FROM RESEARCH TO INDUSTRY

cea tech

Mmw readout

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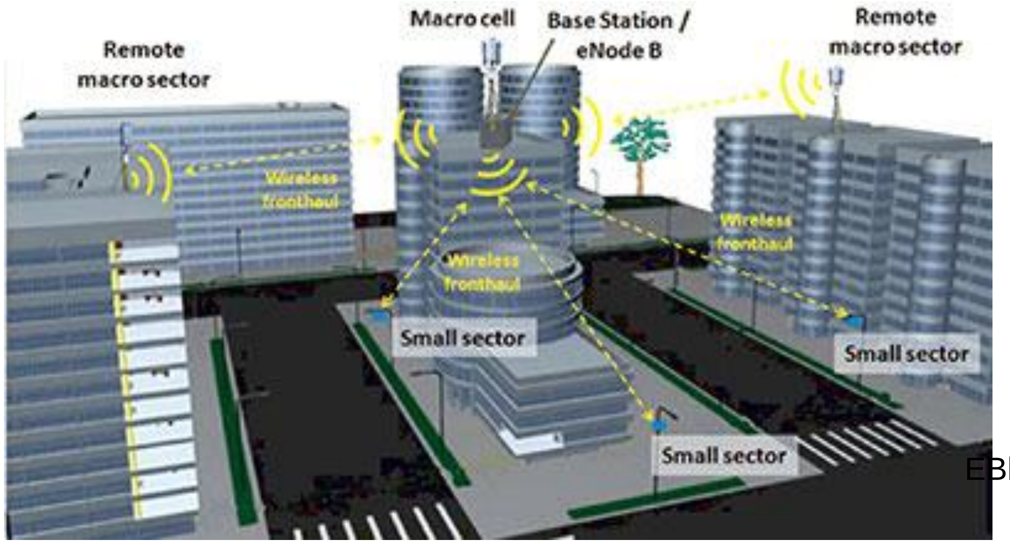
leti & list

Millimeter wave current key applications

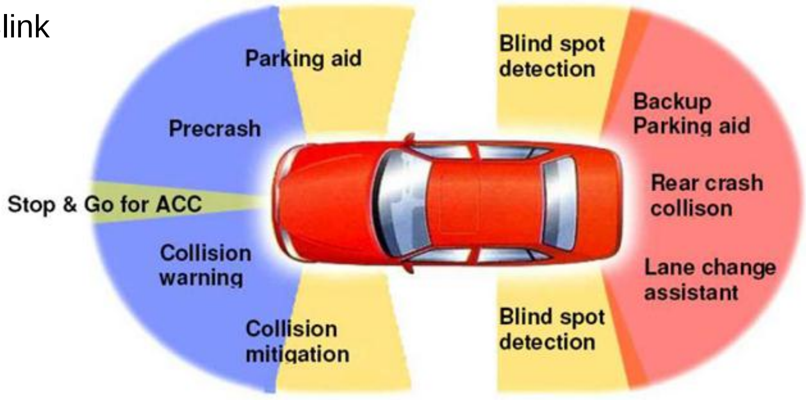
Wireless HD and WLAN 802.11ad (WiGig)



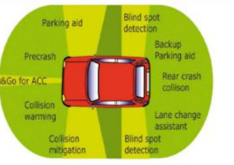
EBlink

Backhaul and fronthaul

24 and 79GHz Automotive Radar



Past realizations, spectrum positioning



SRR — 21,5-26,5GHz

WiHD
WIGIG/802.11ad
UWB impulse — 57-66GHz

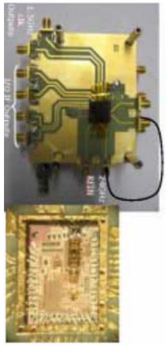
Backhaul — 71-76GHz

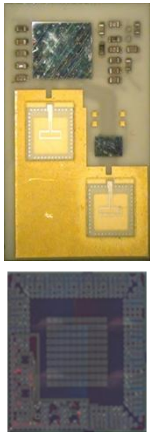
ACC

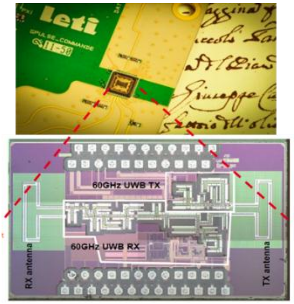
SRR — 77-81GHz

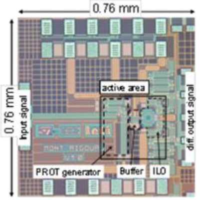
Backhaul — 81-86GHz

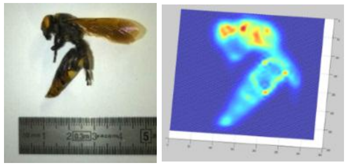
LRR — 94GHz

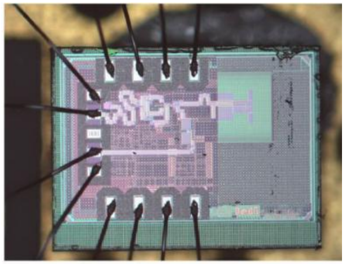












ISM — 122GHz

ISM — 240GHz

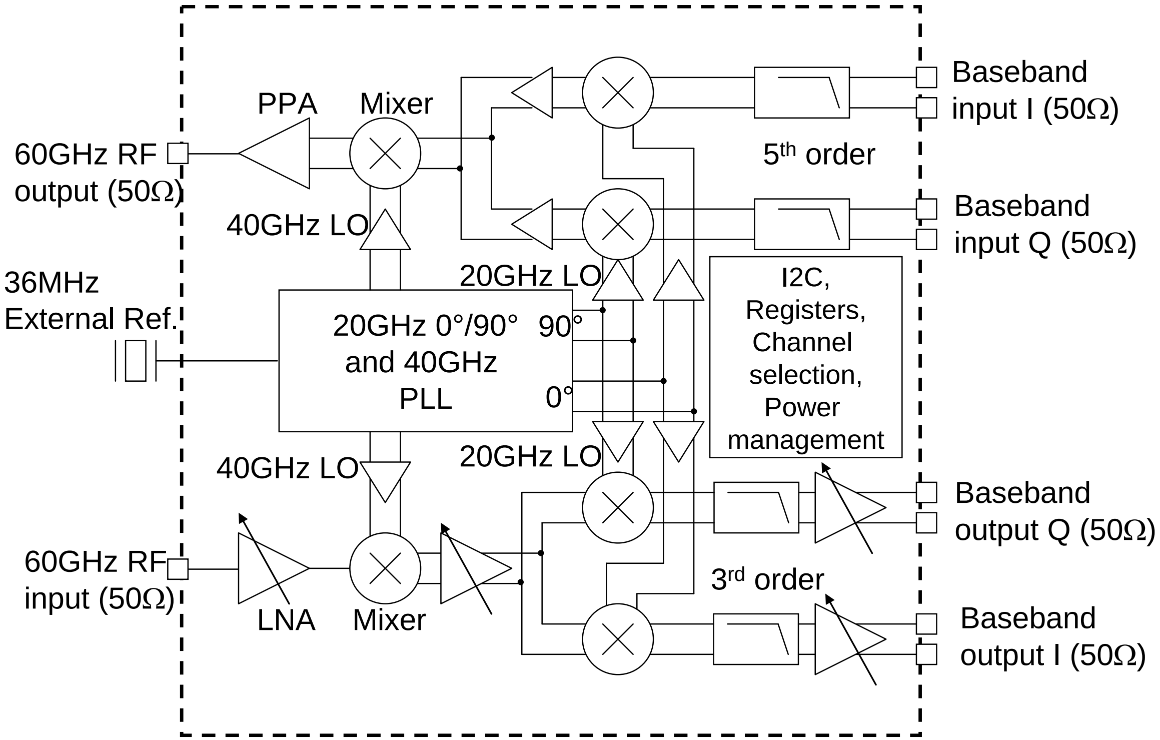
C2C
Sub THz
Imaging — 275-300GHz

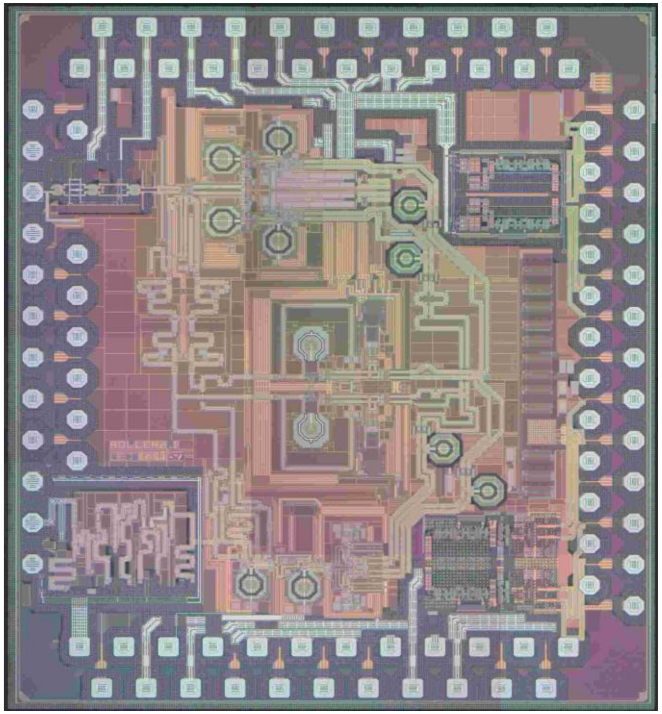
CEA Leti mmw portfolio

Chip	Standard	Range	Data rate	Power consumption	Maturity
Frequency domain 60GHz transceiver	802.11ad WiHD	0,5-2m	1-4Gbps	~400mW	prototype
Time domain 60GHz transceiver	No standard	5-20cm (2-5m with lens)	500Mbps-2Gbps	~70mW	prototype
E-band Backhaul	No standard	100-200m with lens	1-8Gbps	NA	Some IPs

60GHz frequency domain transceiver

- Sliding IF architecture
- Cover the 4 IEEE channels
- Compatible with WiHD/WiGig standards
- 3 ISSCC papers 2010 & 2011

