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Wireless data transmission for trackers

(Richard Brenner on the behalf of WADAPT - Wireless Allowing Data And Power Transmission)

Outline

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- Motivation
- Implementation of WiFi technology in trackers
- Basic studies
- Towards a WiFi GBT link demonstrator
- Future prospects
- Summary and outlook

Motivations

Topology

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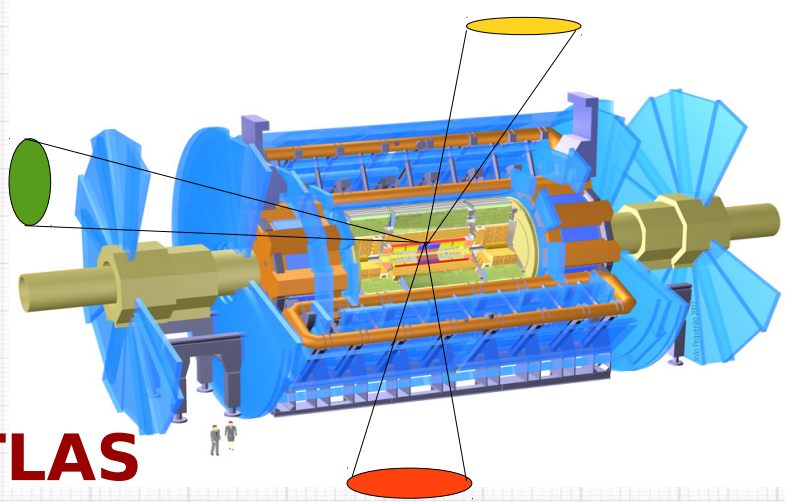
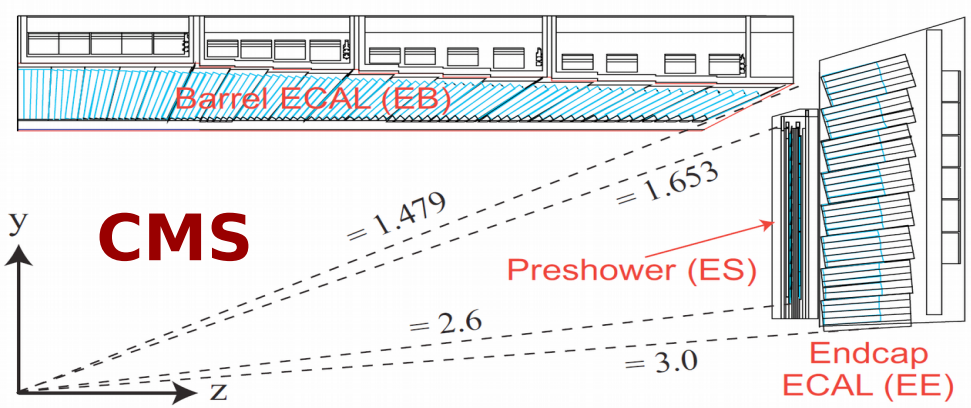
Physics events propagate from the collision point radially outwards in φ-η





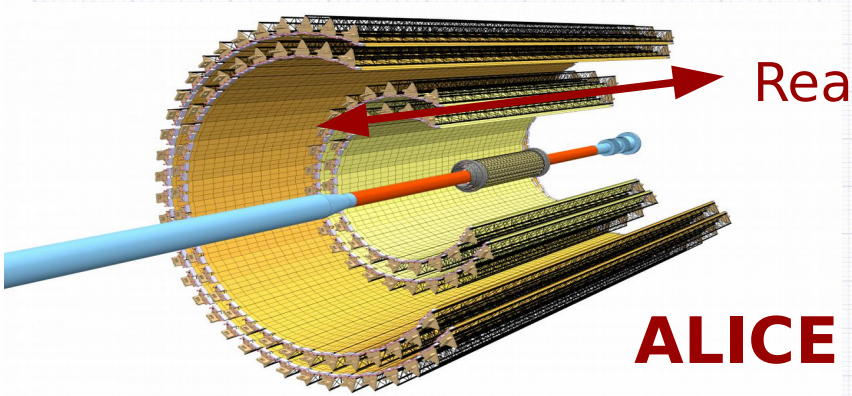
Physics events are triggerd in RoI that are conical regions radial from the interaction point in φ and η

Example: CMS Crystal Calorimeter is tiled to match Event topology

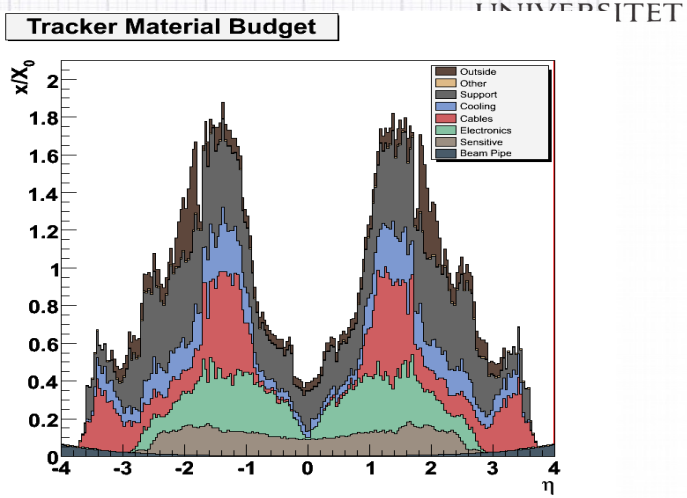
<u>The first trigger decision in the LHC detectors is done within 3μs</u>

- Fast signal transfer
- Fast extraction of trigger/physics objects
- Efficient to partition detector in topological regions (Region-of-Interest)
- Combination of objects from several sub-detectors

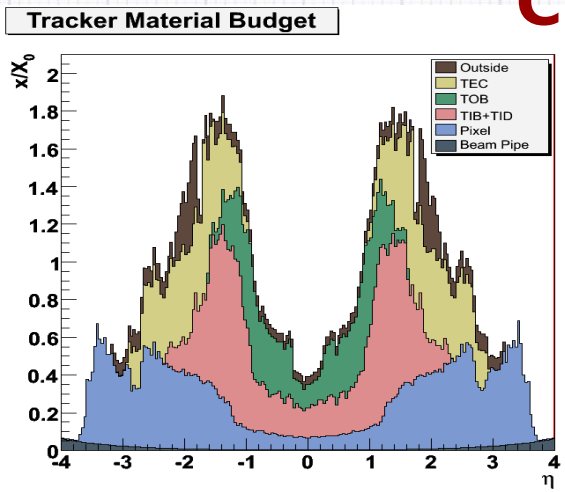
Silicon trackers



Axial tracker readout resulting in long paths,
Long latency etc.



