FROM RESEARCH TO INDUSTRY

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Towards the integration of millimeter wave access points and backhauls in 2020 5G heterogeneous networks: stakes, challenges, and key enabling technologies

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Data traffic trends in cellular networks

- Mobile data traffic increased by 70% in 2012
- Driven by smartphones and tablets (189 to 342MB/month/user) with 81% annual growth rate
- Smartphone penetration rate is 18% in 2012, 30% in 2013, expected to reach 92% in 2017
- Total mobile traffic > 6 exabytes (6×10^18) per month in 2017

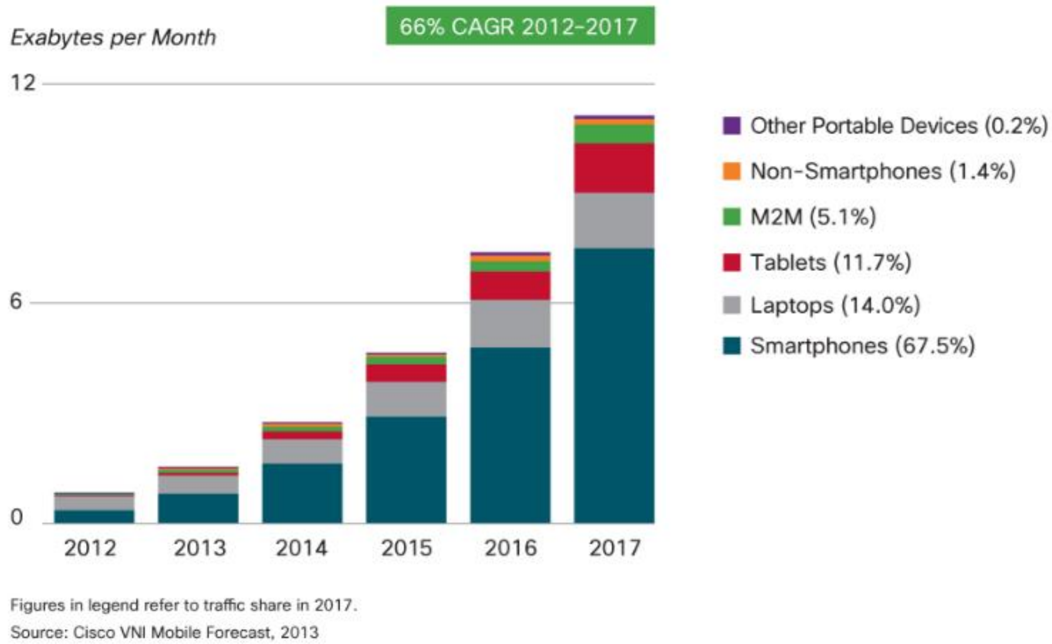
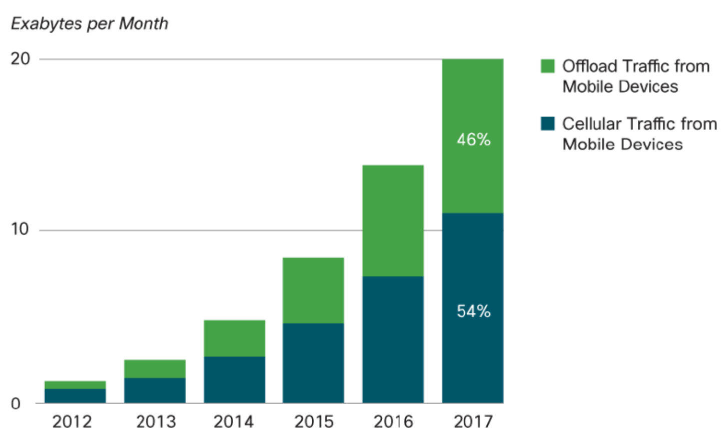


Figure 1: Global mobile data growth (in exabytes per month) function of devices

Data traffic trends in cellular networks

- LTE should absorb 45% of the traffic by 2017. Thus, the mobile network connection speed should increase 7 times, to reach 4Mbps in average per user
- However with 81% growth rate in data traffic, LTE network could be saturated in only 4 years
- One possible solution:
  - deployment of Wi-Fi access points and femtocells in dense urban area to offload a great part of the mobile data traffic
  - Indeed the percentage of offloaded mobile data traffic is forecasted to raise 46% in 2017.



Source: Cisco VNI Mobile Forecast, 2013

Figure 1: 46% of total mobile data traffic will be offloaded in 2017

Data traffic trends in cellular networks

Issues regarding traffic offloading to wireless access points:

- Routing of the huge data traffic from the wireless network to the fiber backbone with low latency
- The multiplication of fiber connections in urban area requires tricky and costly excavations
  - → Wireless backhaul
- Transfer of market shares from cellular operators to internet access providers. Pricing. Modification of the economic model
- Non centralized data resource management: weak spectrum efficiency, coexistence issues
- Electromagnetic field (EMF) exposure. Population concerns
- Scarcity of the spectrum resources between 2 and 6GHz
- Cost of dense network of small cells
  - ~20000 cells for covering Paris area

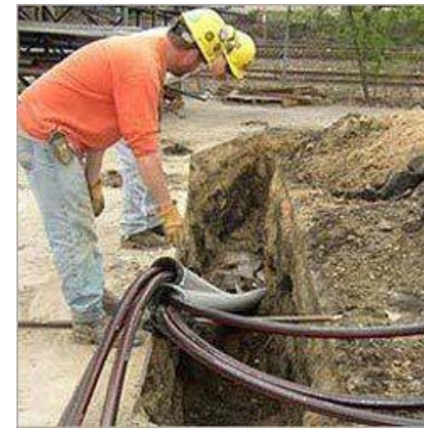
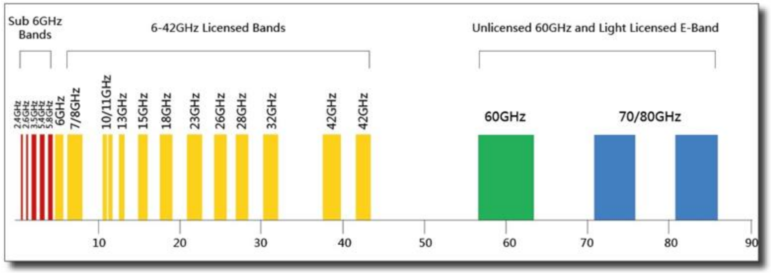