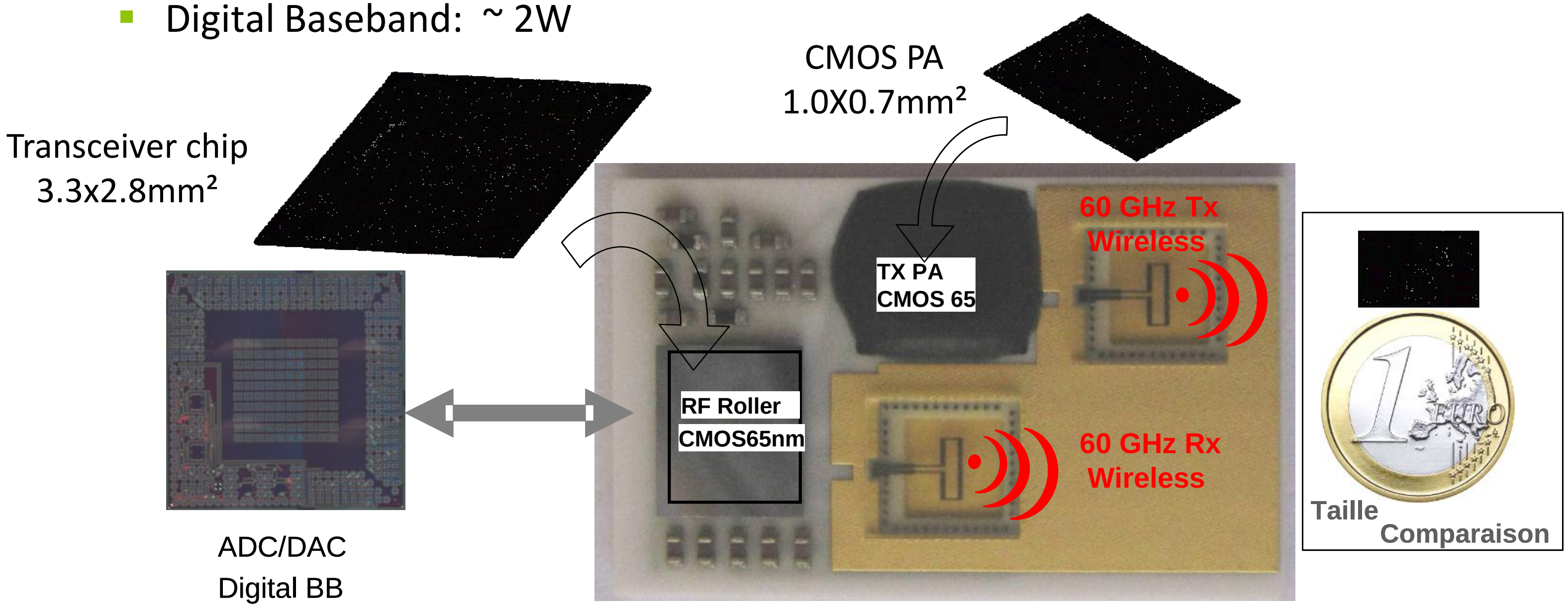




Frequency domain 60GHz SiP1

- 13.5*8.5mm² mmW RFFE module on industrial HTCC
  - Covers the 4 IEEE channels between 57 and 66GHz
  - 3.8Gbps OFDM 16QAM, 3 meters
  - Single IPD glass antenna
  - CMOS 65nm chips :
    - Front-end RF: TX: 357mW - RX: 454mW
    - PA CMOS: 0.7W
    - Digital Baseband: ~ 2W

2 ISSCC '10
ISSCC '11
JSSC '12
EuCAP '10

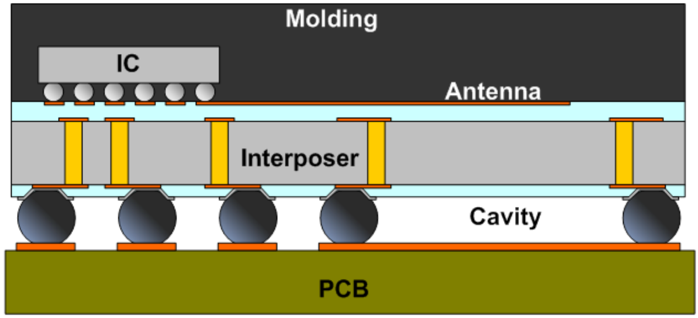


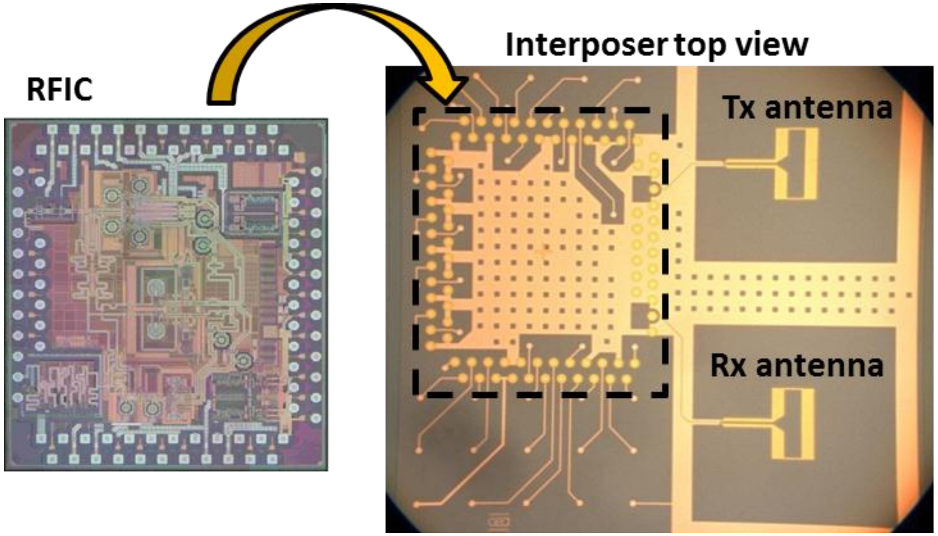
Frequency domain 60GHz SiP2

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

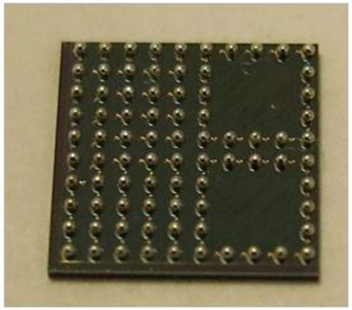
- 3.8Gbps OFDM 16QAM, 1 meter
- 120 µm HR-Si interposer
- 2-metal layer back-end: antennas, interconnects
- TSV for shielding and vertical interconnects
- T/R RFIC flip-chipped on the interposer
- BGA connection of the interposer on the PCB
- Polymer molding

ECTC'13
MTT'12
3DIC'13

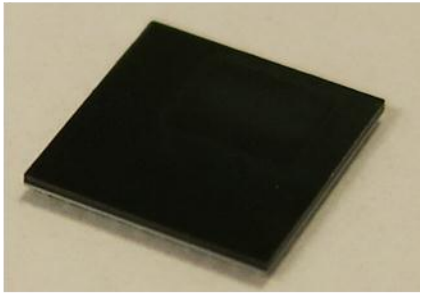




Balled interposer



Molded interposer

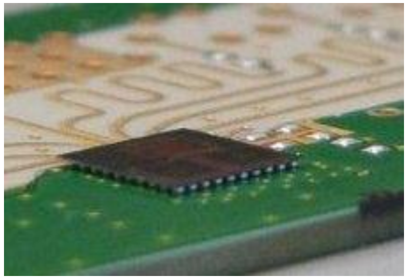


Frequency domain 60GHz demo

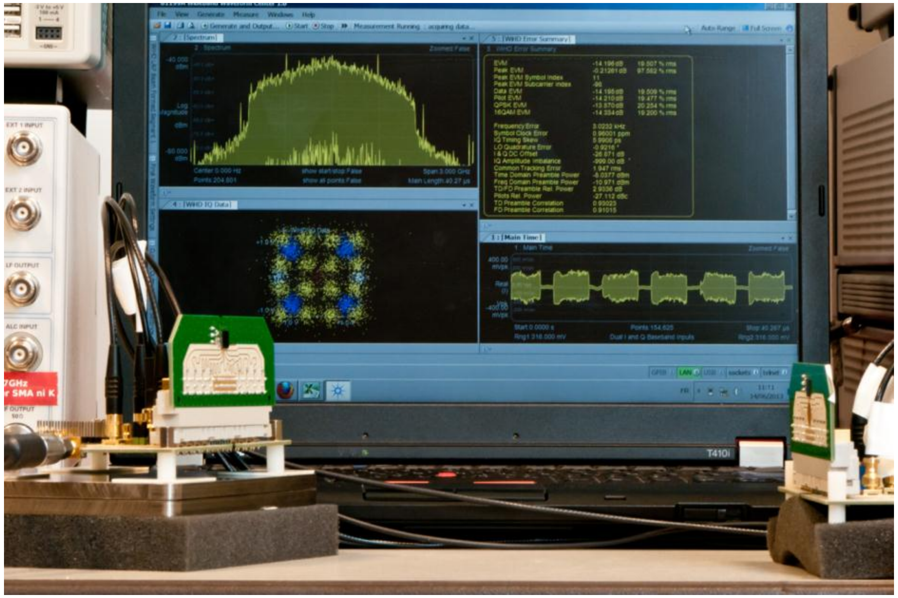
Data transmission tests

- Transmission of Wireless HD data frames at 4Gbps (OFDM 16QAM) over 80 cm, 2Gbps over 2m
- The system operates over the 4 IEEE channels between 57 and 66 GHz
- Low interconnection losses (~1dB)
- Good heat dissipation in the interposer substrate (max 42°C)

