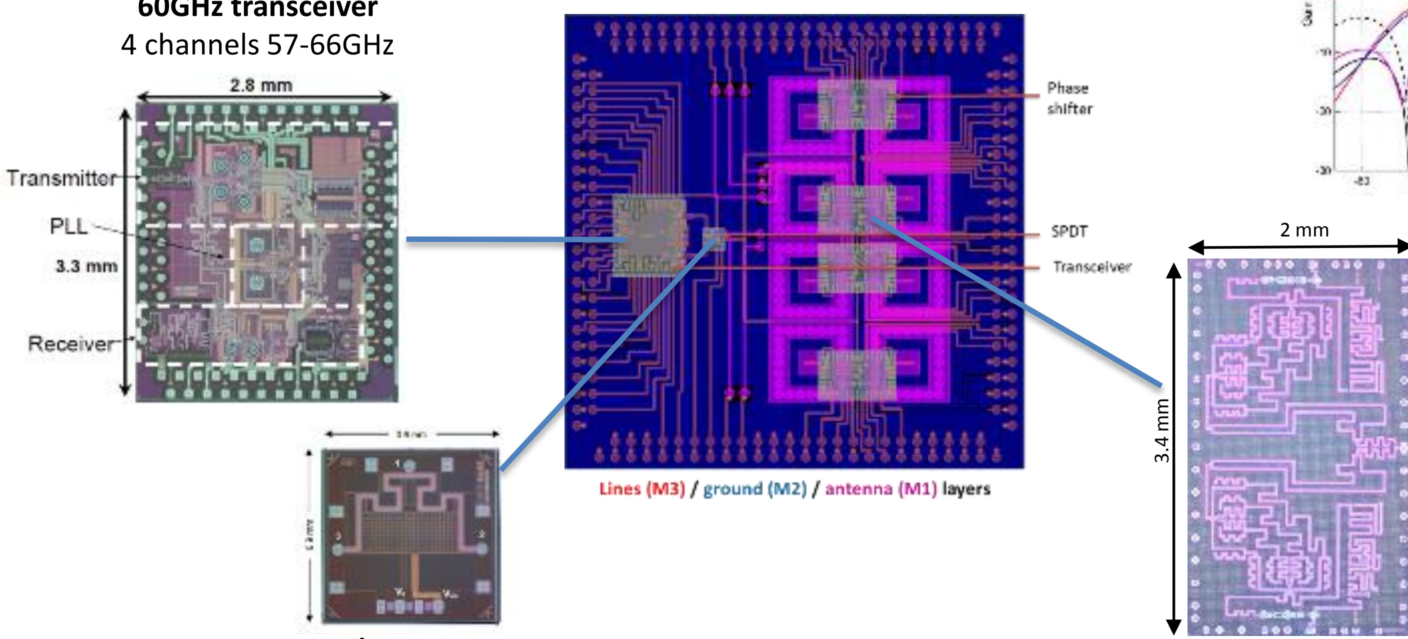
- 2*4 antenna array, 17dBi gain, 36dBm EIRP
- {PA, LNA, phase shifter} circuit in BICMOS55nm
  - Compensation of the power splitter and phase shifter losses
  - Vector modulator phase shifter
- 3D multi-layer organic module (LCP), 20*20mm²