CMS



- Silicon tracking detectors are built for convenience with a axial central part (Barrel) with disks in forward-backward direction. Several drawbacks:
  - Short radiation length because of massive services in region between Barrel and Disks
  - Long data path
  - Not segmented in ROI

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Implementation of technology in trackers

Track trigger and data rate reduction

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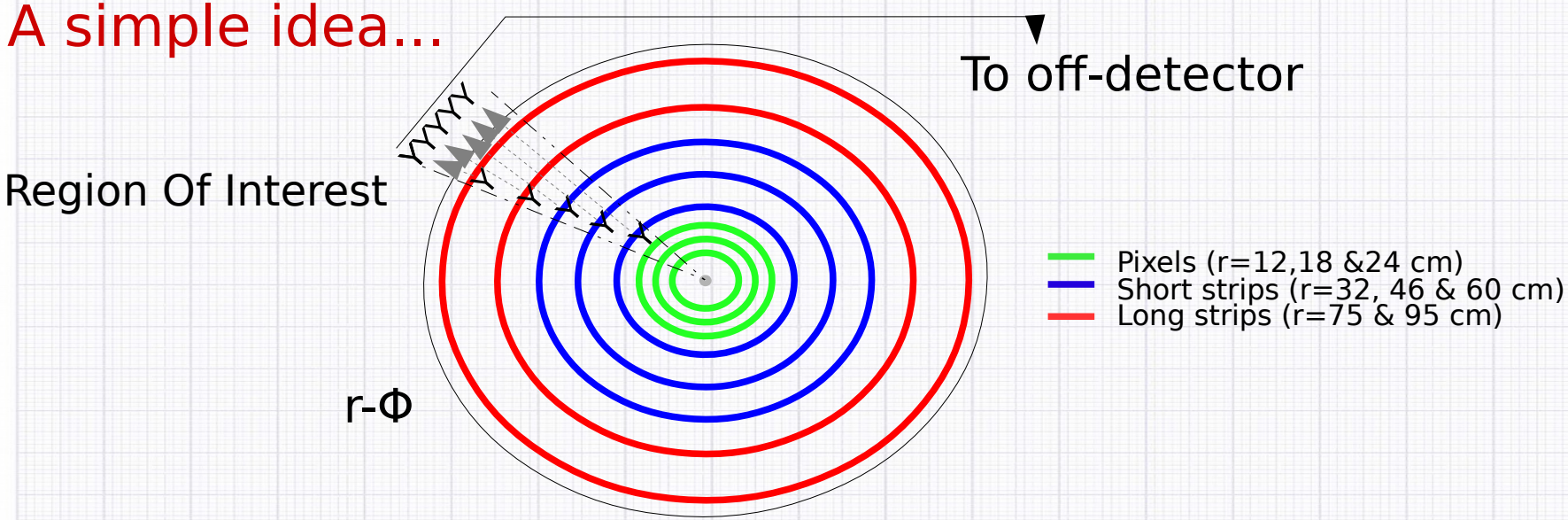
A simple idea...



...but not trivial to build on detector

- If only 1-2 hit clusters from a few strip layers are read out for L1 trigger the required bandwidth is 50-100 Tb/s!
- The detectors is fortunately divided into a 20-50k independent segments and if each is provided with a link then the bandwidth/link < 5 Gb/s

....perhaps doable after all?

A simple architecture for wireless transfer of L1 trigger data

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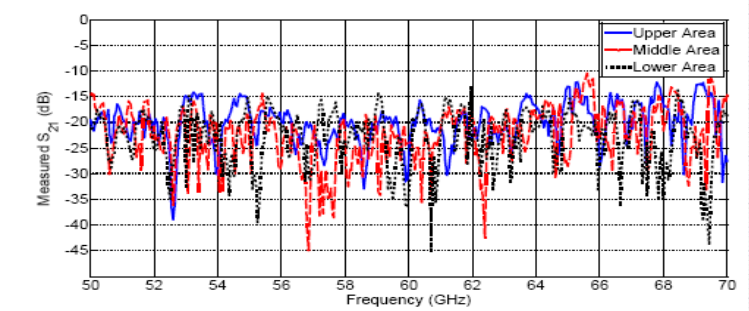
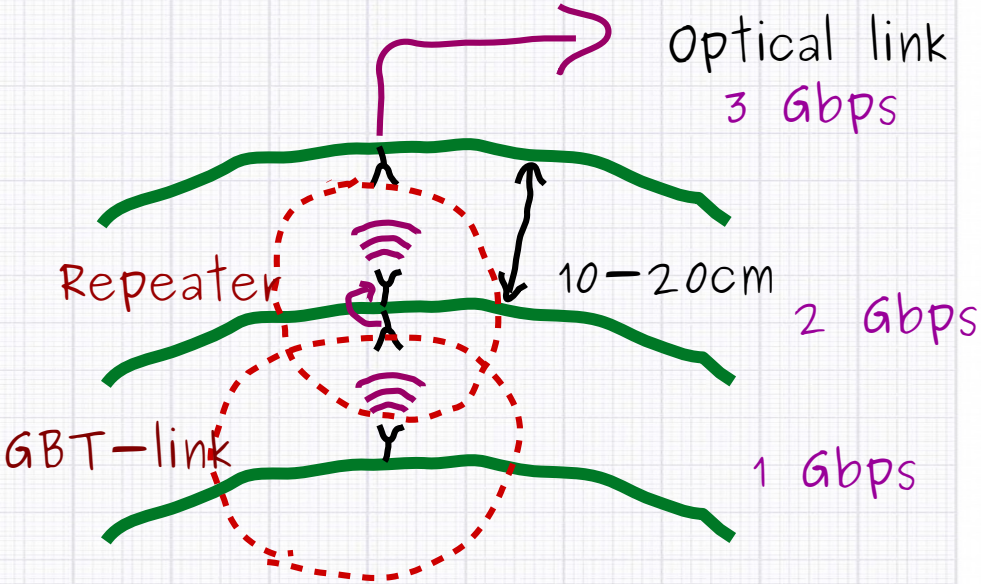
- All complicated logic off-module → simple implementation on module
- Not possible to transfer 60GHz radially data trough silicon layers



Transmission test through a silicon module



- Solution: data transfer on wire from inside module to outside and antennas on both sides.

Basic studies

Cross talk between links (Uni. Heidelberg)