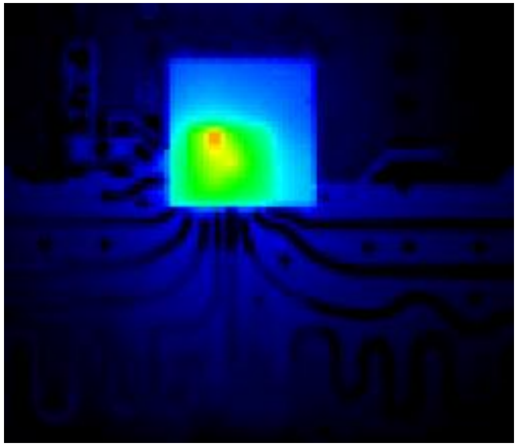
Interposer on PCB



Experimental test bed



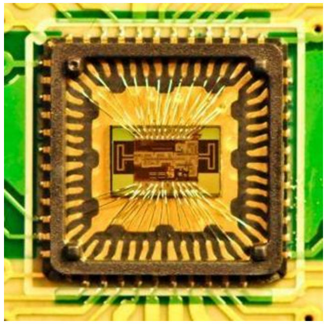
Thermal image of the interposer



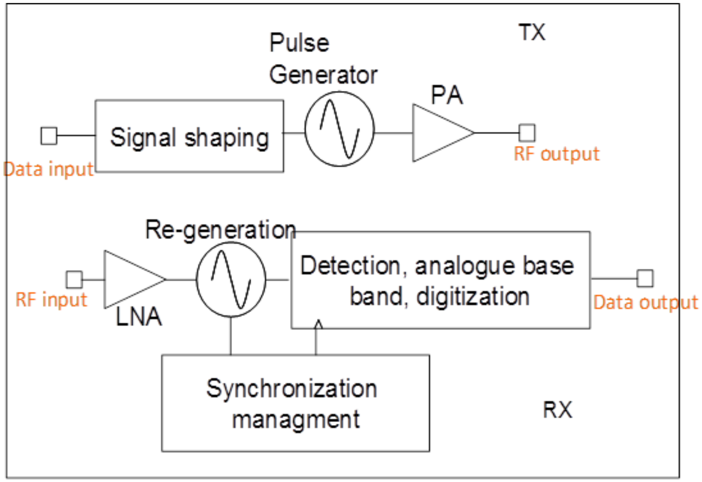
Time Domain 60GHz transceiver

IR UWB at 60GHz will offer new uses cases for device to device communication

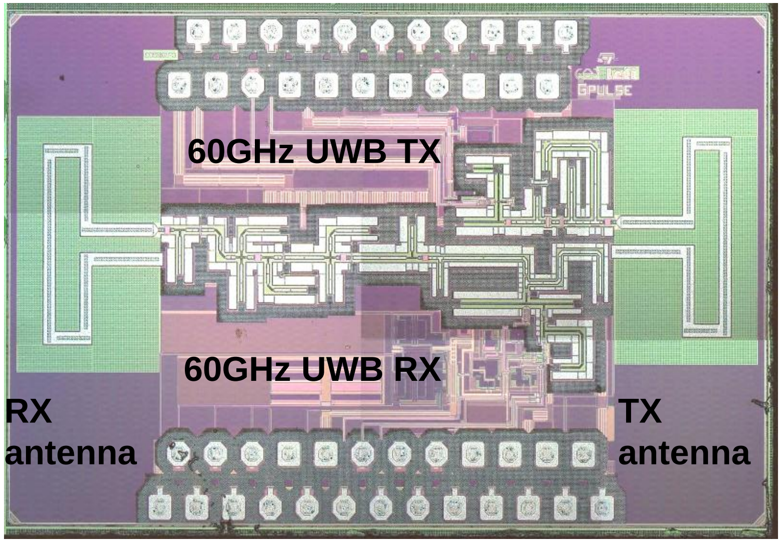
- 100mW @ 2.5Gbps (RFFE +DBB): TX 30mW, RX 70mW
- Range 0.2m meter with single antenna
- Scalable data rate from 100Mbps to 2.5Gbps
- Integrated 4dBi 60GHz antenna (thanks to SOI 65nm HR process)
- Very low cost (standard QFN package)



JSSC '10
SIRF '11
ESSIRC '09
RFIC '09
RFIC'13



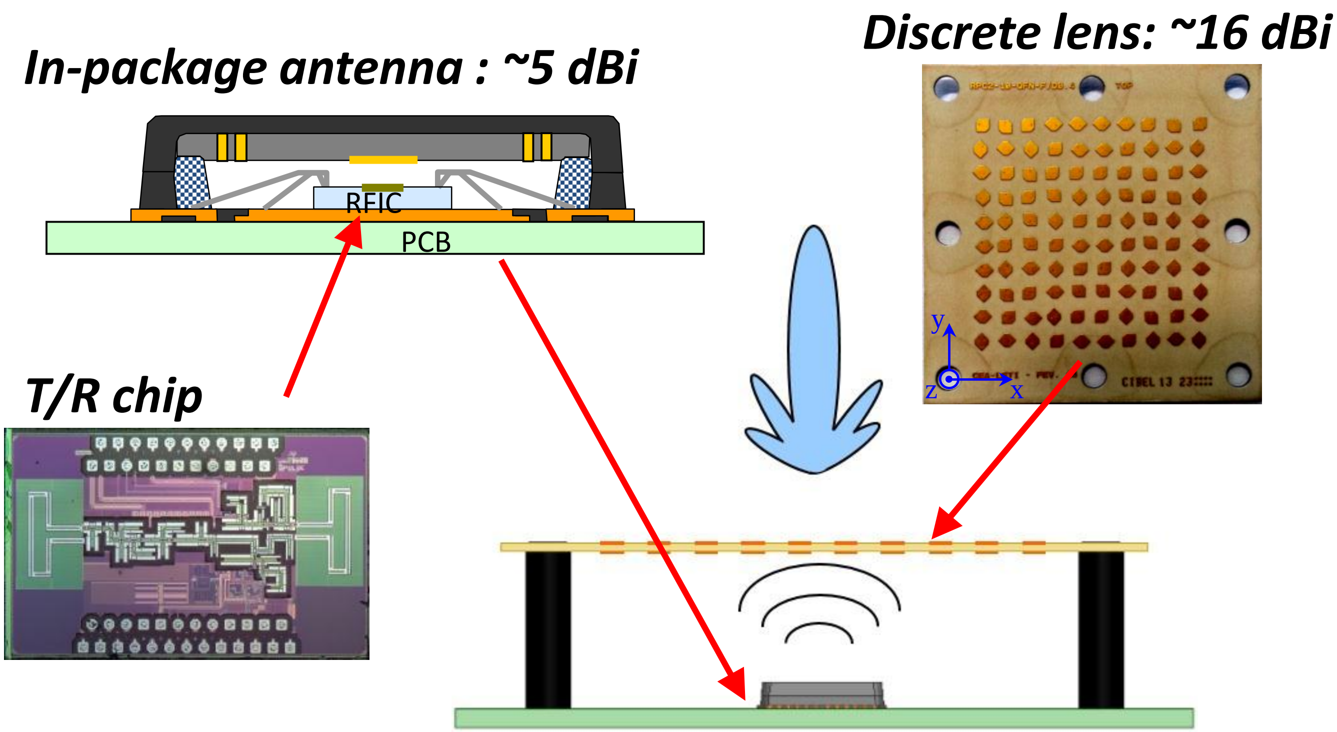
1,9mm x 3,1mm



Time Domain 60GHz transceiver

In-Package coupled antenna and focusing lens:

- No mmW interconnection; +15 dB antenna gain improvement
- Chip size: 2x3.3 mm^2; package 7x7 mm^2; lens 25x25 mm^2

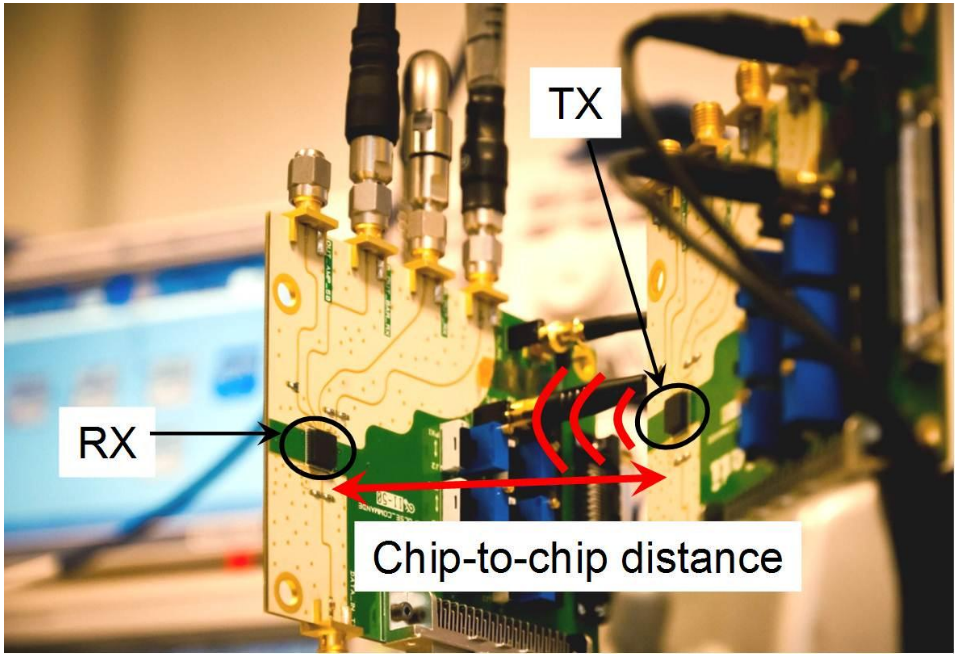


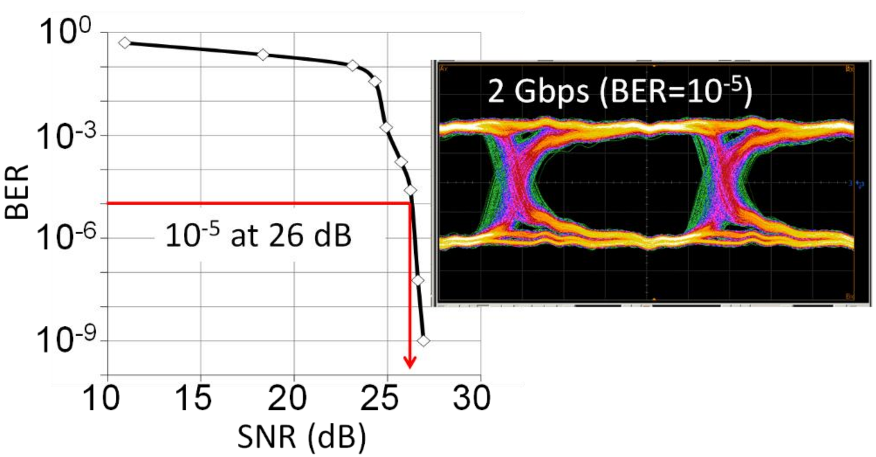
Time domain 60GHz demo

Data transmission tests

- Transmission of PRBS @10e-9 at : 2Gbps over 5 cm, 0,5Gbps over 20cm
- Up to 5m range with discrete lens