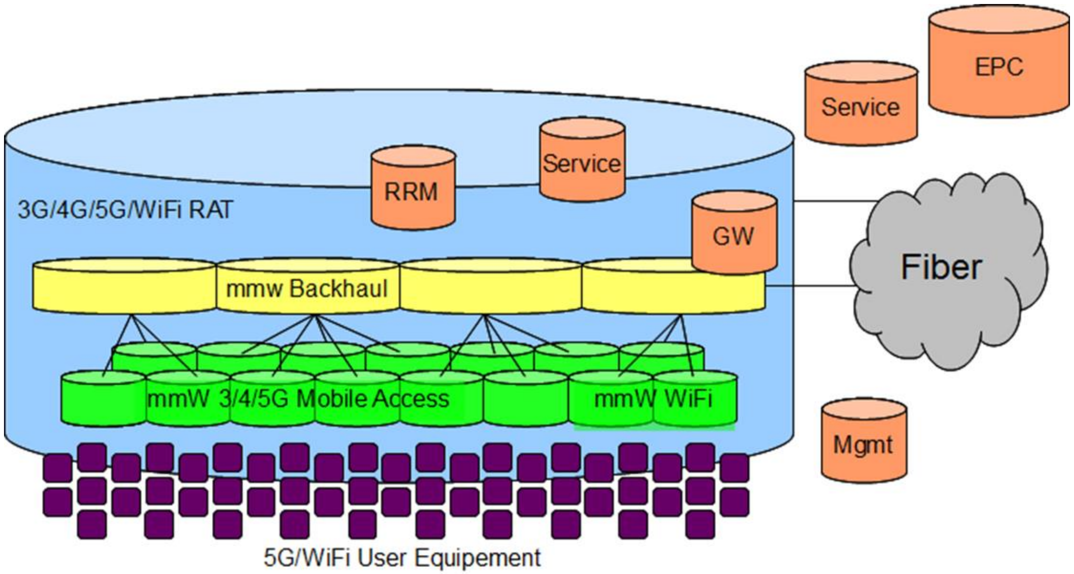
Figure 2: Ceragon's E-Band Solution

Proposition of heterogeneous network for 5G

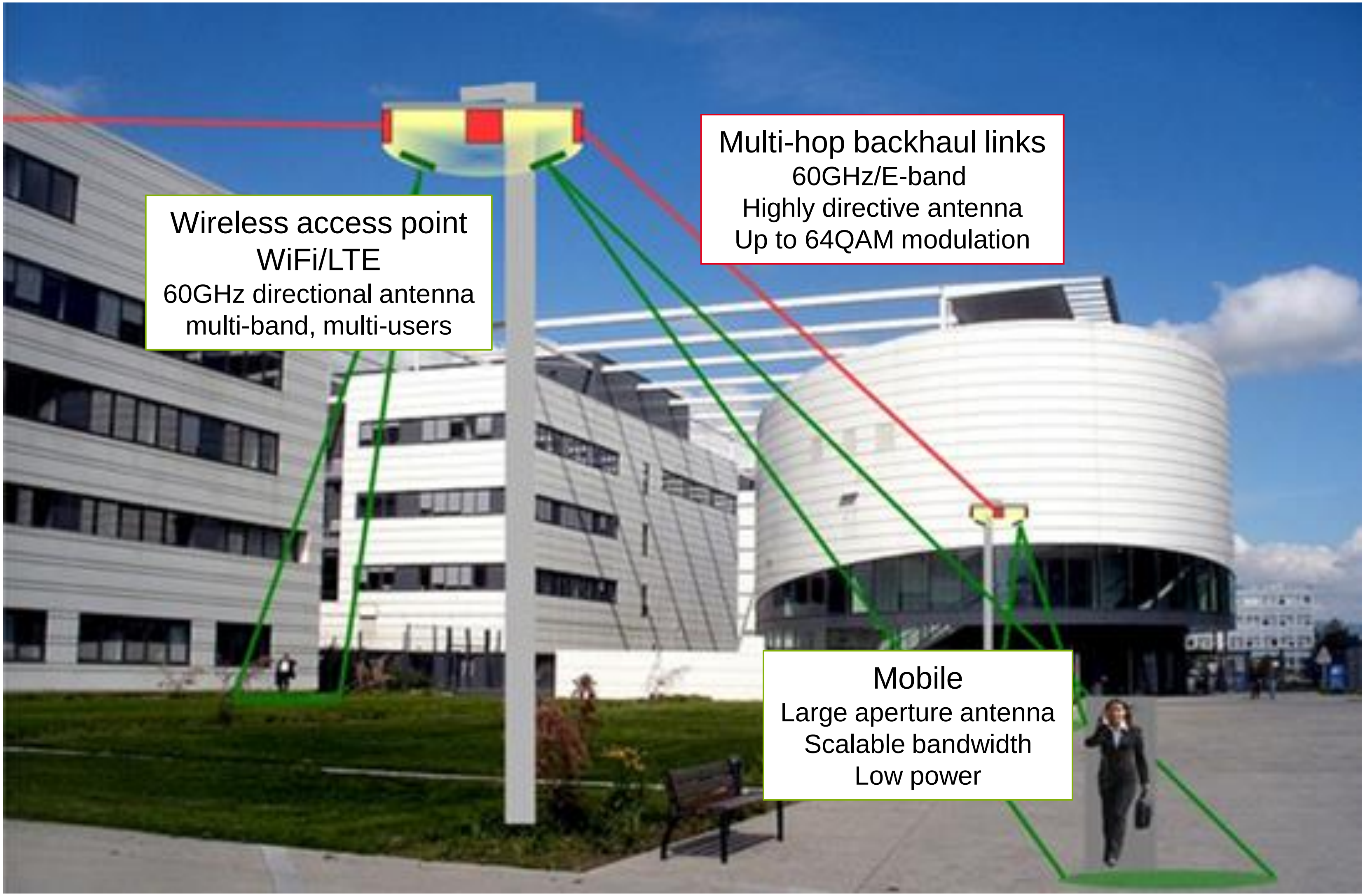
- Mmw access point and backhauling
  - Huge available bandwidth
  - High frequency reuse
  - Natural immunity to interference
  - Low EMF (<1mW/cm²)