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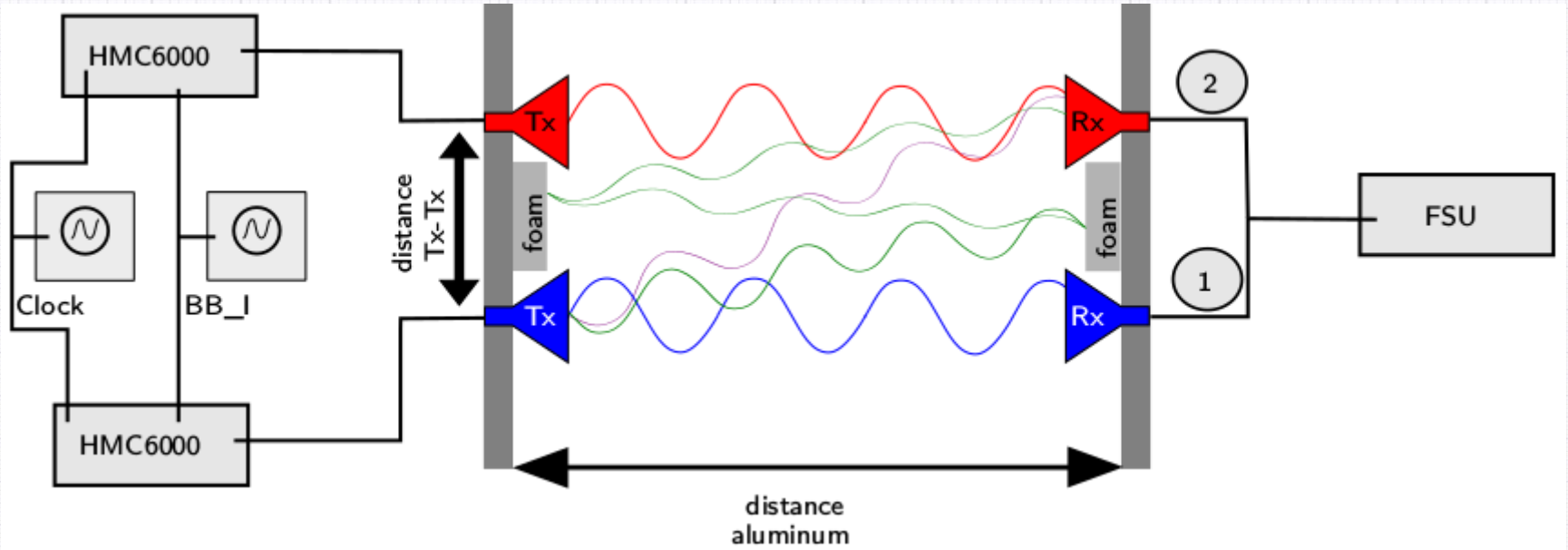
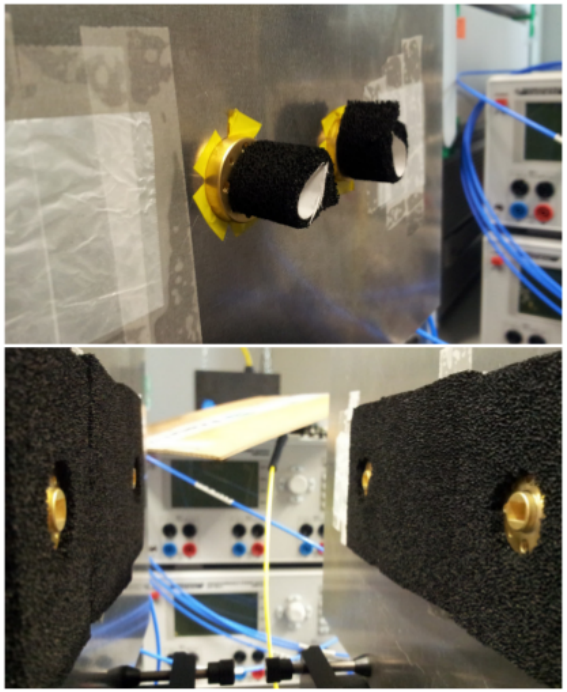
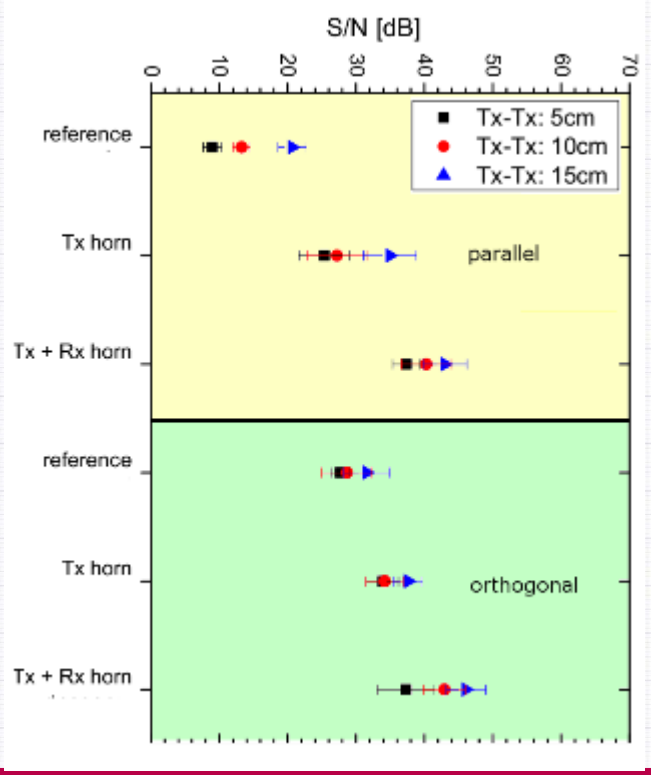
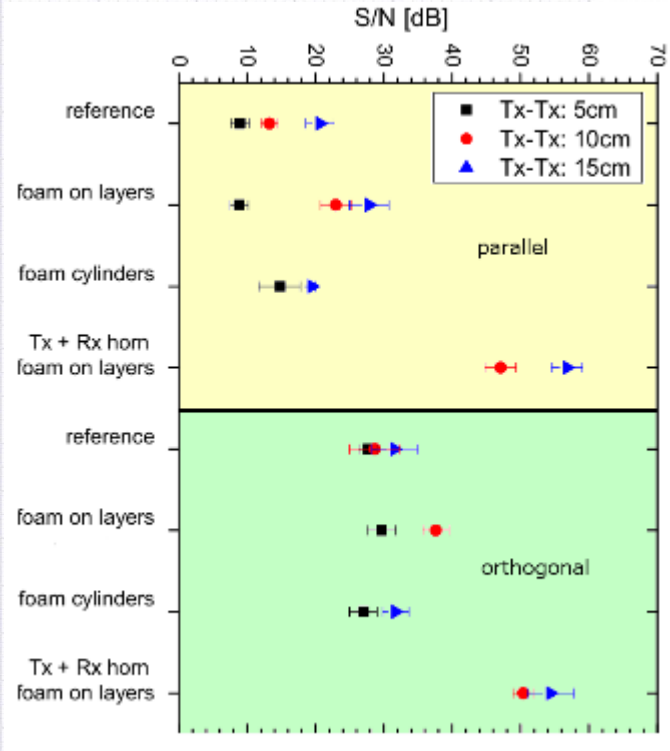
- Study reflections in multi-path setup
- Measured signal to noise in RF
- Different transmitter pitches: 5 cm, 10 cm and 15 cm



- Polarisation has huge effect for close-by links
- High directivity also decreases multi-path crosstalk strongly
- Foam on layers can reduce noise additionally
- https://arxiv.org/pdf/1604.06259







Bit Error Rate (Uni. Heidelberg and LETI)