Data Rate	Range
0.5 Gbps	530 cm
1 Gbps	400 cm
1.5 Gbps	353 cm
2 Gbps	190 cm
2.2 Gbps	175 cm

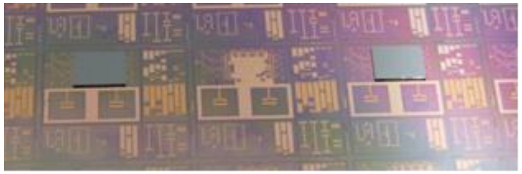




Our Lab

- Complete CAO design environment
  - ADS/Goldengate under Cadence, CST, EMPro, HSFSS, etc
  - Access to preliminary design kit (ST: CMOS 28nm, BICMOS55nm, FD-SOI)
- Early access to Leti & ST technologies:

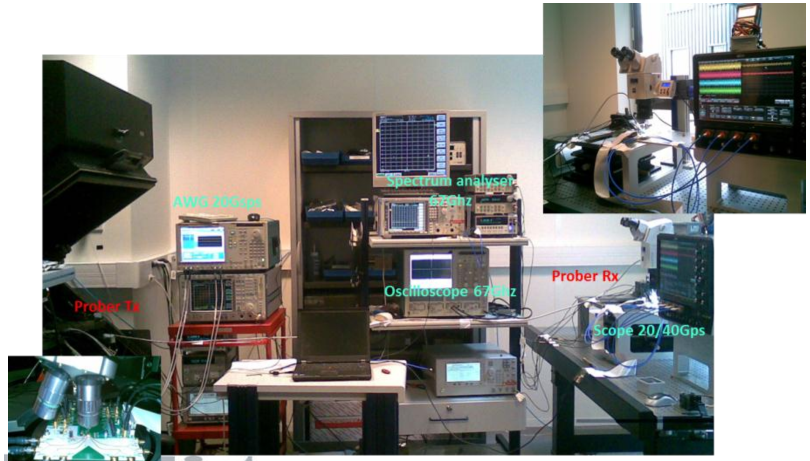
  SOI, BICMOS, 3D packaging with TSV, MEMS/NEMS

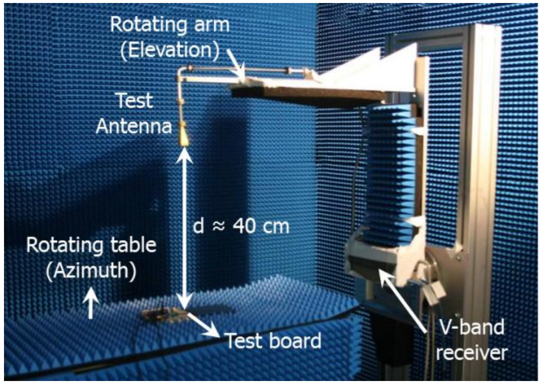


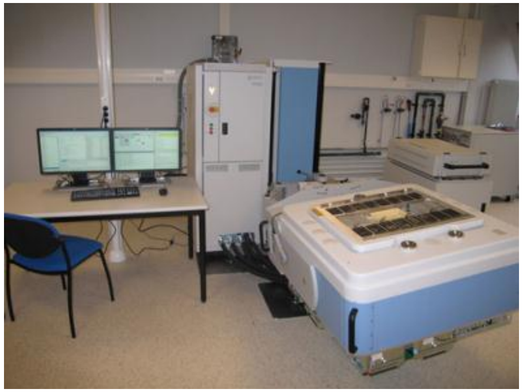
- Test and characterization of chips and antennas up to 67GHz