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



5G Heterogeneous network with mmw small cells



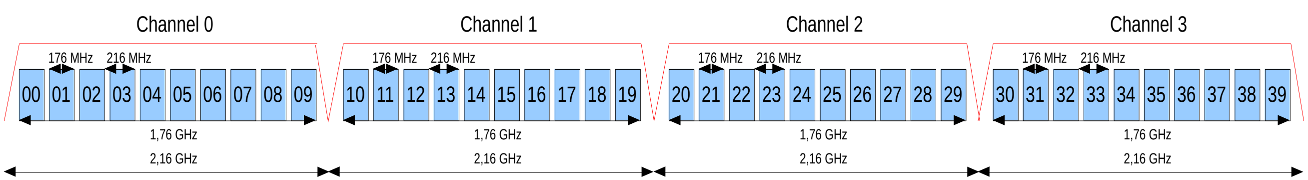
Low cost backhaul link

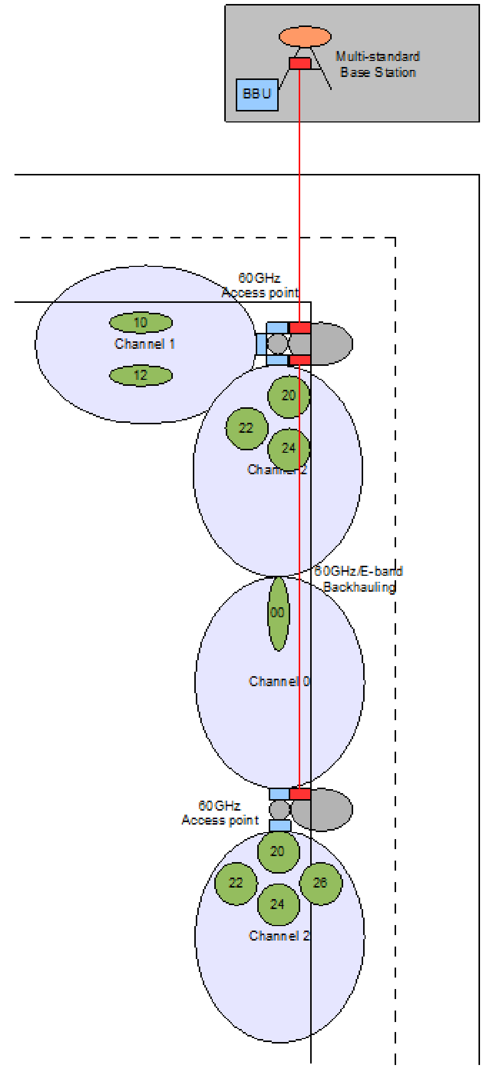
	16QAM	64QAM
Emitter		
Bandwidth (GHz)	1,76	1,76
P1dB at PA output (dBm)	15,00	18,00
PA output back off (dB)	5,00	8,00
Mean power at PA output (dBm)	10,00	10,00
PA-antenna interconnexion loss (dB)	2,00	2,00
Emitted mean power (dBm)	8,00	8,00
Antenna gain (dB)	32,00	32,00
EIRP (dBm)	40,00	40,00
Channel		
Distance (m)	170,00	100,00
Carrier frequency (Ghz)	64,80	64,80
Oxygen and rain attenuation (dB)	5,44	3,20
Path loss (dB)	-118,72	-111,87
Receiver		
Antenna gain (dBi)	32,00	32,00
LNA-antenna interconnexion loss (dB	2,00	2,00
Power at LNA input (dBm)	-48,72	-41,87
Signal to Noise Ratio		
Thermal noise (dBm)	-81,52	-81,52
Implementation loss (dB)	3,00	5,00
Noise factor (dB)	8,00	8,00
SNR at ADC input (dB)	21,80	26,65
Signal processing		
Required SNR for BER=1e-5 (dB)	16,00	21,00
Margin (dB)	5,80	5,65
Raw Data rate (Mbps)	5280	7920

- 60GHz versus E-band
  - 60GHz
    - 4*1,76GHz free bandwidth
    - Oxygen attenuation
    - EIRP 40dBm max
    - TDMA
    - 15% bandwidth
  - 71-76 and 81-86GHz
    - Aggregated 250MHz licensed bandwidth
    - EIRP 55dBm max
    - FDMA, full duplex (high isolation duplexer)
    - 19% bandwidth
- Budget link 8Gbps/channel@100m
  - 15 to 18dBm OCP1dB -> BICMOS PA
  - 32dBi antenna -> 100cm² planar antenna array

Access point to user terminal link

- Assumptions for mobile terminal:
  - No extra transceiver for connectivity -> use 802.11ad 60GHz transceiver
  - Low form factor antenna -> gain reduced to 5dBi
  - Low DC power consumption -> optimized transceiver and package (loss), reduction of bandwidth and data rate





- Assumptions for 60GHz access point:
  - Low cost CMOS/BICMOS technologies
  - Address multiple users in a cell by TDMA, FDMA or SDMA
  - High directivity antenna with beamforming capabilities, simultaneous multiple beams for spatial division access