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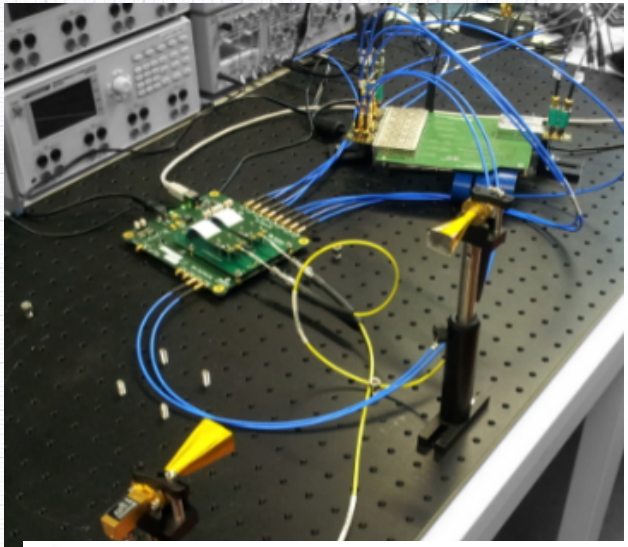
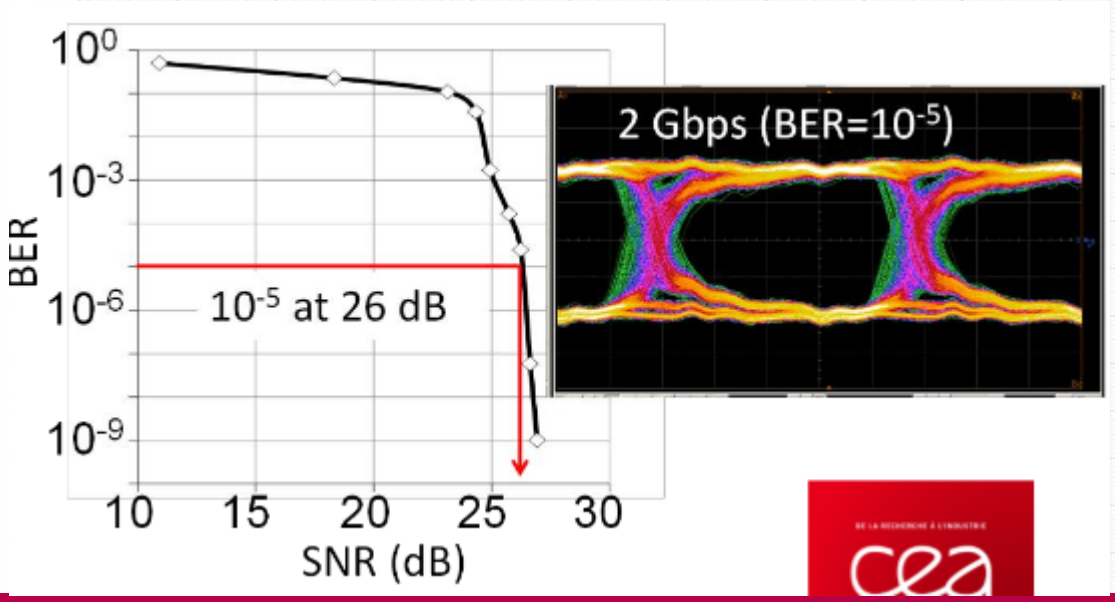
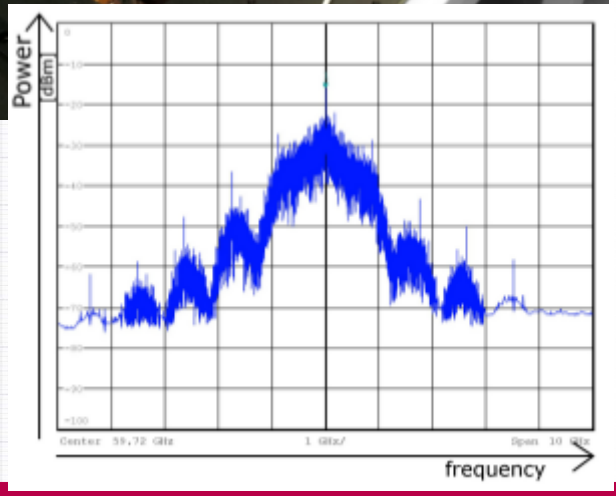
- Lab-test with Wifi links done
- BER with lab-purpose links running at 1.76 Gbps $< 4.0 \times 10^{-15}$ (fast and stable data transmission)
- BER with compact low-power link $< 10^{-5}$







Compact antennas (Uppsala Uni. and LETI)

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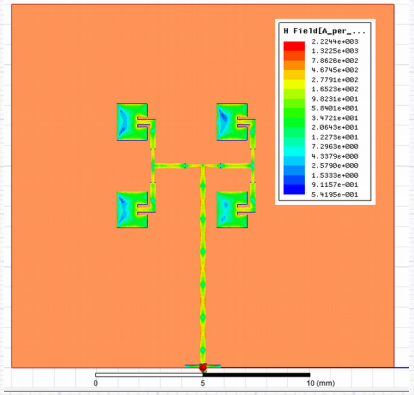
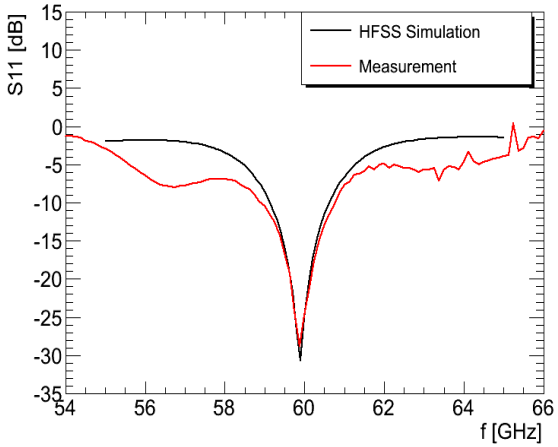
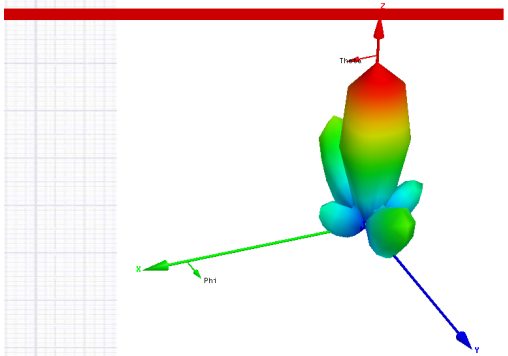
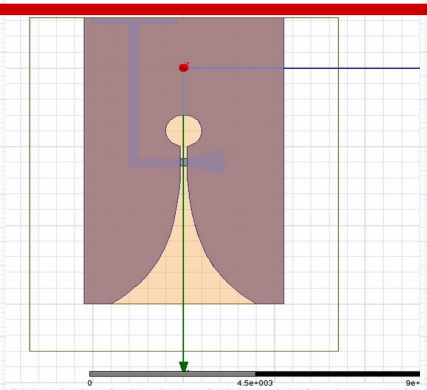
- (Multi) patch antenna for focused radiation

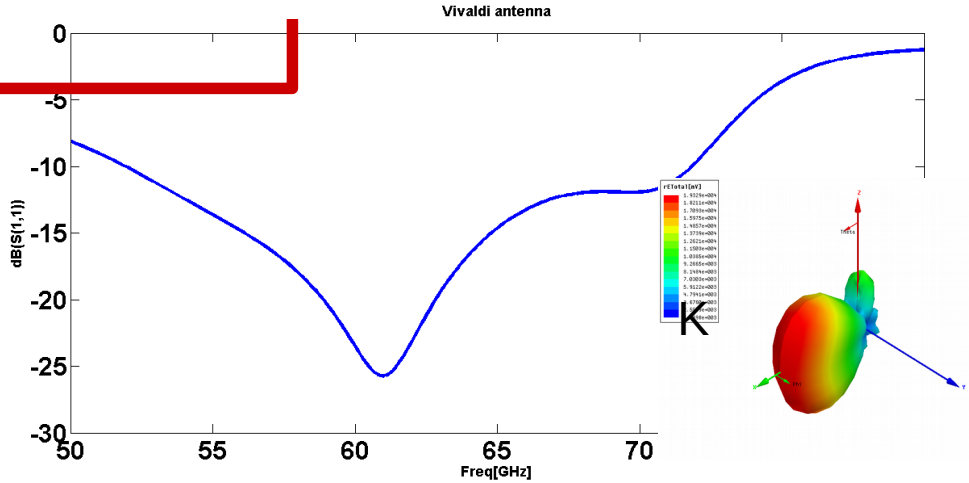






- Vivalidi broadband antenna





Lenses (Uppsala Uni. and LETI)

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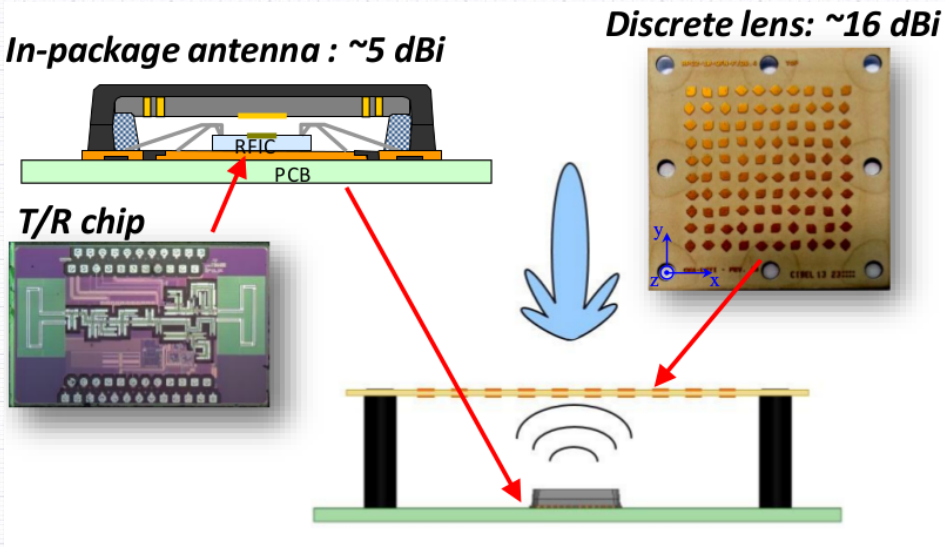
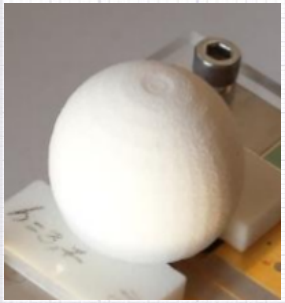
TRANSMIT ARRAY LENS