  And agreement with CNRS IEMN for test up to 300GHz
- Address manufacturability

  Design For Test, Industrial automatic tester Verigy 9300





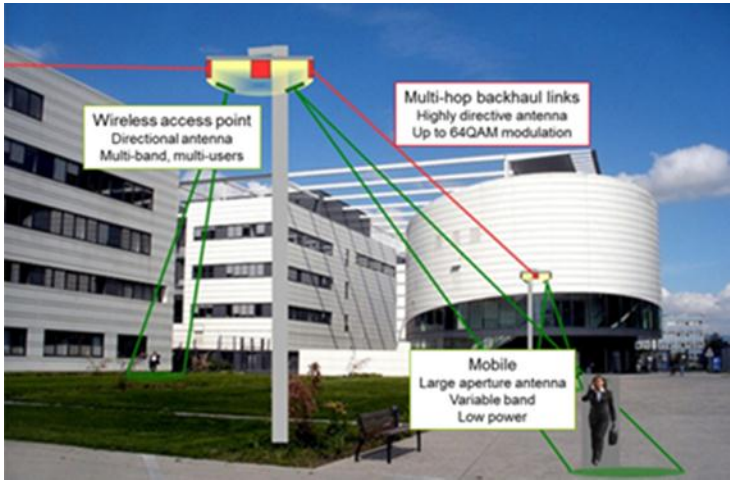


Ongoing developments

Frequency domain

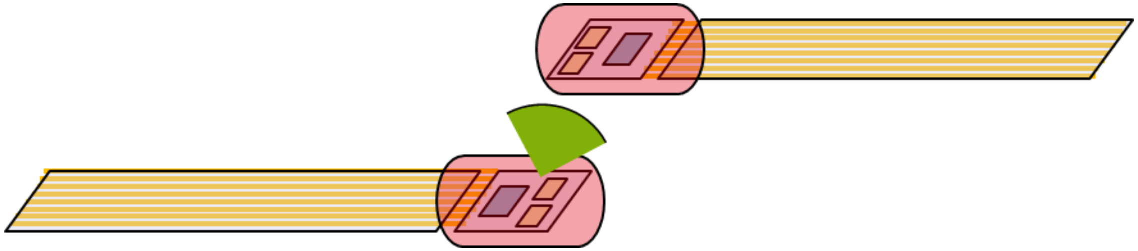
5G mmw small cell

Access point and Backhauling



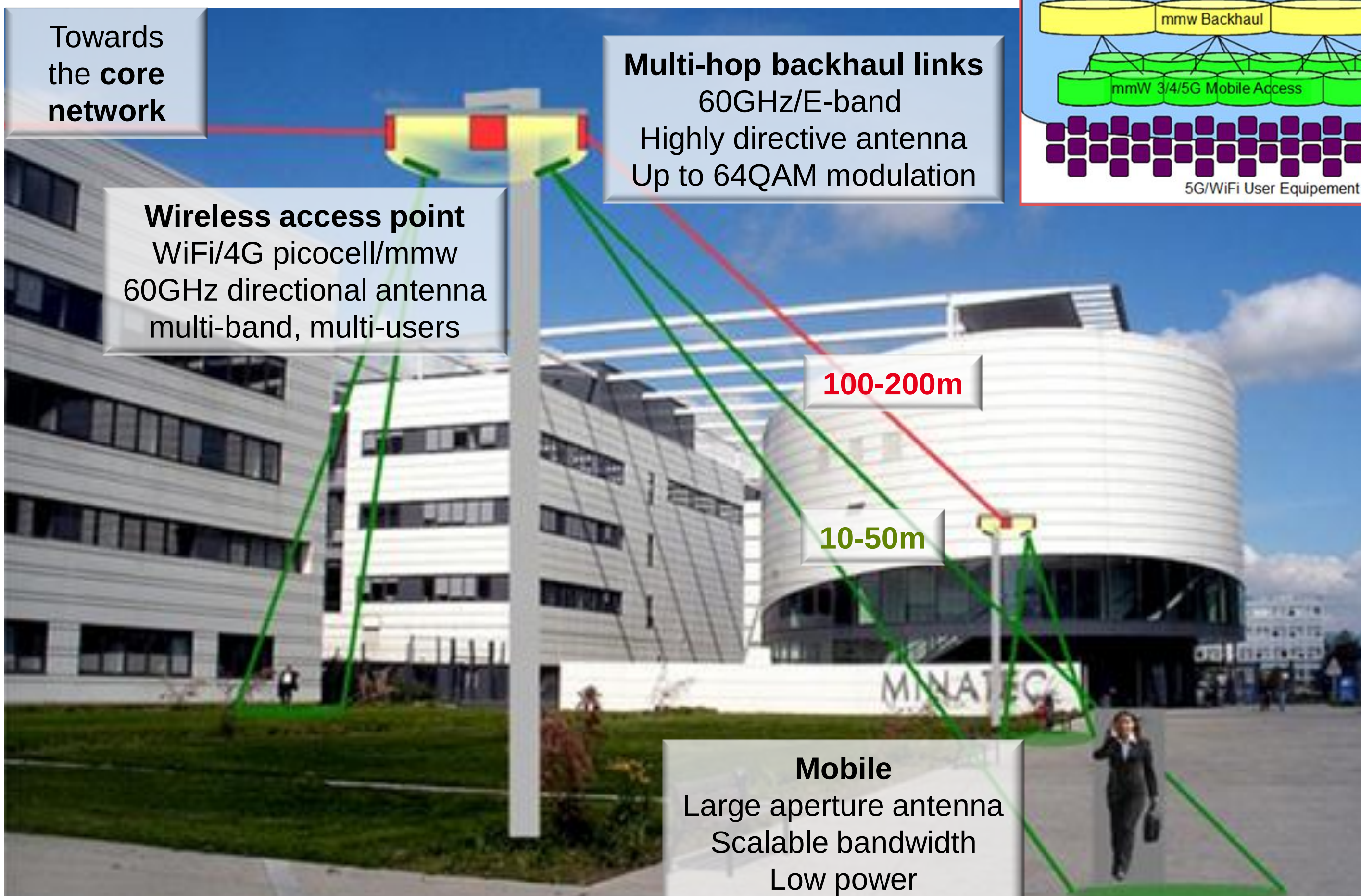
Time domain

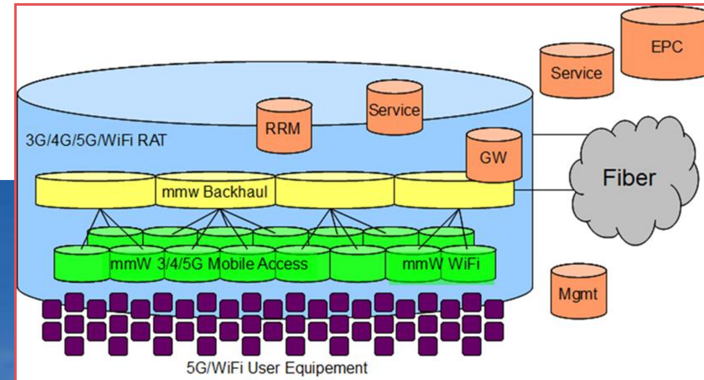
Contactless Connectors



Ongoing developments - Frequency domain

5G Heterogeneous Network with mmw small cells

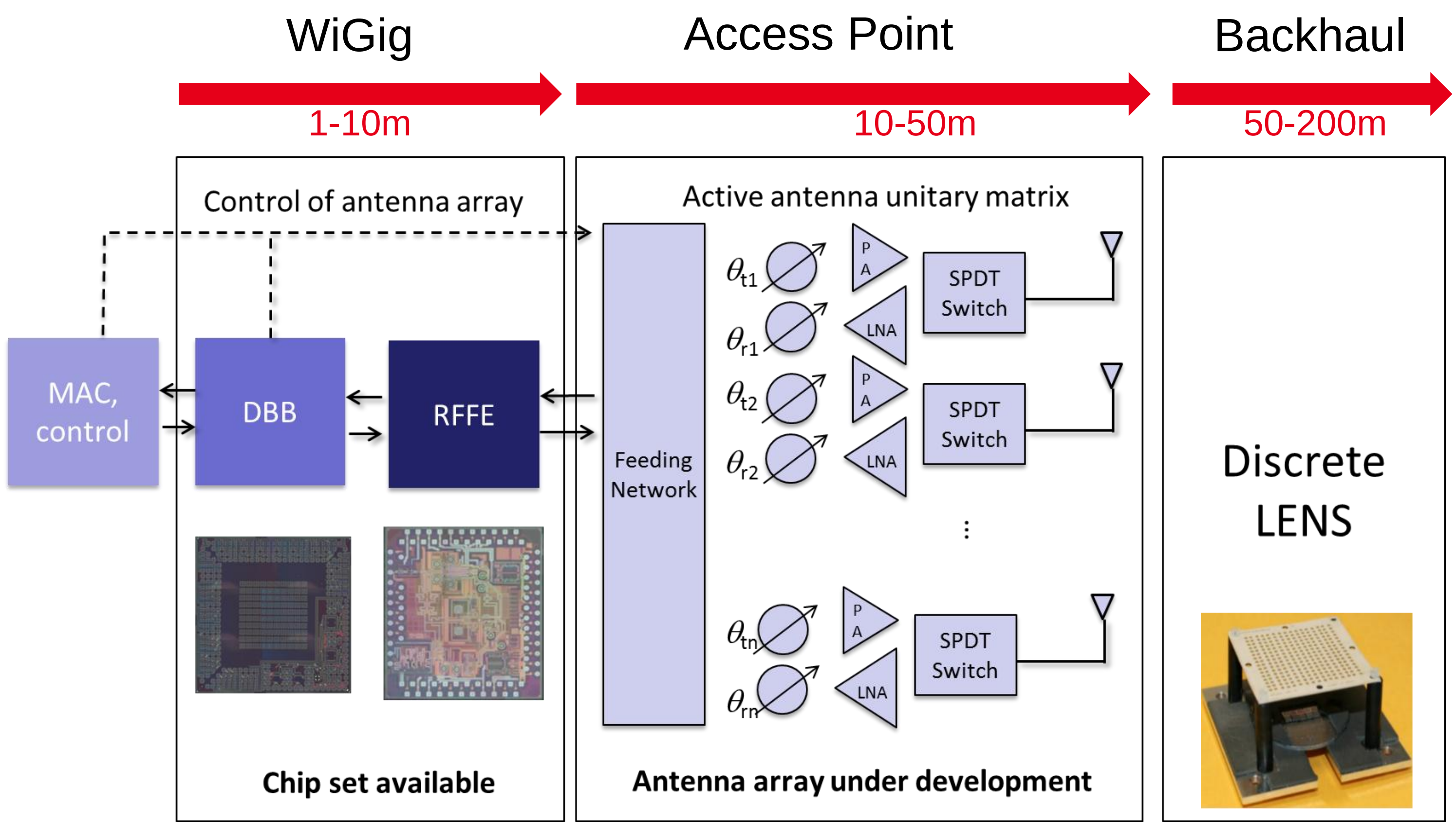




IMS WS'15

Ongoing developments - Frequency domain

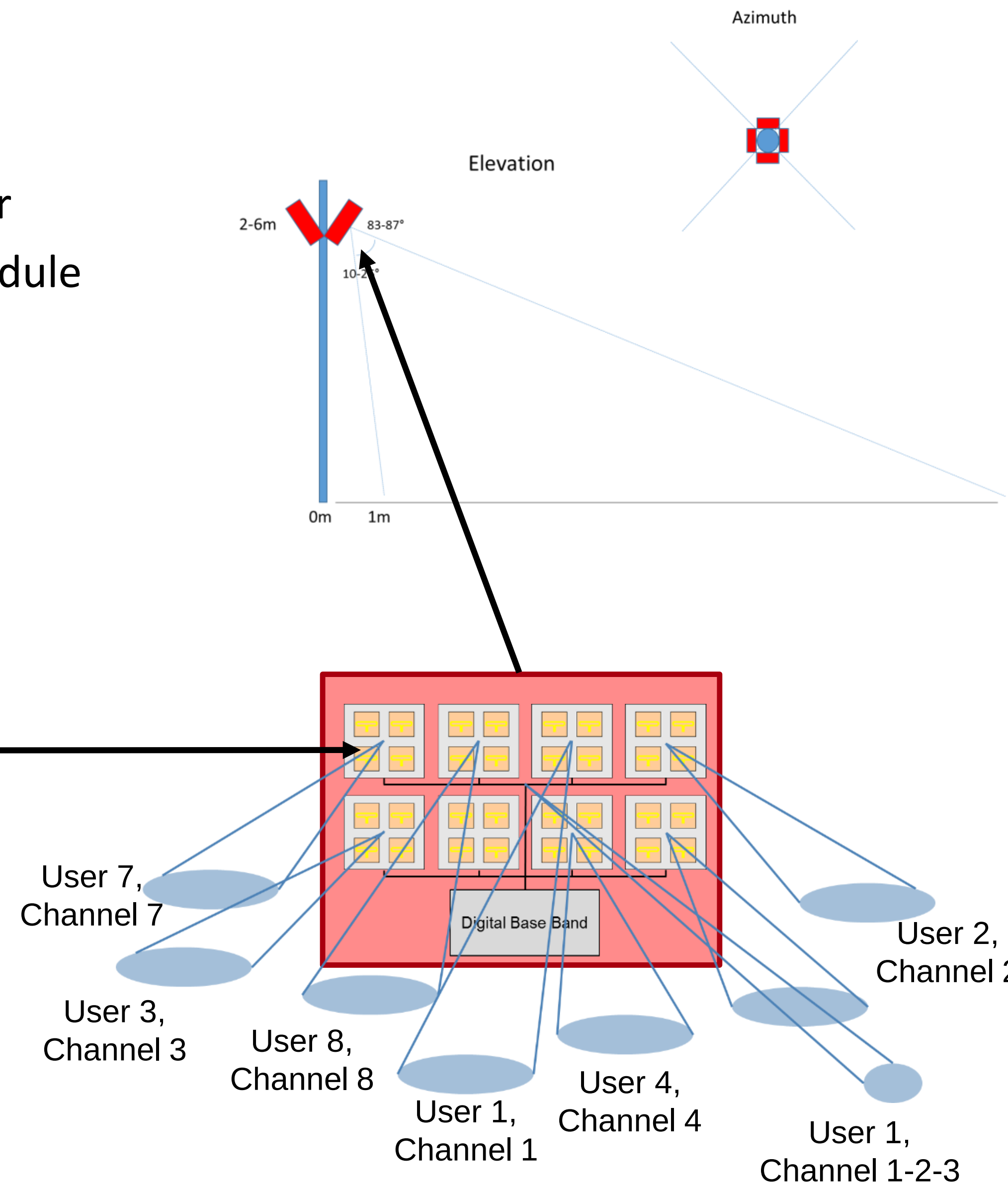
Incremental approach to satisfy various applications

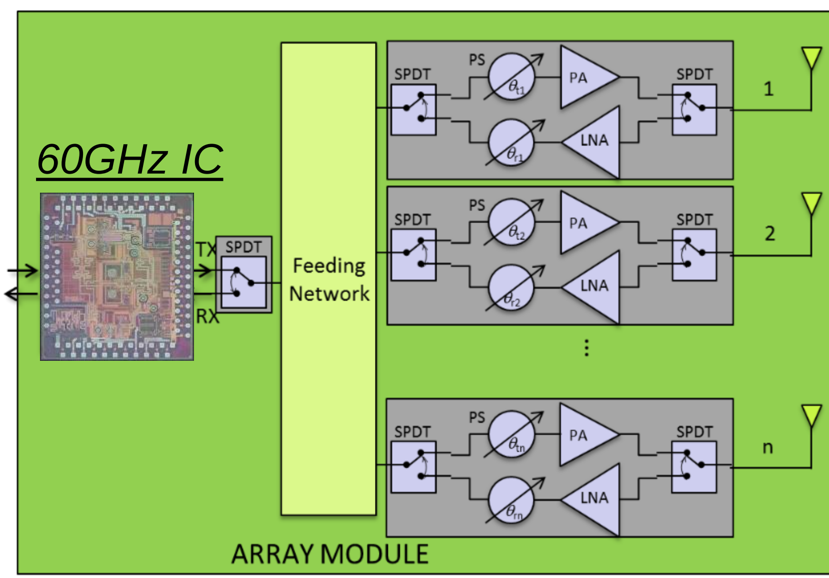


Ongoing developments - Frequency domain

Access point scheme

- From available WiHD/Wigig transceiver
- Active phase shifted antenna array module
- Synchronization of modules
  to increase range/data rate