Access point to user terminal link

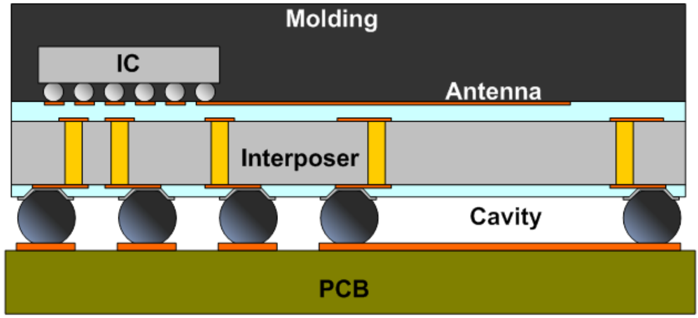
UPLINK	QPSK	BPSK
Emitter		
Bandwidth (GHz)	0,22	0,22
P1dB at PA output (dBm)	12	10
PA output back off (dB)	2	0
Mean power at PA output (dBm)	10	10
PA-antenna interconnexion loss (dB)	2	2
Emitted mean power (dBm)	8,00	8,00
Antenna gain (dB)	5	5
EIRP (dBm)	13,00	13,00
Channel		
Distance (m)	20	50
Attenuation coefficient	2	2
Carrier frequency (Ghz)	64,8	64,8
Oxygen and rain attenuation (dB)	0,64	1,60
Path loss (dB)	-94,69	-102,65
Receiver		
Antenna gain (dBi)	18	18
LNA-antenna interconnexion loss (dB)	3	3
Power at LNA input (dBm)	-66,69	-74,65
Signal to Noise Ratio		
Thermal noise (dBm)	-90,56	-90,56
Implementation loss (dB)	2	1
Noise factor (dB)	8	8
SNR at ADC input (dB)	13,86	6,90
Signal processing		
Required SNR for BER=1e-5 (dB)	12	8,5
Margin (dB)	1,86	-1,60
Data rate (Mbps)	330	165

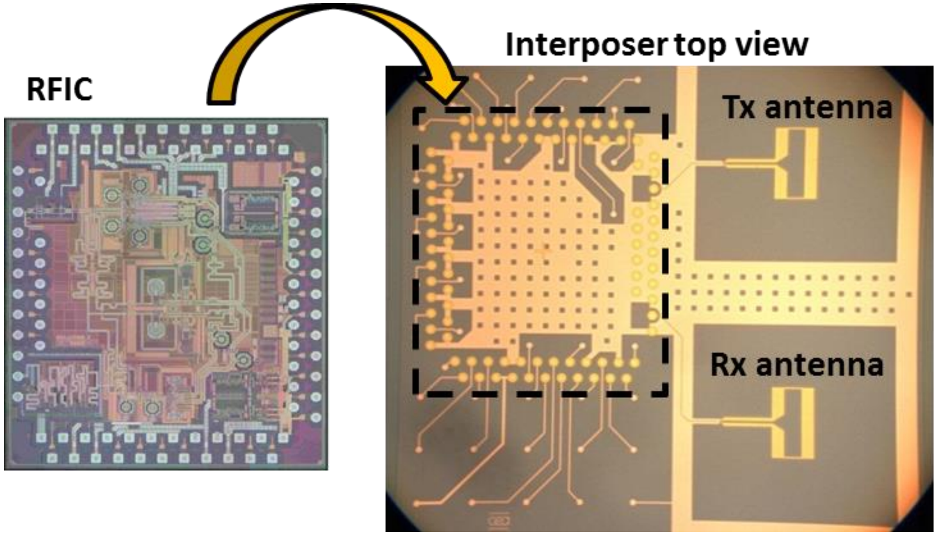
DOWNLINK	16QAM	16QAM	QPSK
Emitter			
Bandwidth (GHz)	0,44	0,22	0,22
P1dB at PA output (dBm)	15	15	14
PA output back off (dB)	5	5	4
Mean power at PA output (dBm)	10	10	10
PA-antenna interconnexion loss (dB)	3	3	3
Emitted mean power (dBm)	20,80	20,80	20,80
Antenna gain (dB)	22	22	22
EIRP (dBm)	42,80	42,80	42,80
Channel			
Distance (m)	20	30	50
Attenuation coefficient	2	2	2
Carrier frequency (Ghz)	64,8	64,8	64,8
Oxygen and rain attenuation (dB)	0,64	0,96	1,60
Path loss (dB)	-94,69	-98,22	-102,65
Receiver			
Antenna gain (dBi)	5	5	5
LNA-antenna interconnexion loss (dB)	2	2	2
Power at LNA input (dBm)	-48,89	-52,41	-56,85
Signal to Noise Ratio			
Thermal noise (dBm)	-87,55	-90,56	-90,56
Implementation loss (dB)	3	3	2
Noise factor (dB)	8	8	8
SNR at ADC input (dB)	27,65	27,14	23,71
Signal processing			
Required SNR for BER=1e-5 (dB)	15	15	12
Margin (dB)	12,65	12,14	11,71
Data rate (Mbps)	1173,33	586,67	330,00

Key enabling technology: SiP interposer for mobile terminal

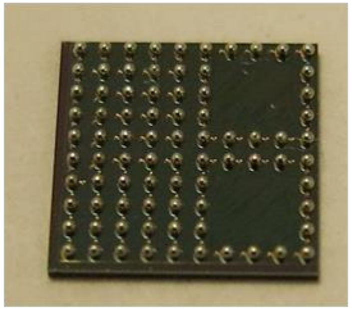
Example: 6,5*6,5mm² module with mmw transceiver and antennas

- 120 µm HR-Si interposer
- 2-metal layer back-end: antennas, interconnects
- TSV for shielding and vertical interconnects
- T/R RFIC flip-chipped on the interposer
- BGA connection of the interposer on the PCB
- Polymer molding