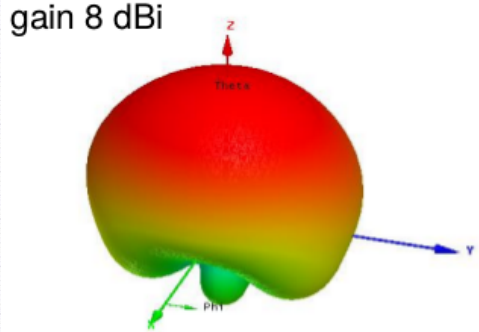
- Improves directionality
- Gain increase > 10 dBi

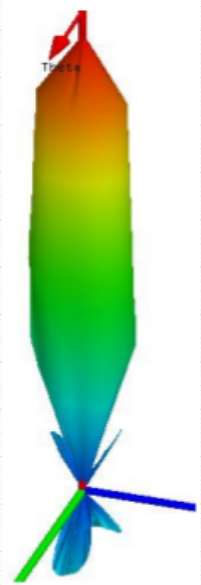
HEMISPHERICAL LENS

diff. patch ant. +
hyper-hemispherical lens
3D printing of polyamide (ε_r=3.3)
optimized distance (d = 2.75 mm)
extension of 1.5 x R (R=10 mm)
overall gain 21.5 dBi



differential patch antenna
gain 8 dBi





Transmission trough layers

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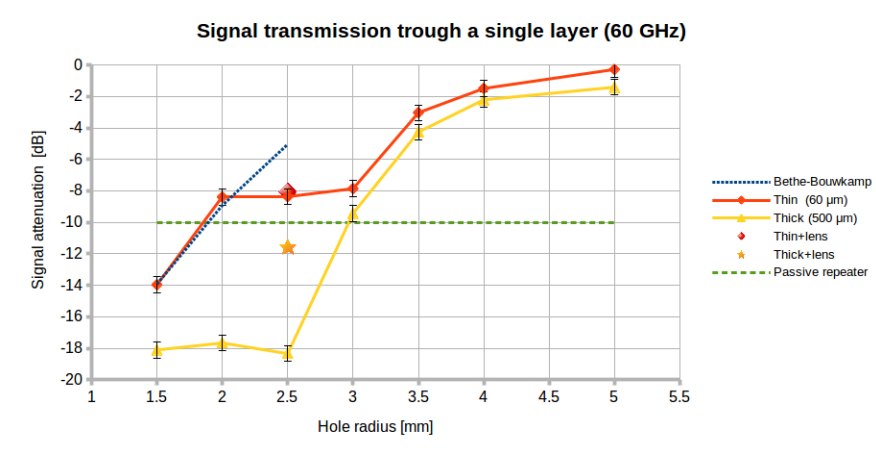
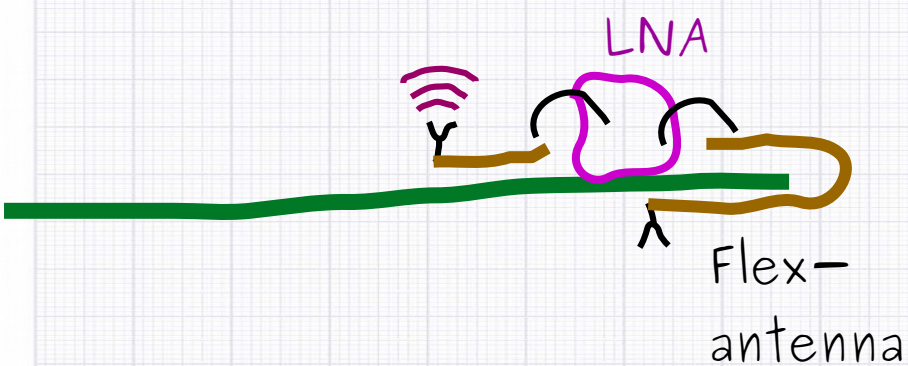
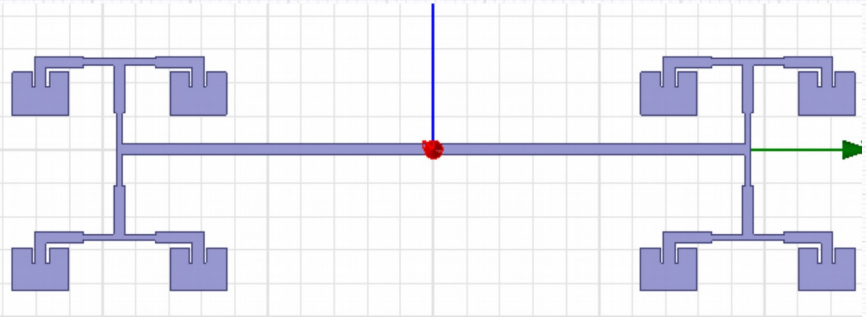
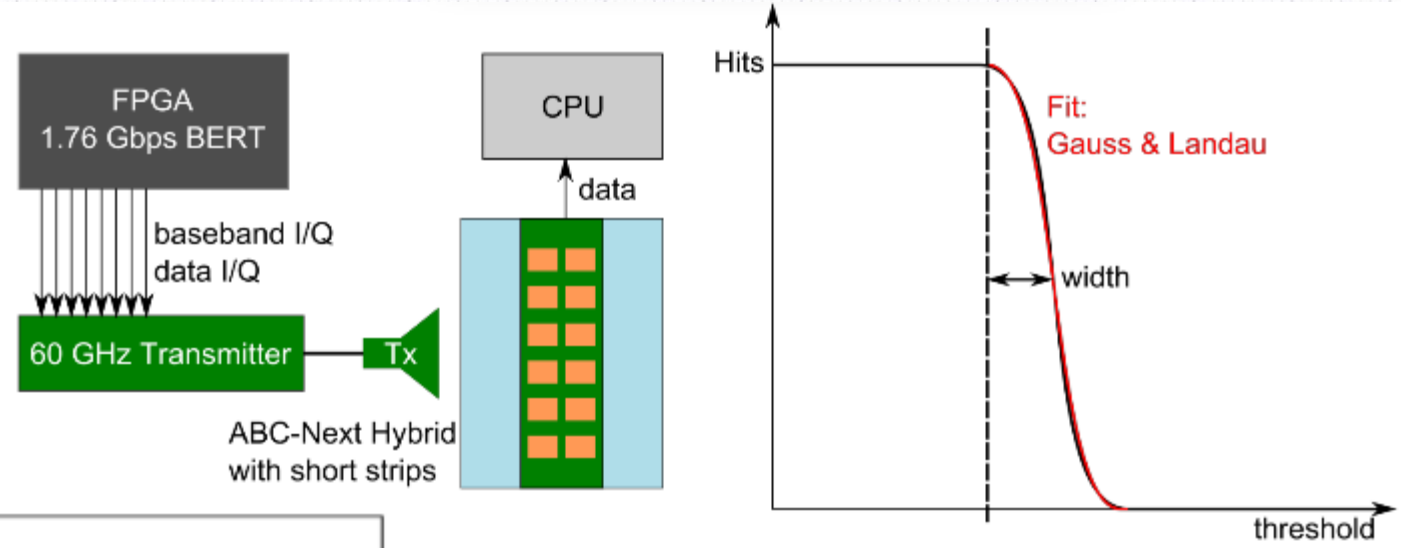
- Silicon layers not transparent to radio because of metallization (high resistivity is OK)
- To transmit signals through boundaries some mechanism to bring signal trough a layer → wave guide, hole, repeater?