LCP interposer module layout

60GHz transceiver
4 channels 57-66GHz



Lines (M3) / ground (M2) / antenna (M1) layers

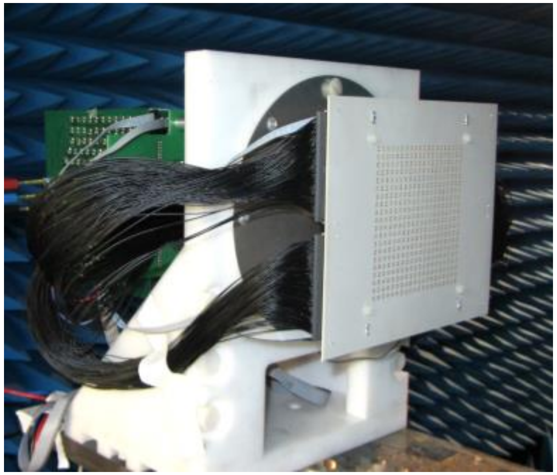
Tx/Rx switch

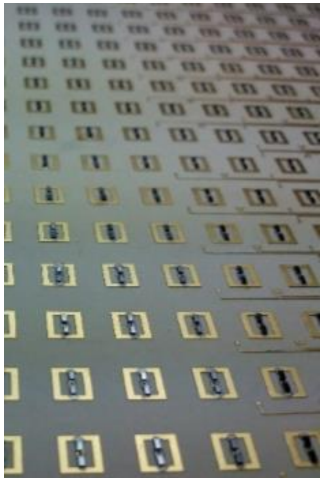
PA, LNA, phase shifter IC

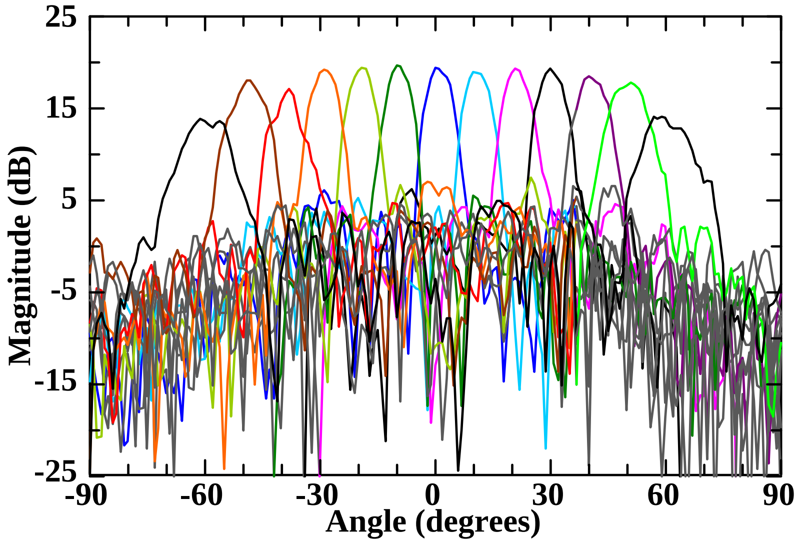
MmW Access Point: RF beam switching

Reconfigurable transmit array lens in Ka-band

- 1-bit electronically reconfigurable transmit array with 400 antenna elements
- 3-dB bandwidth: 15%; 3-dB Axial Ratio bandwidth: 18%
- Efficiency: 58%
- Beamsteering: ±60° in every azimuth plane (5-dB scan loss at 60°)







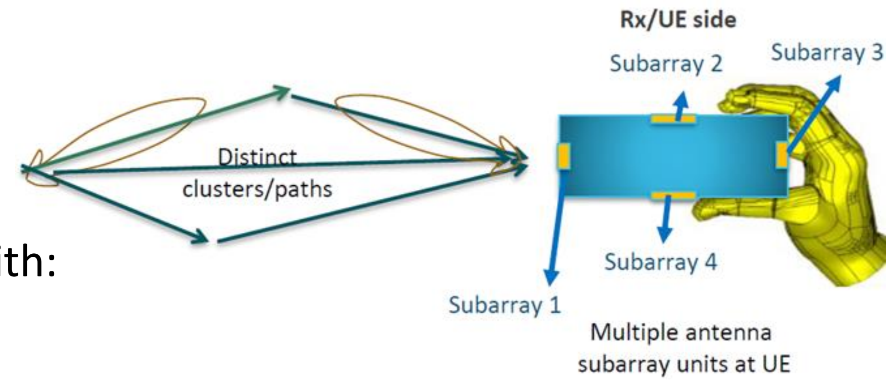
➔ Active components on the planar lens can leverage the complexity at the source level and lead to an overall system efficiency improvement.

Di Palma, TAP, 2017

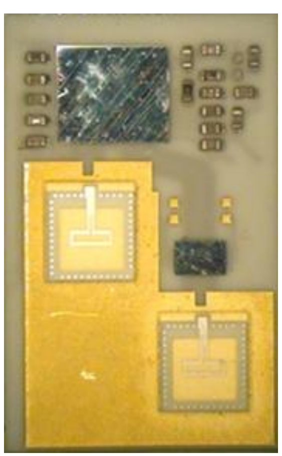
Integration of mmw RFIC in mobile

Challenges

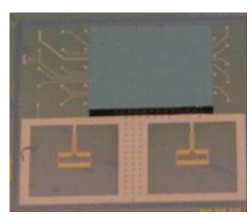
- High performance low cost CMOS
- Low power analog/digital ICs
- Low cost small form factor packaging with:
  - Minimum routing length
  - High radiation performance
  - Good thermal dissipation