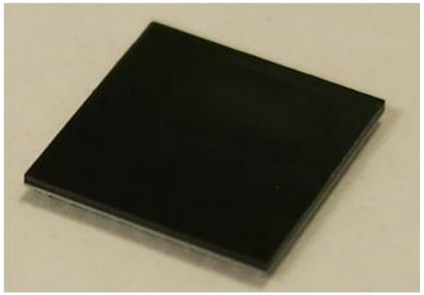




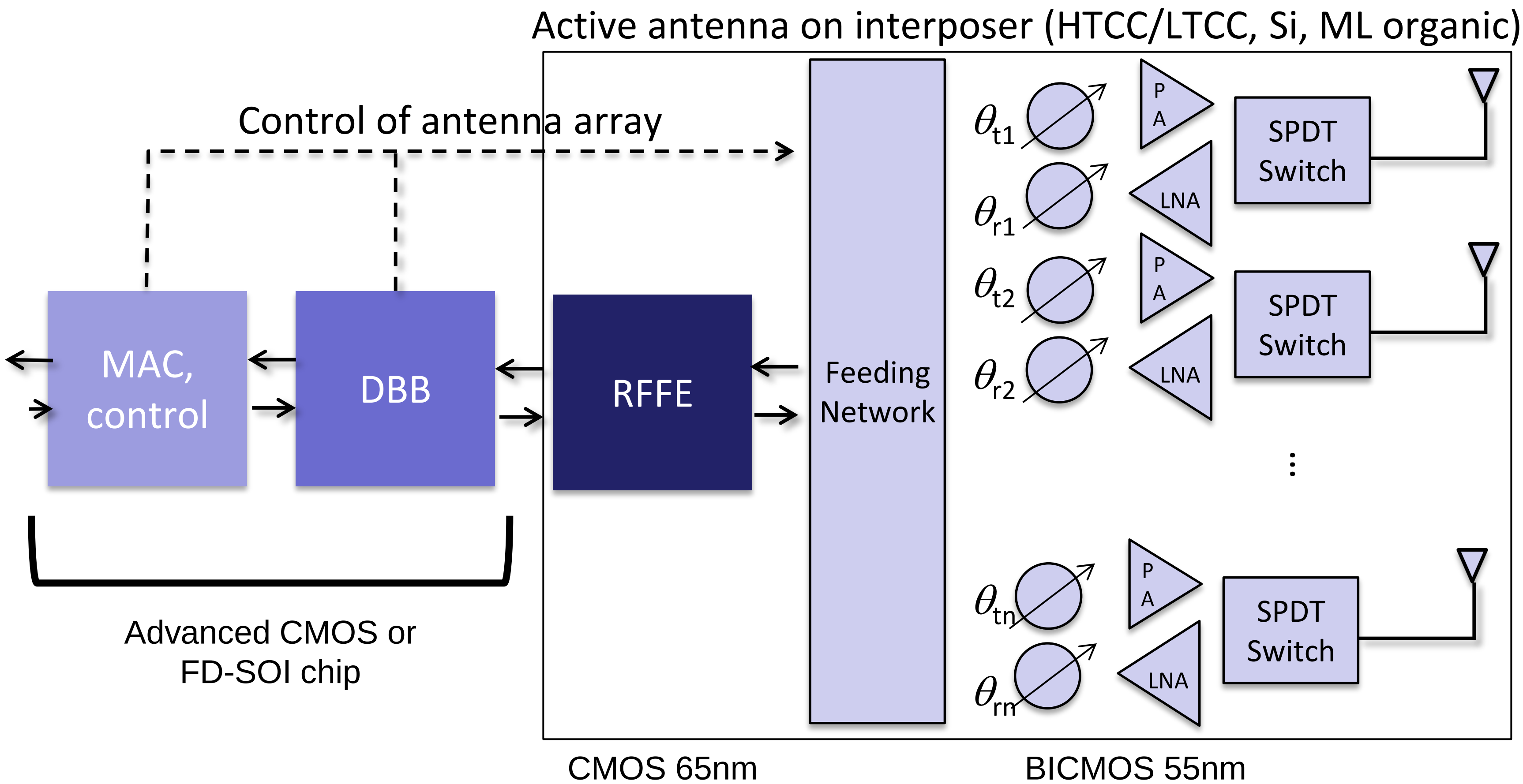
Balled interposer

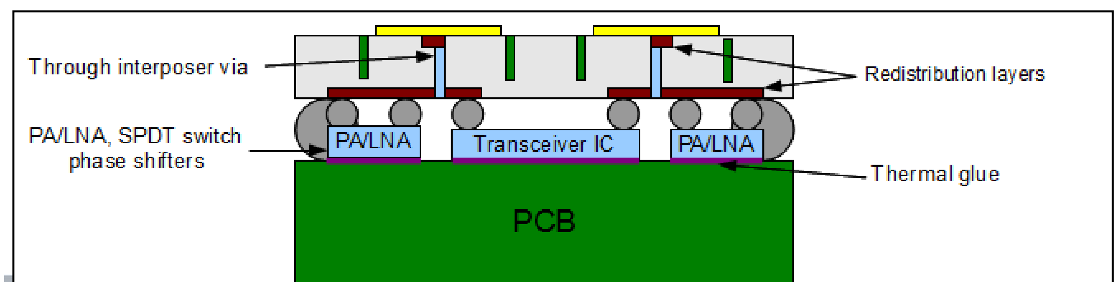


Molded interposer



Key enabling technology: antenna array module

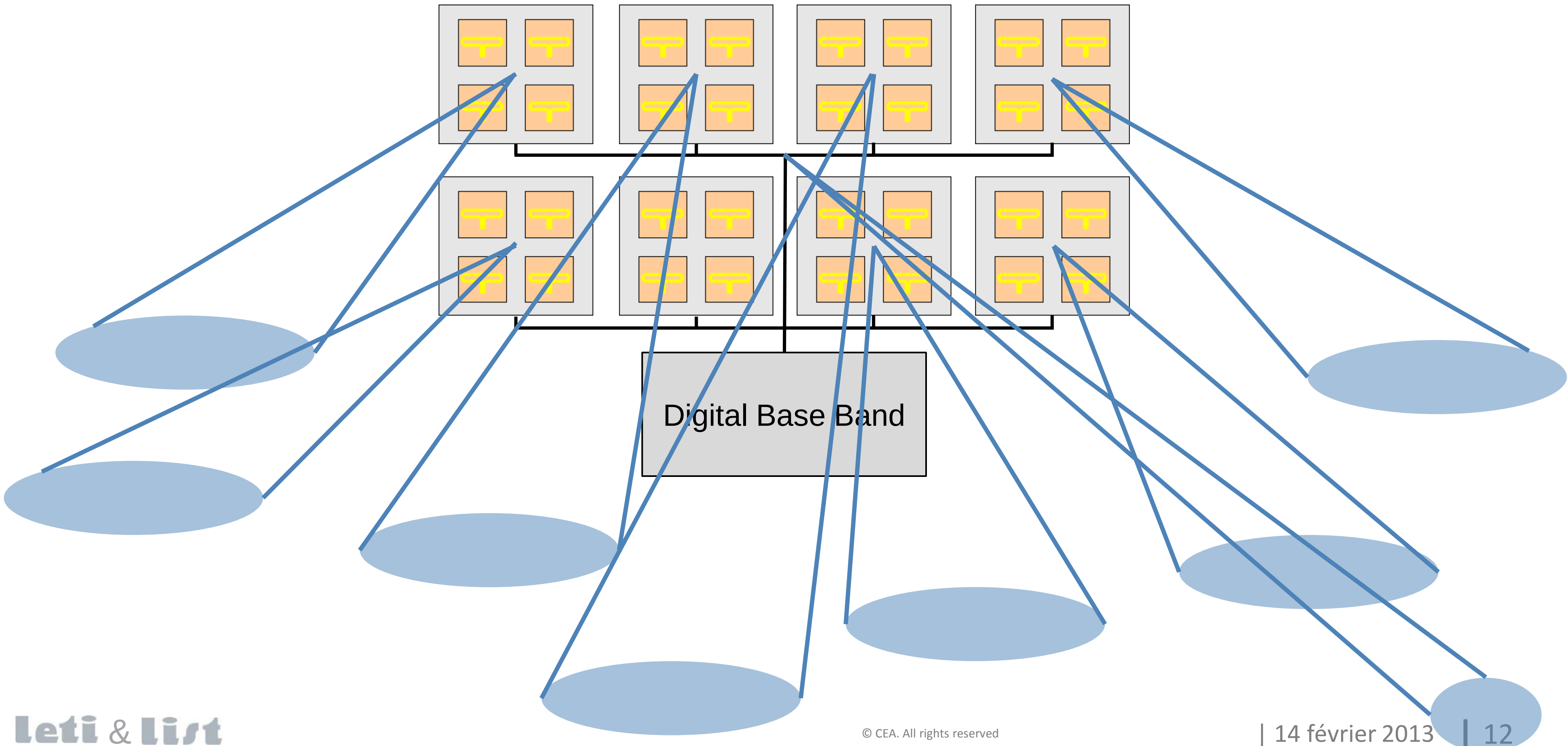




Key enabling technology: synchronized modules for access point

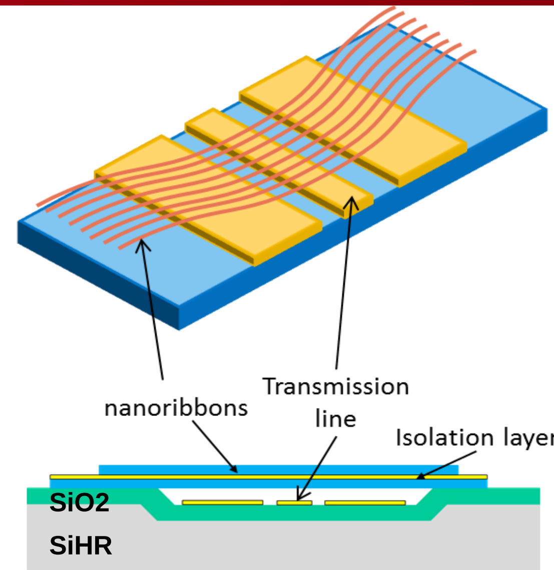
Matrix of modules for multi-user access point

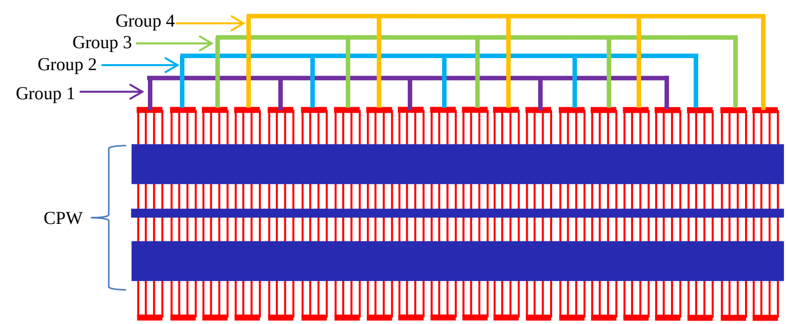
- Simultaneous multiple beams to address multiple users in the cell
- Synchronization of modules to increase range/data rate towards a user