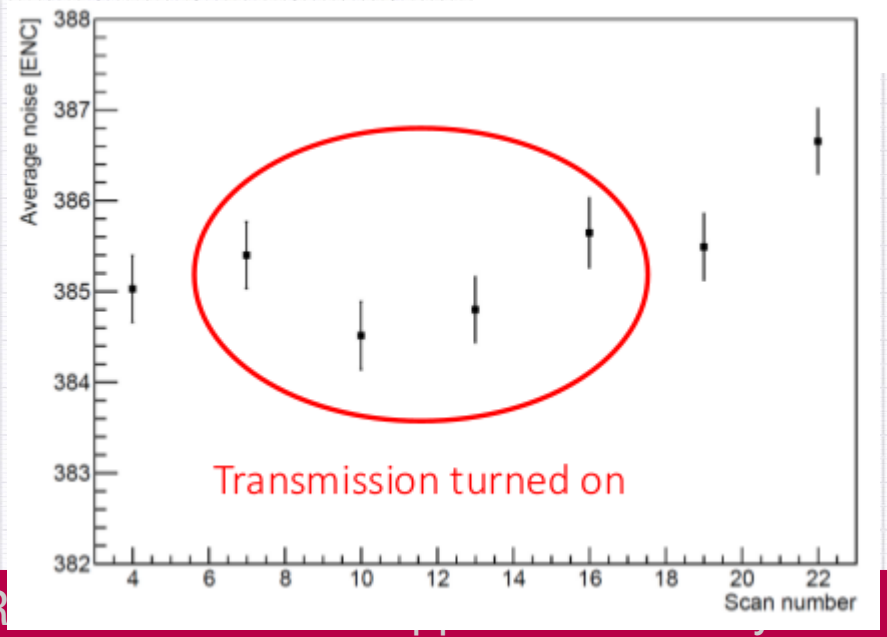






Interference on 60 GHz on detector readout





- Test with ITK hybrid with ABC130 ASICS

  → No measurable increase in noise

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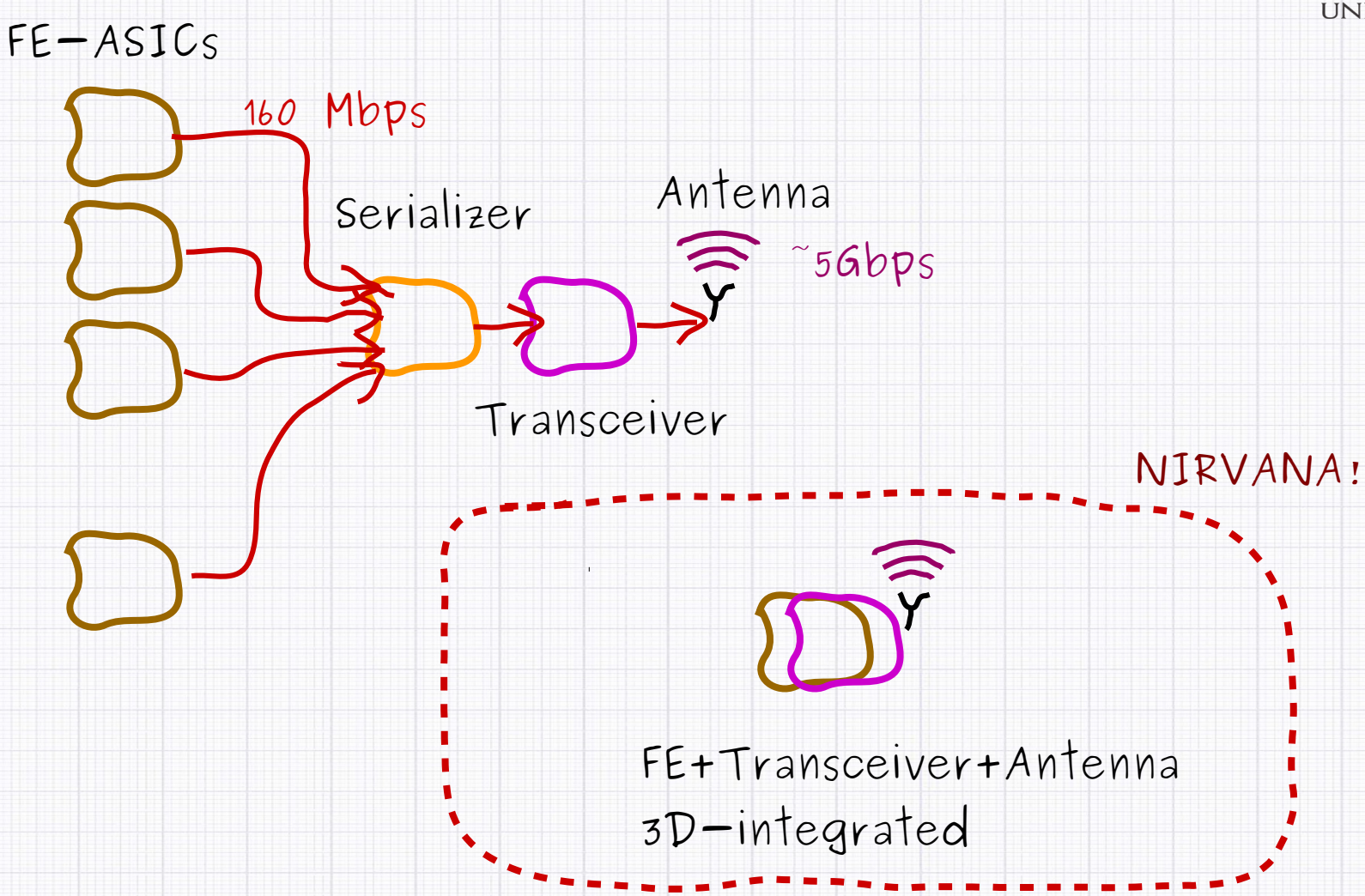
Towards a WiFi GBT link demonstrator

GBT-link


FE-ASICs
160 Mbps
Serializer
Antenna
~5Gbps
Transceiver
NIRVANA!
FE+Transceiver+Antenna
3D-integrated