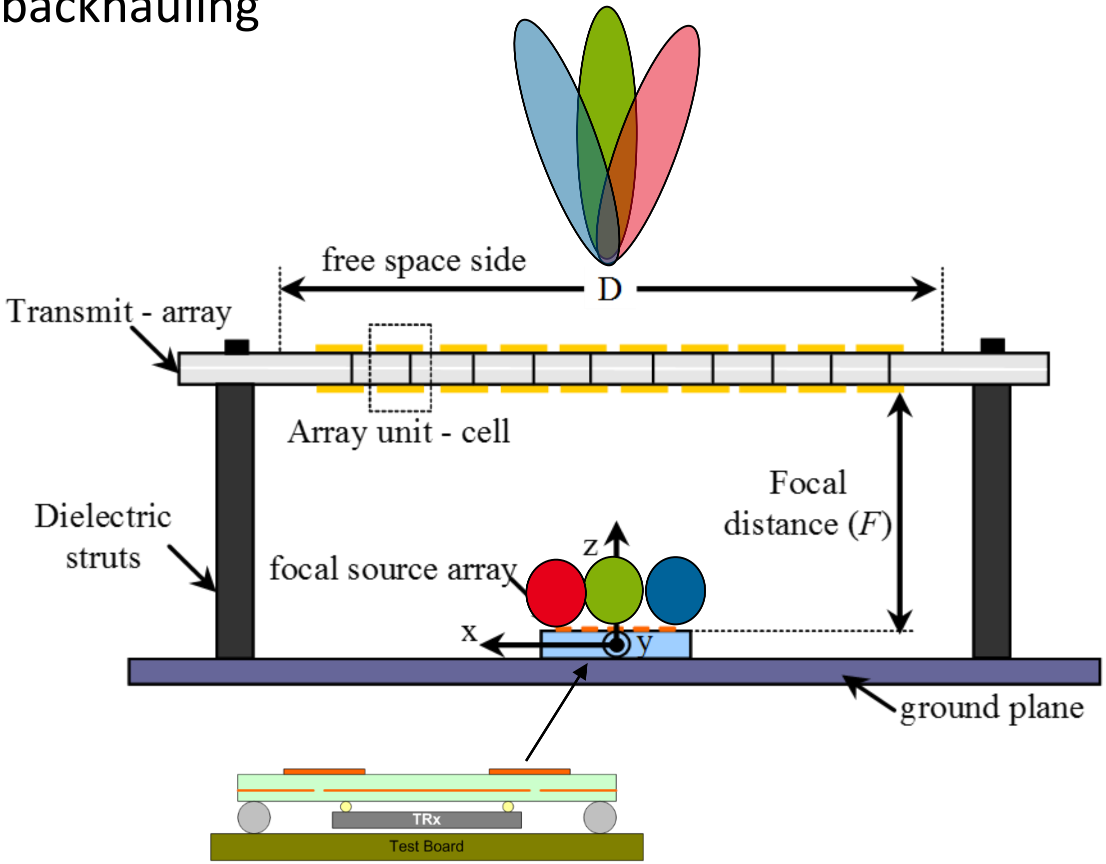


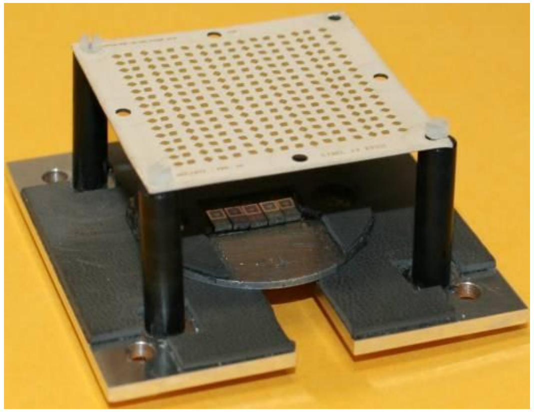


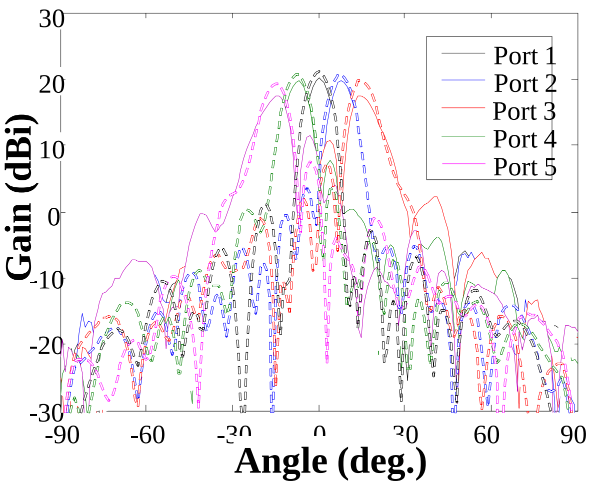
IEEE Com. Mag. Sept 14

Ongoing developments - Frequency domain

60GHz switched-beam antenna for small cell backhauling







Reconfigurable antenna pattern for link adaption

- **Low cost**, wideband and compact form factor
- Passive transmit-array on standard PCB technology
- **Switchable** antenna source on silicon interposer

Ongoing developments – Time domain

Contactless connector for consumer market
mm range high data rate applications

Wireless power and data transmission between mobile and docking station

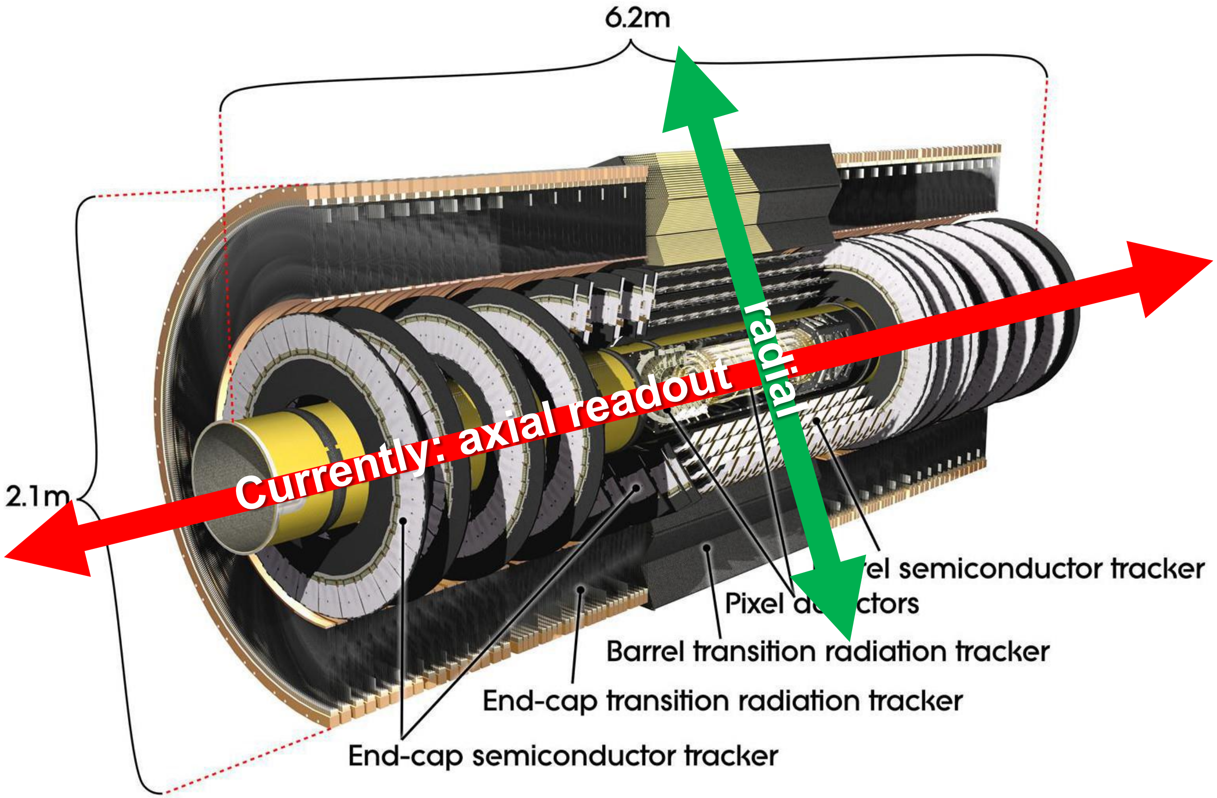
Slim and waterproof connectorless mobile device

Wireless USB or Ethernet

Features	Docking	Wireless USB
Frequency	60GHz	60GHz
Range	Few mm	Few cm
Data rate	2-5Gbps	5-10Gbps
Pdc	50mW	100mW

Large collider readout problematic

- **Minimize material budget** of cables/connectors
- No IR! Detector electronics should be in the dark



ATLAS inner tracker © ATLAS/CERN

- Reduce "dead material"
- More flexible transceiver placement
- Direct communication between layer possible
- Point-to-Multipoint links
- Data follows event topology enabling fast triggering