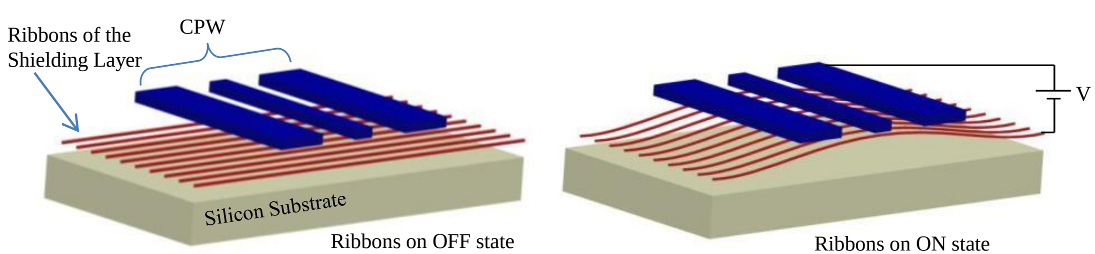


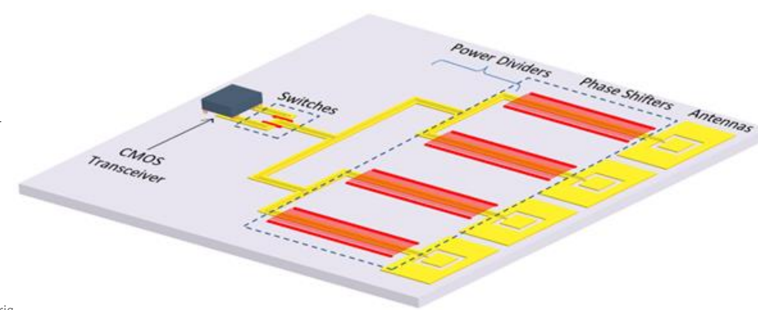
Key enabling technology: slow wave phase shifters

- CNRS IMEP/LAHC
- SiN/Au/SiN nanoribbons (MEMS)
- Coplanar waveguide transmission lines
- The actuation of the nonoribbons creates a slow wave effect within the transmission line inducing a delay in the transmited signal
- Nonoribbons digitally controlled par group for rough/fine phase shift granularity
- Phase shifts obtained with very low insertion loss (<2dB/360°)
- MEMS fabrication process
- Slow wave phase shifters for low loss, low consumption antenna arrays