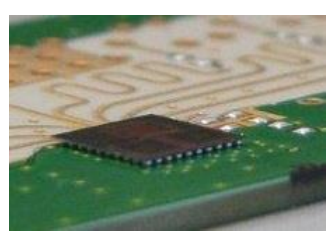


HTCC
13.5*8.5mm²

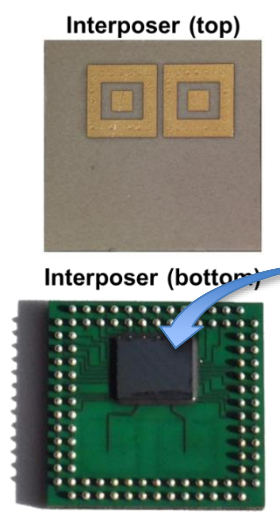


Si
6.5*6.5mm²

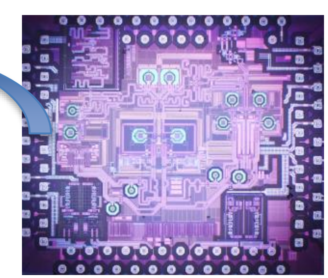




LCP 10*10mm²



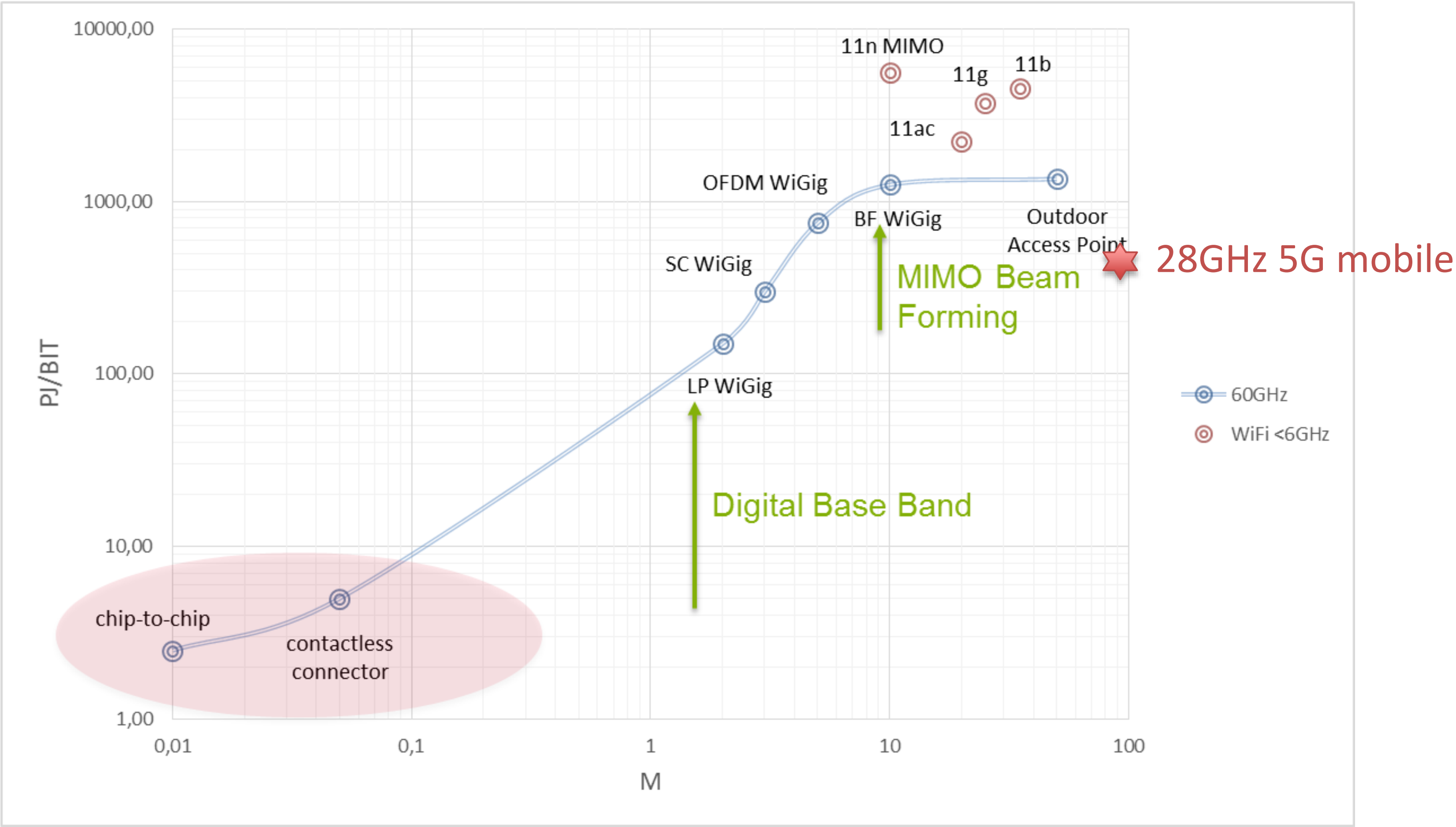
Mmw transceiver IC



Zigbee

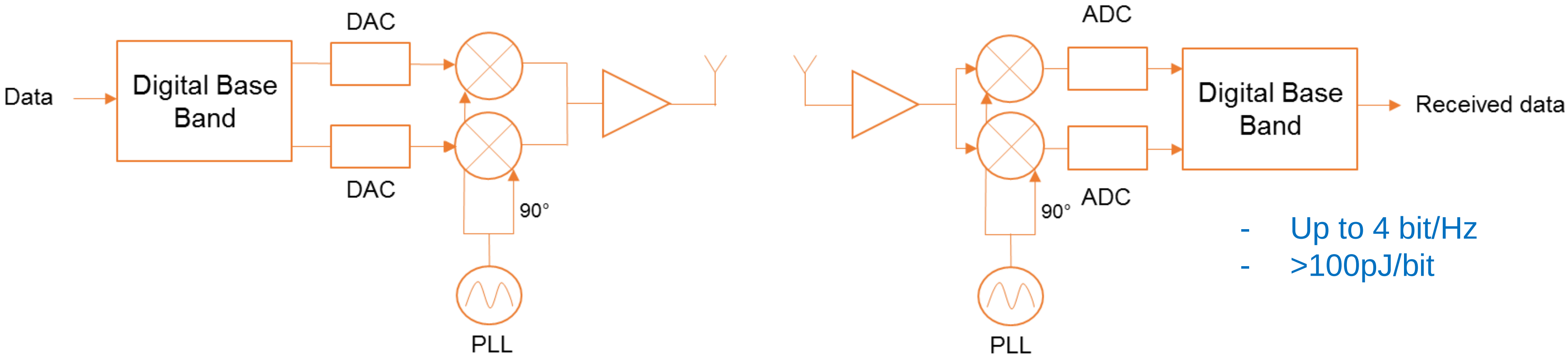
Bluetooth LE

- Is mmW low power ?