Development by LETI

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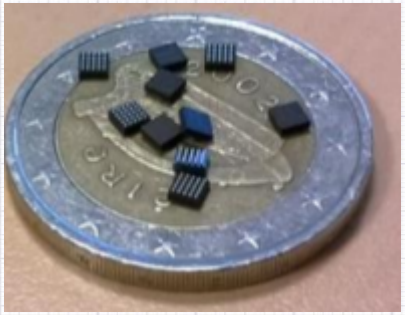
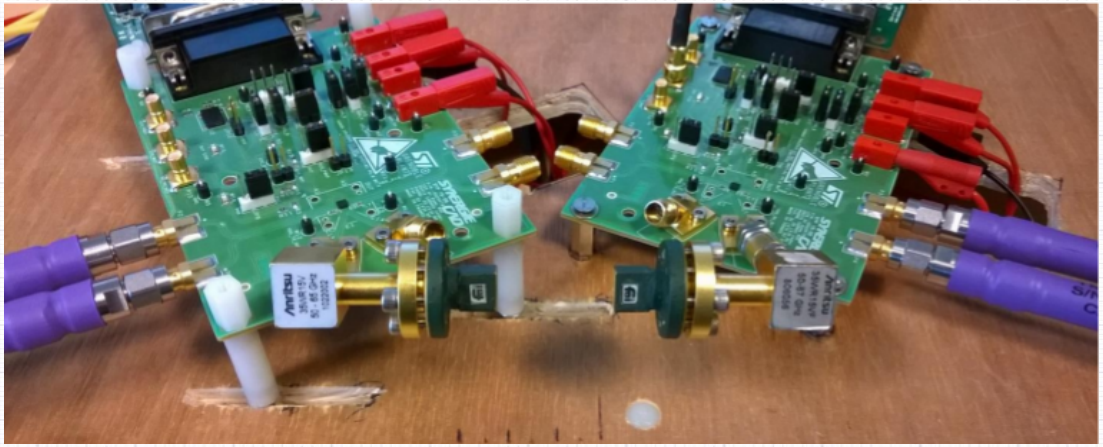
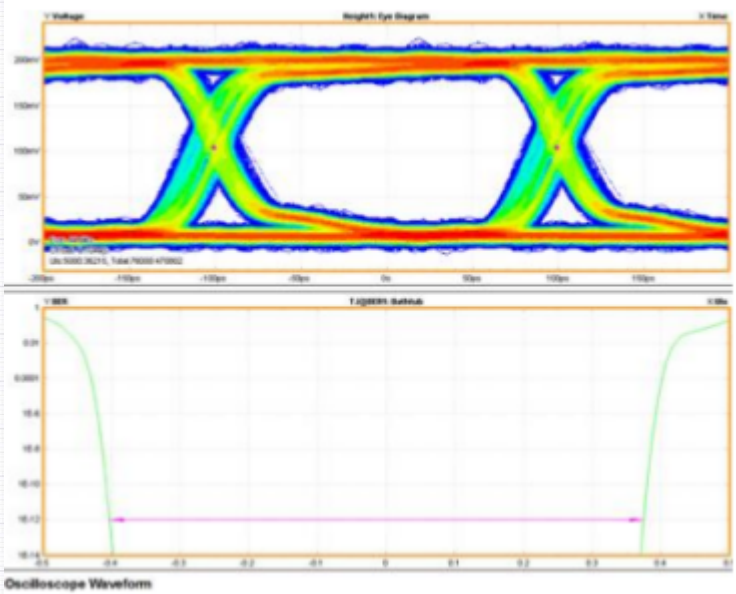
- CMOS65nm chip, BGA package
- OOK/ASK modulation
- Data rate: 500Mbps-8Gbps
- Range: 2-3cm (with 6dB antenna gain)
- Power consumption:
- 40mW Tx/20mW Rx
- BER<1e-12 at 5 Gbps







Development by Uni. Heidelberg/Bergen

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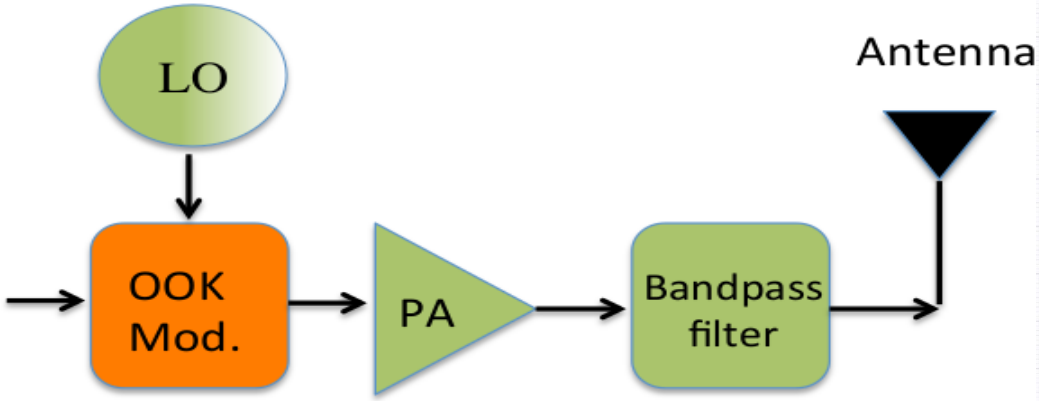
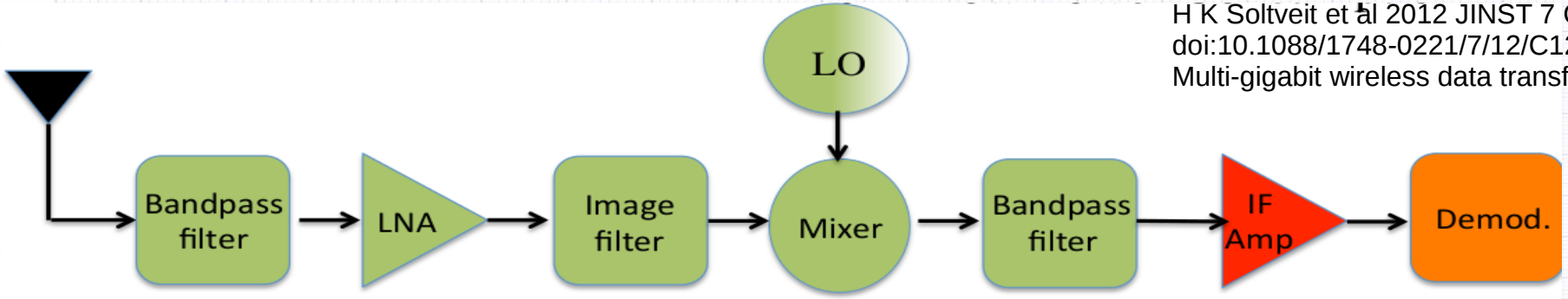


- Transmitter:
  - Deliver required output power
  - Power efficient
  - High gain and stability
- Receiver:
  - Balance gain, linearity and NF
  - Low Power Consumption

H K Soltveit et al 2012 JINST 7 C12016
doi:10.1088/1748-0221/7/12/C12016
Multi-gigabit wireless data transfer at 60 GHz



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Technology

- 130 nm SiGe-Bi-CMOS
- SiGe NPNs, We = 120 nm, ft = 200 GHz, BVceo = 1.8V
- 130 nm CMOS FETs 1.5/25V

High Integration level

- Fully-characterized Millimeter Wave Passive Elements
- Resistors, Varactors, MOS, MIM-caps, inductors,
- Transmissions lines, etc.