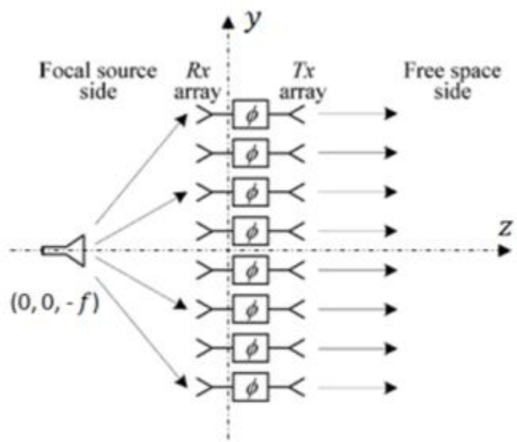


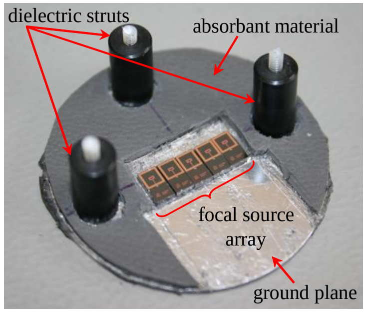


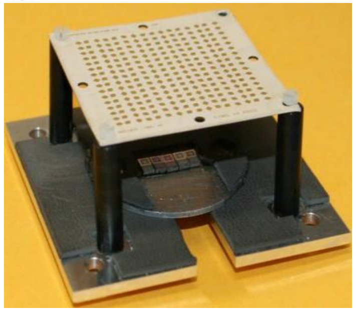


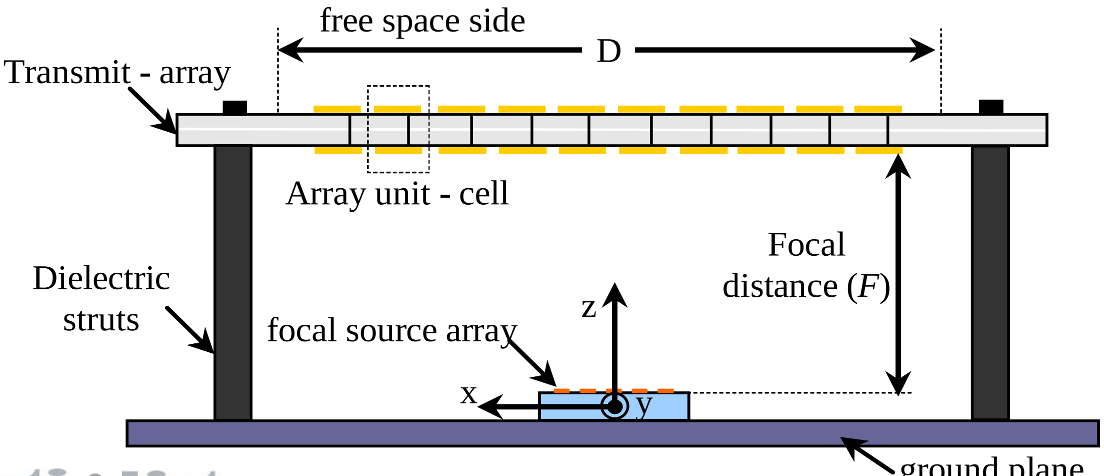
Key enabling technology: transmit array antenna

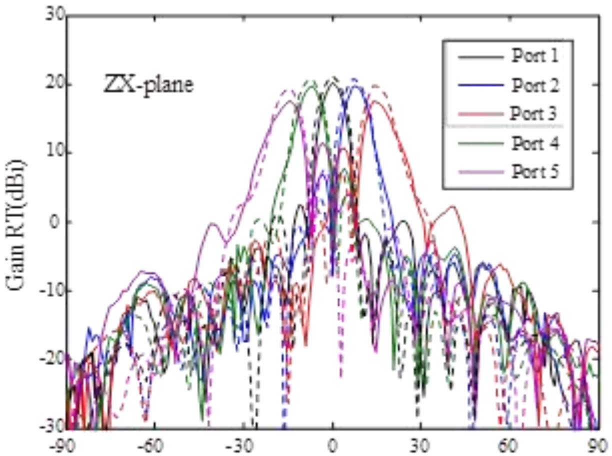
- Discrete lens for backhauling
- Composed on patch antenna arrays on the two sides of a low cost PCB
- Compensation of geometrical phase shifts within the PCB
- Commutation of source for beam switch over +/-20°
- 20-35dBi gain function of lens area