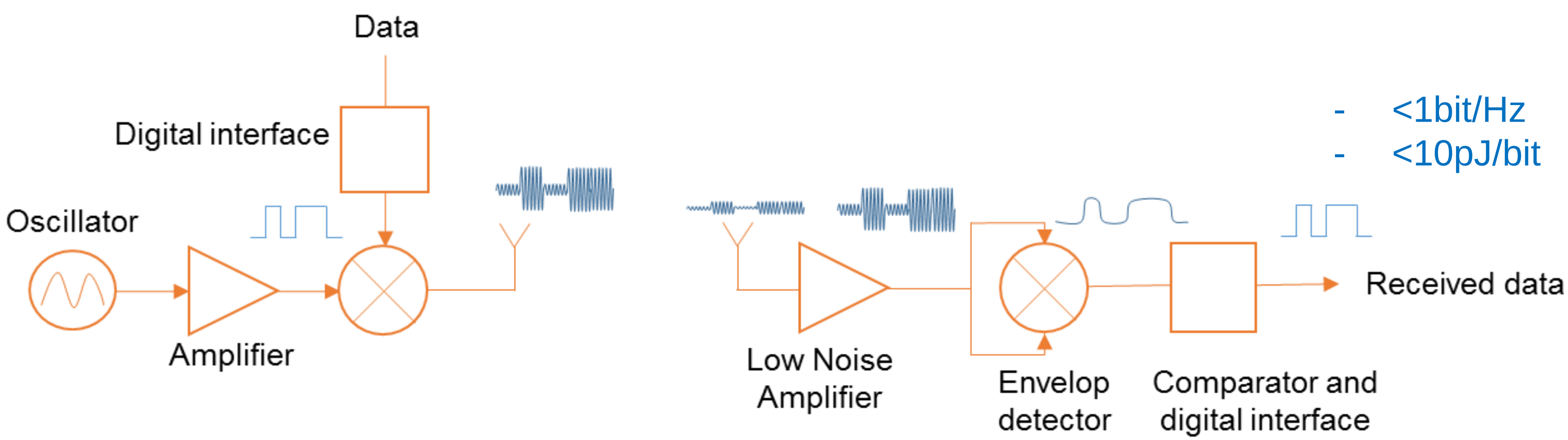
MmW Contactless connector

- Coherent architecture



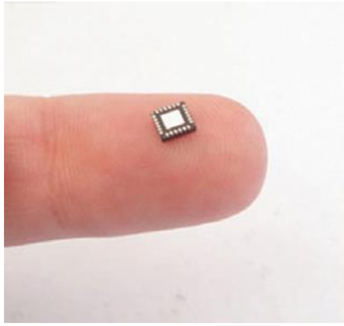
- Up to 4 bit/Hz
- >100pJ/bit

- Non coherent architecture (On/Off keying)

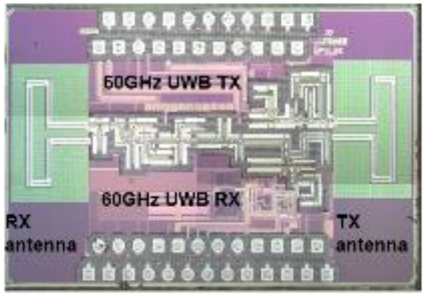


- <1bit/Hz
- <10pJ/bit

Contactless connector



1,9mm x 3,1mm



60GHz contactless connector (2016)

<u>Technology</u>:

- 60GHz OOK transceiver in CMOS SOI 65nm
- Integrated antennas

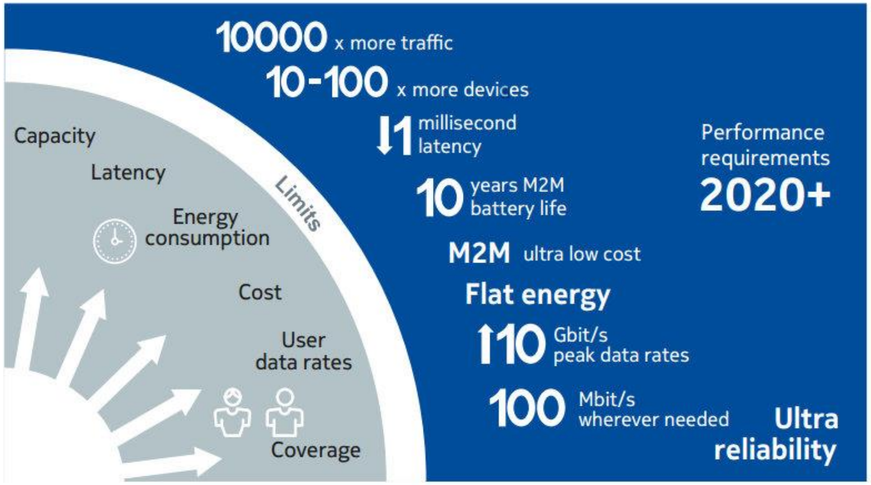
<u>Demonstrated performances</u>:

- HD Video streaming
- Data rate: up to 2.5Gbps
- Range: 10cm
- Power consumption: 50mW

Inductive Charging Docking Station **& data transfer**

Conclusions

- Not a clear 5G roadmap yet
- Mmw frequencies should take an important role by H2020
- Device-to-device short range communication to pave the way for mass-market
- Small cell backhauling race has already started
- MmW outdoor access point is the next hot topic
- New progress in SOI/CMOS/BICMOS technologies, antennas and packaging would reduce the cost of mmW
- Innovative approaches still needed to solve the major technical challenges



3GPP Roadmap