19

Requirements

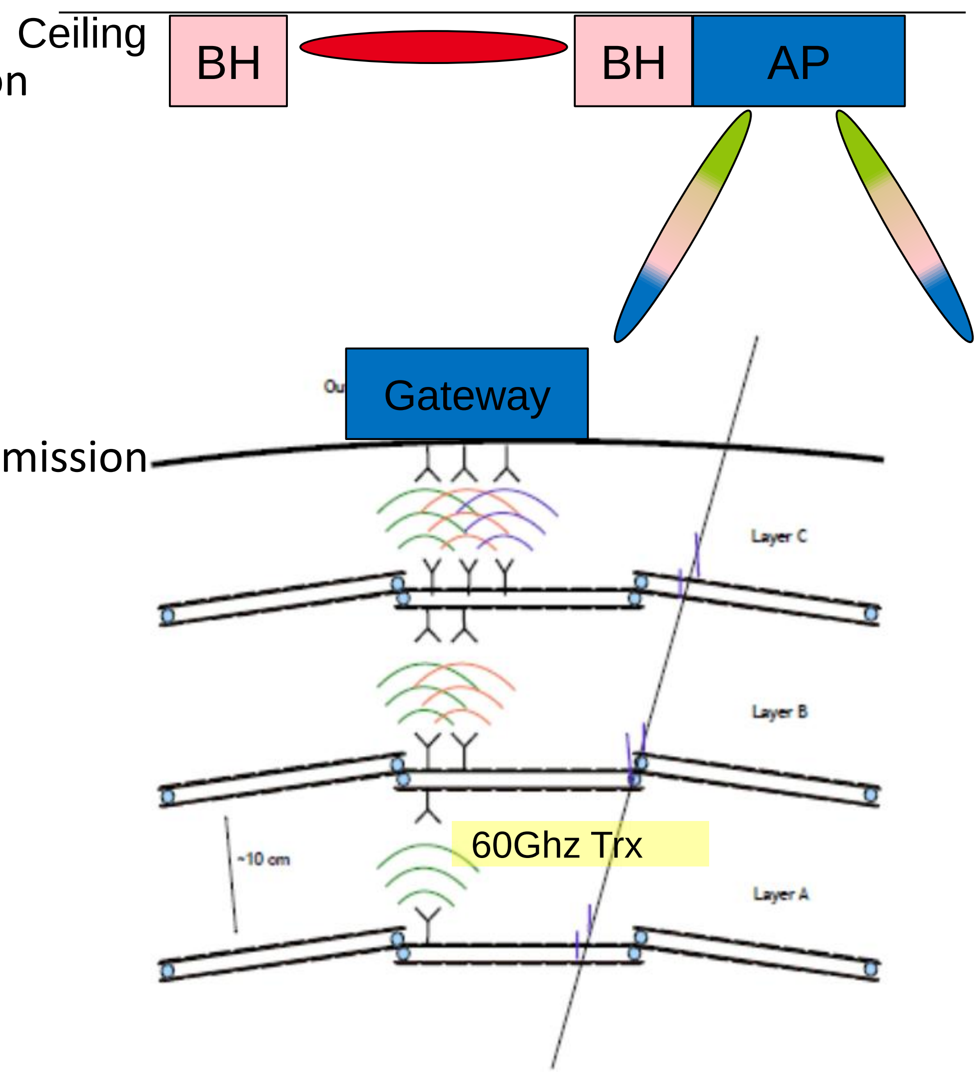
- CERN specifications
  - Radial wireless transmission of detector data
  - Remote power supply as a must
- Technical issues
  - Important aggregated data rate from detectors (Tbytes/s)
  - Important number of detector modules (20000 for ATLAS)
  - Crosstalks
  - Signal confinement
  - Liability in harsh environment (radiations)
  - Low power consumption (for remote power supply)
  - Efficiency of remote power transmission
  - Etc.

-> Wifi not suitable: Limited data rate, low QoS, important power consumption

-> Optical links not suitable: Difficult implementation

Possible radio schemes

1. Layer to layer transmission of data @60GHz
   - Proposed by Heidelberg Univ.
   - Low power short range transmission
   - Time domain transceiver



2. Gateway
   - Aggregation of data
   - Medium range high data rate transmission
   - Frequency domain transceiver

3. Wireless access point
   - Multi user access scheme
   - Very high data rate
   - Frequency domain transceiver

4. Data Backhauling

Possible radio schemes

Radio scheme	Typical Range	Data rate	Power consumption	Closest mass market application	Expected commercial availability
1. Cross layer data transmission	10cm	0.1-2Gbps	~50mW	Contacless connector	2 years
2. Gateway	5m	5-7Gbps	1W	802.11ad	Almost now
3. Access point	5m	20-25Gbps	5-10W	5G small cell AP	5 years
4. Backhaul	50-200m	20-40Gbps	5-10W	5G BH small cell	2 years

Possible CEA Leti contributions – short term

- Architecture and system studies
  - Characterization of the environment, propagation medium, channel modeling, interference
  - Type modulation: SC QAM, FM, PM, UWB impulse, etc. Pros and cons.
  - Choice of Carrier Frequency vs application : 60-300GHz (range, precision, material penetration, O2/H2O absorption peaks, etc)
  - System study and budget link
  - Strategy for data aggregation, data fusion and compression
  - Crosstalks and coexistence issues
  - System definition and specification
  - Simulation chain for RF and digital specifications
- Preliminary experimentation
  - Build measurement set-up (from prototypes or commercial products)
  - Propagation, channel sounding in realistic environment
  - Data transmission for proof of concept

Possible CEA Leti contributions – medium term

- RF/mmw design
  - Customization of existing 60GHz chips towards LHC requirements (from system studies)
    - Focusing on the cross layers data transmission
  - Design of higher data rate transceiver
    - At higher frequencies (e.g. 300GHz), associated to wider bandwidth
    - Operating on multiple frequency channels (FDMA)
    - With multiple inputs multiple outputs (MIMO)
- Antenna/package design
  - Design of antenna/package with a directive pattern (antenna array or lens), and/or polarization diversity
  - Mitigation of the crosstalk/coexistence issues
- Prototyping
  - Design and fabrication of prototype boards
  - Experimentation of data transmission in a realistic environment

Resources and planning (over 5 years)

- Phase I: short term
  - Architecture and system studies: 18 months duration, 2 men year
  - Experimentation: 6 months duration, 0.5 man year
- Phase II: medium term
  - RF/mmw design: 2-3 years durations, 2-6 men year function of objectives
  - Antenna/package design: 1-2 year duration, 1-2 men year function of objectives
  - Prototyping: 6 months duration, 0.5 man year

1man/year charged cost: 190keur

Silicon fabrication cost: around 50keur for 2 runs of $3mm^2$ chip

Package fabrication and assembly cost: around 20keur

Subcontracting of board design and fabrication: around 10keur

Funding

- CEA shall reuse transceiver and IPs from other projects and industrial collaborations
- Possible Carnot Label (French national research agency) project funding
- PhD thesis CEA/TelecomParistech proposed in May to French authorities (IDEX funding)
- TBD

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list

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Cedex

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Major publications

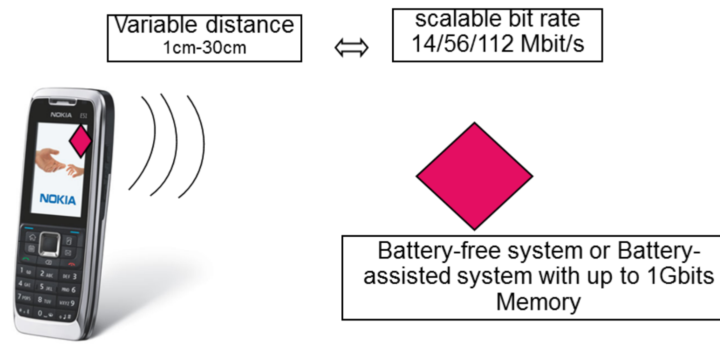
- Richard, O et. al. "A 17.5-to-20.94GHz and 35-to-41.88GHz PLL in 65nm CMOS for wireless HD applications," Solid-State Circuits Conference Digest of Technical Papers (**ISSCC**), 2010 IEEE International , vol., no., pp.252,253, 7-11 Feb. 2010
- Siligaris, A et. al."A 60 GHz Power Amplifier With 14.5 dBm Saturation Power and 25% Peak PAE in CMOS 65 nm SOI," IEEE Journal of Solid-State Circuits (**JSSC**), vol.45, no.7, pp.1286,1294, July 2010
- A. Siligaris et al., "A 65 nm CMOS fully integrated transceiver module for 60 GHz Wireless HD applications," International Solid-State Circuits Conference (**ISSCC**), San Francisco, 20-24 February 2011.
- A. Siligaris et al., "A 65-nm CMOS fully integrated transceiver module for 60-GHz Wireless HD applications," IEEE Journal of Solid-State Circuits (**JSSC**) , Dec. 2011.
- Y. Fu et al., "Characterization of integrated antennas at millimeter-wave frequencies," Int**. Journal of Microwave** and Wireless Technologies, pp. 1-8, 2011.
- H. Kaouach et al., "Wideband low-loss linear and circular polarization transmit-arrays in V-band," **IEEE Trans**. Antennas and Prop., July 2011.
- A. Siligaris et al., "A 60 GHz UWB impulse radio transmitter with integrated antenna in CMOS 65 nm SOI technology," 11th IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems, Phoenix, 17-19 January 2011.
- L. Dussopt, "Integrated antennas and antenna arrays for millimetre-wave high data-rate communications," 2011 Loughborough Ant. and Propag. Conf. (**LAPC** 2011), 14-15 Nov. 2011, Loughborough, UK.
- L. Dussopt, et al., "Silicon Interposer with Integrated Antenna Array for Millimeter-Wave Short-Range Communications," IEEE **MTT-S** Int. Microwave Symp., 17-22 jun. 2012, Montreal, Canada.
- J.A. Zevallos Luna et al., "Hybrid on-chip/in-package integrated antennas for millimeter-wave short-range communications," **IEEE Trans.** on Antennas and Propagation, vol. 61, no. 11, November 2013, pp. 5377-5384.
- A. Siligaris, et al., "A low power 60-GHz 2.2-Gbps UWB transceiver with integrated antennas for short range communications," 2013 IEEE **RFIC** conference, June 2-4, 2013, Seattle, Washington, USA.
- Guerra, J.M et. al., "A 283 GHz low power heterodyne receiver with on-chip local oscillator in 65 nm CMOS process," Radio Frequency Integrated Circuits Symposium (**RFIC**), 2013 IEEE , vol., no., pp.301,304, 2-4 June 2013
- Y. Lamy, et al., "A compact 3D silicon interposer package with integrated antenna for 60 GHz wireless applications," IEEE Int. 3D Systems Integration Conference (**3DIC**), Oct. 2-4, 2013, San Francisco, CA, USA.
- Luna, J.A.Z. et. al."A packaged 60 GHz low-power transceiver with integrated antennas for short-range communications," Radio and Wireless Symposium (**RWS**), 2013 IEEE , vol., no., pp.355,357, 20-23 Jan. 2013
- J.A. Zevallos Luna et al., "A V-band Switched-Beam Transmit-array antenna," to appear in Int. **Journal on Microwave** and Wireless Technology, 2014.
- Dehos, C. et. al., "Millimeter-wave access and backhauling: the solution to the exponential data traffic increase in 5G mobile communications systems?," **IEEE Communications Magazine**, vol.52, no.9, pp.88,95, September 2014