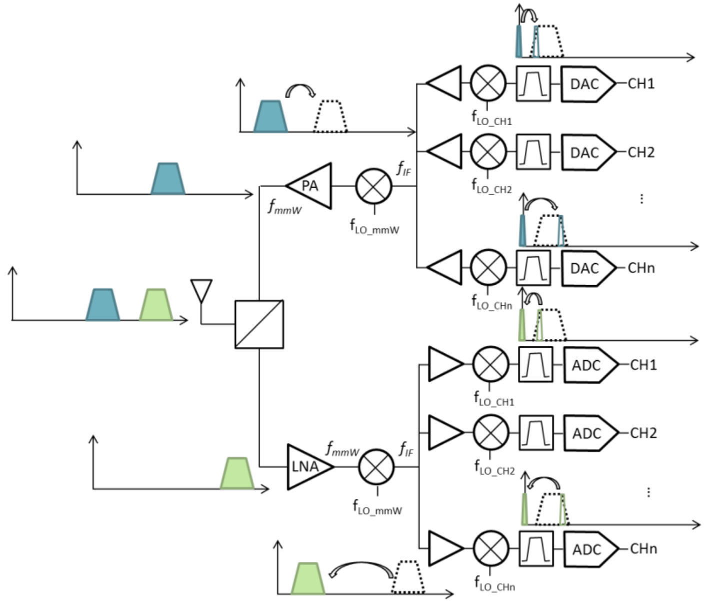


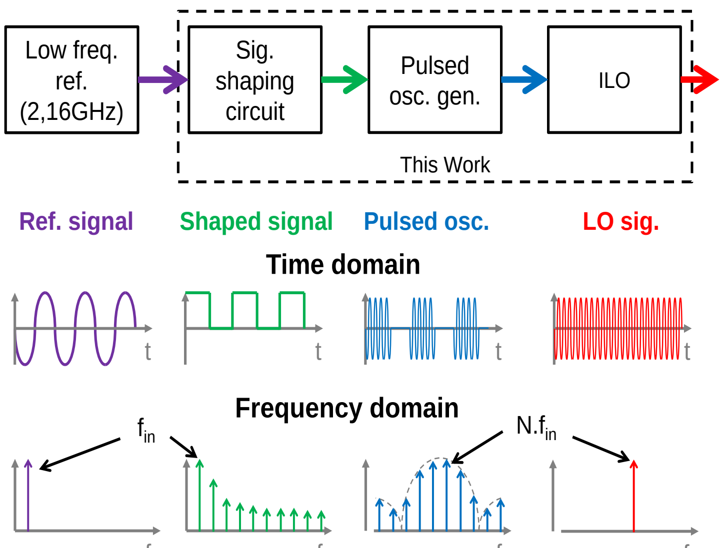
Key enabling technology : multi tones frequency synthesis

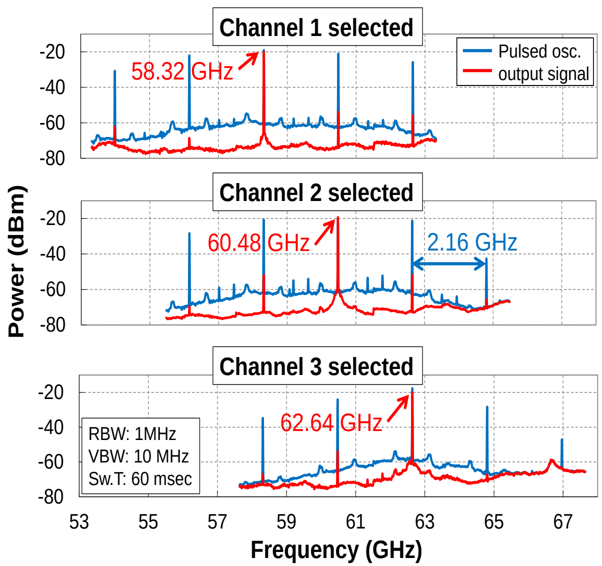
- Backhaul transceiver requires the aggregation of multiple channels simultaneously

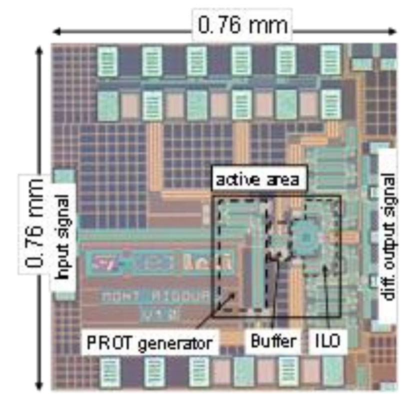
  -> Multi tones frequency synthesis

- 60GHz programmable LO generator based on a pulsed oscillator combined with an injection locked oscillation
  - Low DC consumption (20mW)
  - Low phase noise









Conclusion

- Mmw frequencies should take an important role in 2020 5G networks
  - Dedicated working group within 5GPPP, lead by Samsung UK
  - Many European projects and industrial initiatives
- New advanced in CMOS/BICMOS technologies and in packaging would reduce the cost of mmw devices
- Innovative approaches still needed to solve the technical challenges

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EMF reduction

- Millimeter wave radio access for low EMF and interference
  - Low received power density PD (<0,1mW/cm² at 1cm range)
  - Low skin penetration depth (<2mm) compared with 4cm for 3G/4G
  - Weak superficial skin temp elevation
  - Oxygen absorption ease interference mitigation

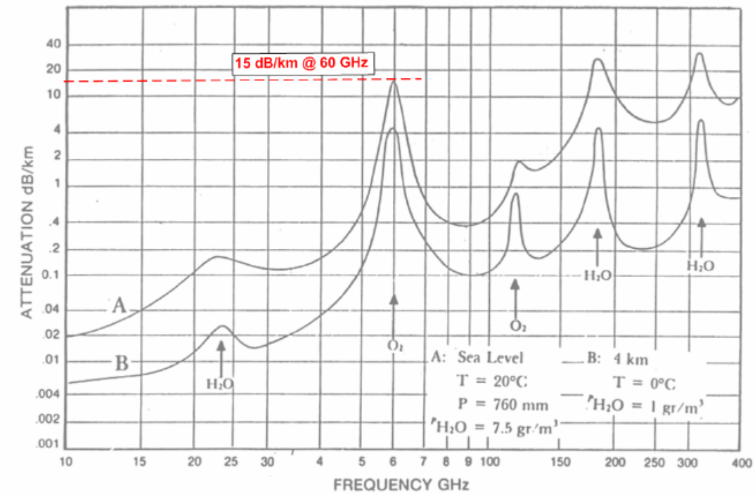
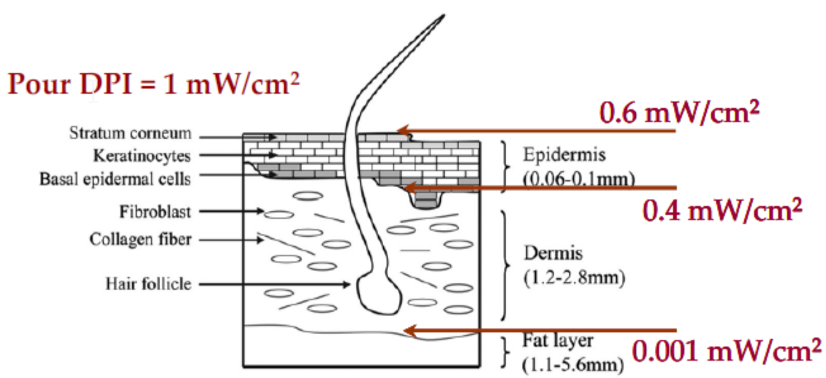


Figure 1: Gaseous Absorption at 60 GH



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