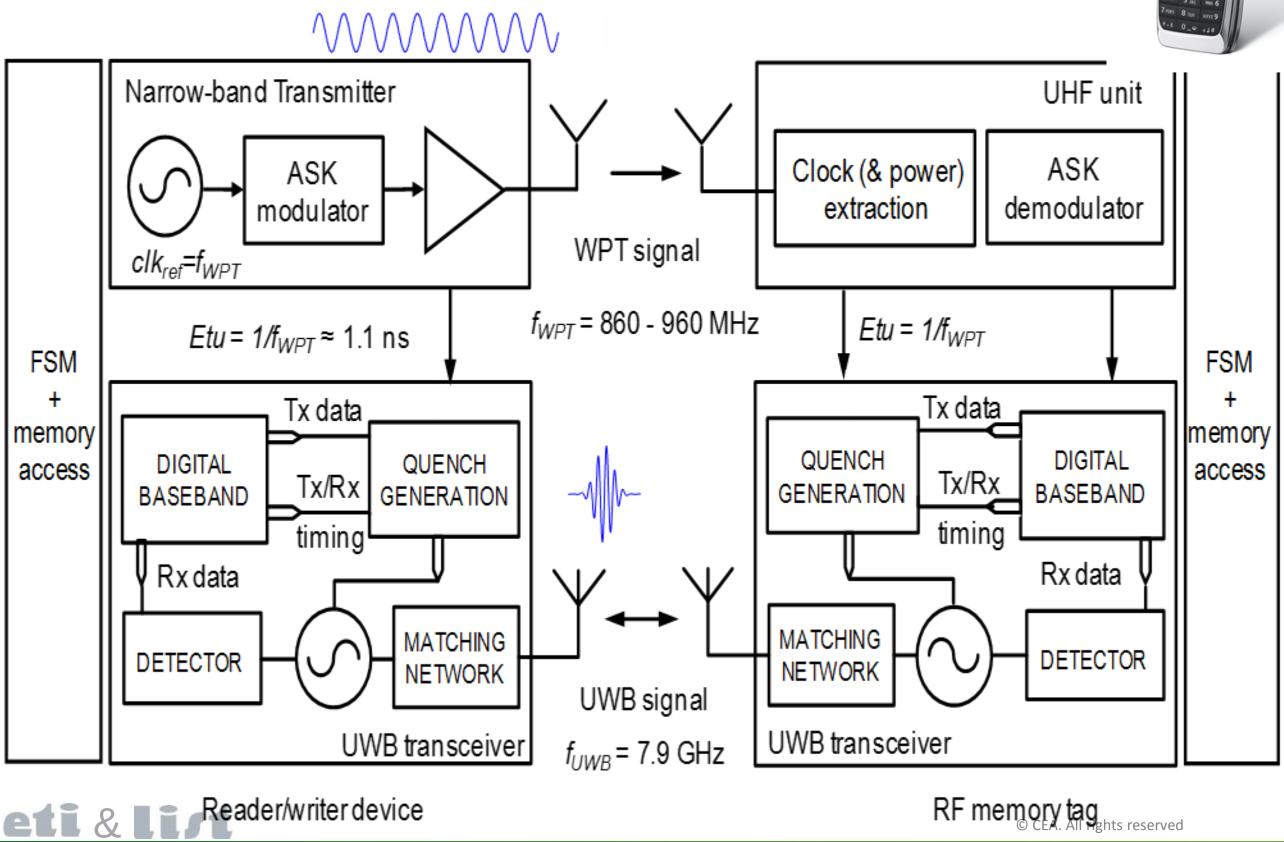
Wireless Power Supply

Example of UHF (900MHz) wireless power supplies of UWB memory tag

RF power supply, around 25% power efficiency (+path loss)

~5mW power supply at 30cm for 2W emitted power





Technology	0.13µm
Remote powering	UHF
Clock Extraction	UHF
Downlink	UWB (7.25-8.5GHz)
Data rate	typ. 112Mb/s
Power consumption	5.4mW
FOM (energy/bit)	48pJ/b
Uplink	UWB (7.25-8.5GHz)
Data rate	typ. 112Mb/s
Power consumption	6.5mW
FOM (energy/bit)	58pJ/b

Example of RFID (13.56MHz)

Magnetic coupling, around 80% power efficiency at short range (<1cm)

>50mW power supply at 1-3cm range for 1W emitted power

Efficiency rapidly drops with range

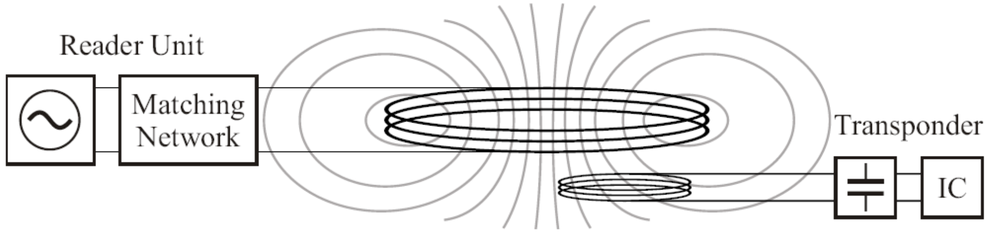
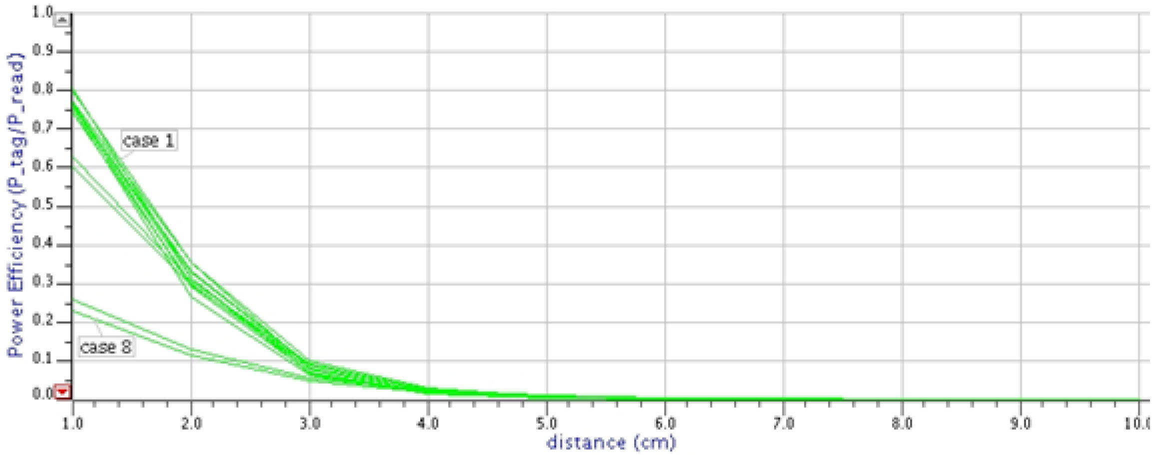


Figure 1: Basic setup of inductive coupled coils in a 13.56MHz RFID system



Wireless Power Supply

RF power transfer

50-100mW could be obtained assuming directive antennas, and high emitted power

e.g. Wireless power supply @ 900MHz

- -5dB power harvester efficiency (30%)
- 14dBi Tx / 11dBi Rx antenna gain
- 44dBm output power (25W)

→ ~100mW maximum available @4m (Friis)

Inductive coupling

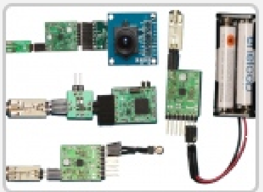
- Good efficiency but restricted to very short range 1-3cm at 13.56MHz
- Coupling at 125kHz to be evaluated (theoretical 1-3m range)

Wireless Power Supply

Technology News

Using Wi-Fi to power the IoT

June 08, 2015 | Rich Pell | 222909149



An article in the MIT Technology Review **presents a power-over-Wi-Fi system that uses existing Wi-Fi chipsets in wireless routers to deliver far-field wireless power to various sensors as well as to recharge coin cell batteries at distances up to 28 feet.**

The power-over-Wi-Fi system - or "PoWiFi" for short - is a University of Washington (Seattle, WA) research project aimed at powering the Internet of Things (IoT) using Wi-Fi signals. Its concept is that Wi-Fi receivers could, in addition to retrieving the information being transmitted over Wi-Fi, be designed to harvest the energy in these signals as well.

The biggest hurdle in achieving this is the discontinuous nature of normal Wi-Fi signals - data is often broadcast in bursts, on a single channel. Initial testing with a temperature sensor that had been fitted with a Wi-Fi antenna showed that while voltage across the sensor often came close to the 300 mV needed for the sensor to operate it was not enough.

To get around this, the researchers injected non-intrusive "power traffic" onto multiple 2.4-GHz Wi-Fi channels to increase channel occupancy - while minimally impacting network performance - so as to allow energy harvesting across multiple channels. They also designed a multi-channel harvester to retrieve the energy from the resulting transmissions, from both the artificial and normal traffic across three non-overlapping channels, and to allow for continuous power delivery.

Using this approach, the researchers found that the temperature sensor could operate at distances of about 6 meters from the router - a distance that increased to 9 meters when a rechargeable battery was added. A further test with a Wi-Fi antenna-enabled low-power camera equipped with a low-leakage storage capacitor showed that it could operate at up to about 5 meters without a battery, and about 7 meters with a battery.

Also demonstrated was the remote battery recharging of a Jawbone fitness tracker. Once equipped with the PoWiFi antenna and placed in the vicinity of a PoWiFi router, the device's coin cell battery was able to be brought to 41% charged from a no-charge state in 2.5 hours.

According to the researchers, the impact of the system on normal Wi-Fi traffic and performance was minimal to users on the networks tested. For more, see "Powering the Next Billion Devices with Wi-Fi" (PDF).