Silicon On Insulator(SOI) → Isolaton in the gigahertzrange

Final choice of technology is still under discussion until final specifications are given

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- Low Noise Amplifier: 13 mW
- Gilbert Mixer: 7 mW
- Local Oscillator: 20 mW
- Intermediate Amplifier: 10 mW
- Modulation Scheme: 20 mW
- Demodulation Scheme: 20 mW
- Power Amplifier: 60 mW

Power Consumption: 150 mW

Specifications	Value
Frequency band	57-66 GHz
Bandwidth	**9 GHz**
Data Rate	**4.5 Gbps**
Modulation	OOK
Minimum sensitivity $S_{rx(min)}$	- 49 dBm
Bit Error Rate (BER)	10^{-12}
Target Power consumption	**150 mW**
Transmission Range	20 cm (1m)

Transceiver + antenna (LETI)

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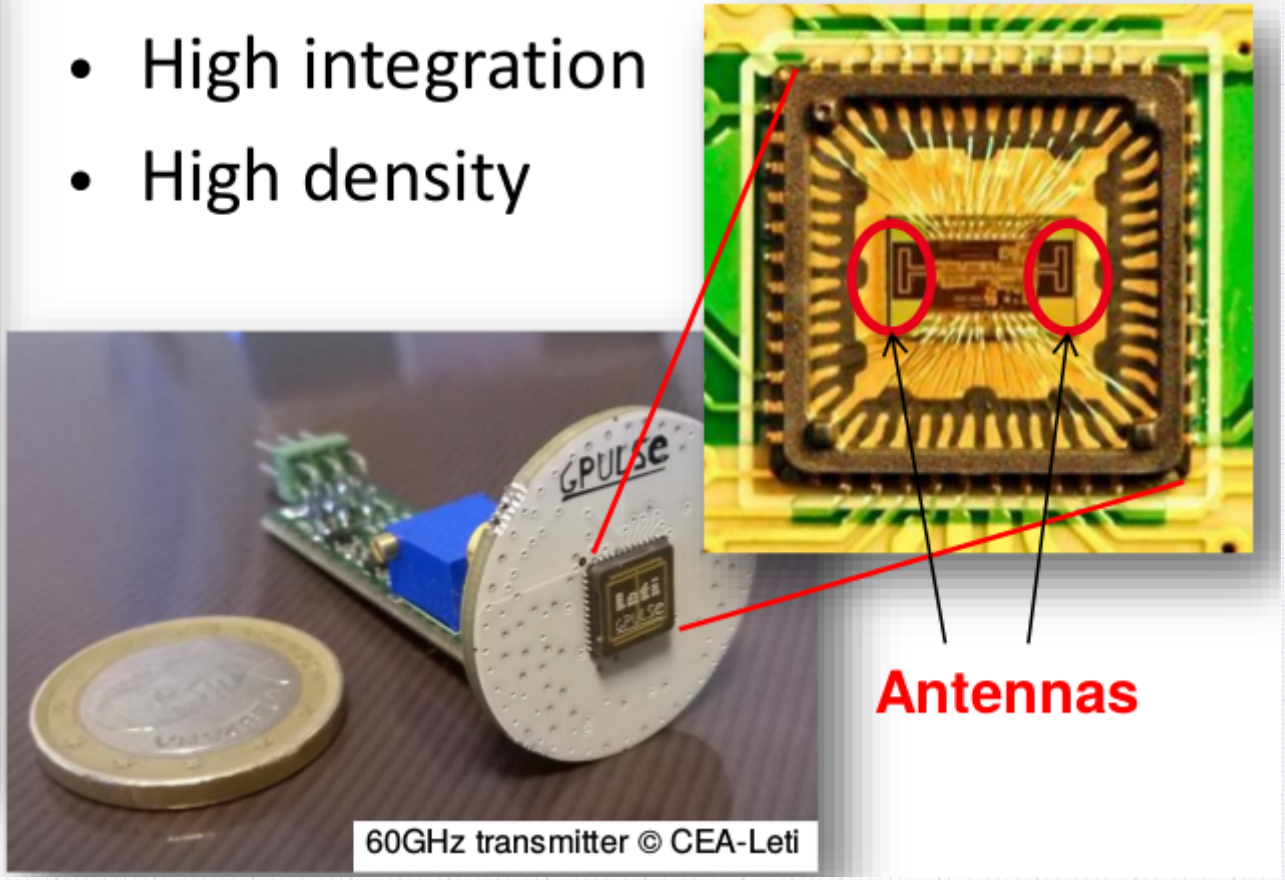
- Compact and low power system
- High integration
- High density



Future prospects

240 GHz wireless transceiver (IHCT Wuppertal)

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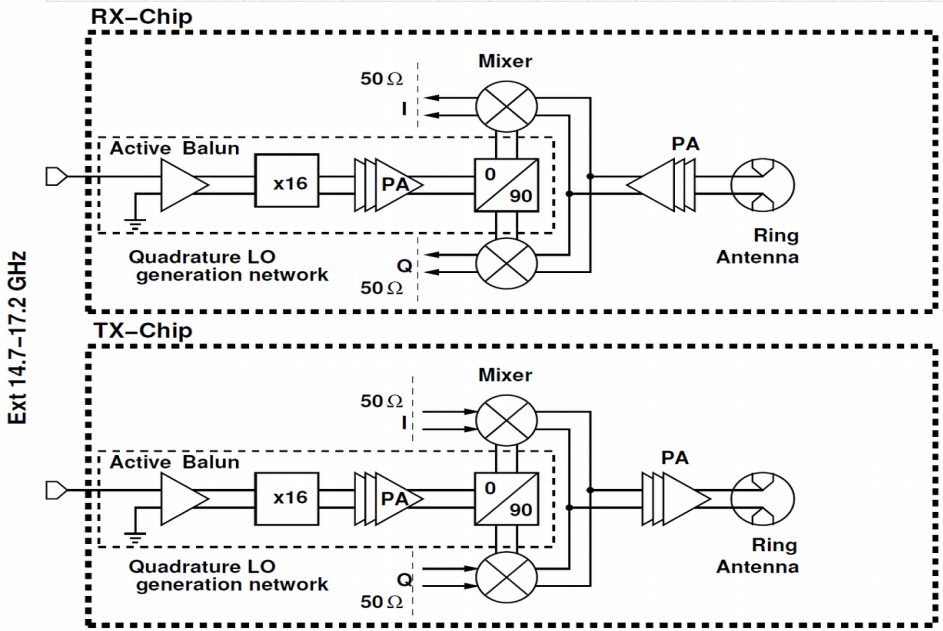
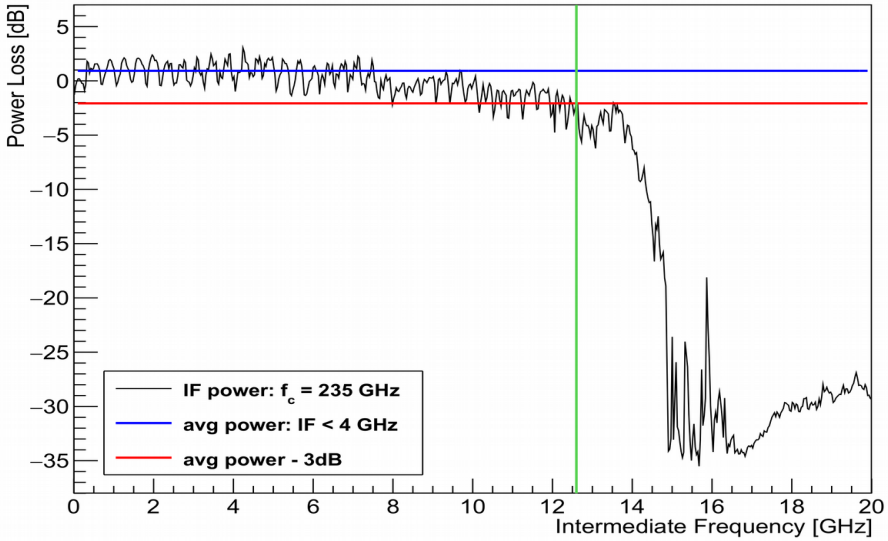


N. Sarmah, P. R Vazquez, J Grzyb, W. Foerster, B. Heinemann, U. R. Pfeiffer
"A Wideband Fully Integrated SiGe Chipset for High Data Rate Communication at 240 GHz"

- 0.13 µm SiGe HBT technology
- Up to 6 dBm of output power
- Power consumption:

  $P_{Tx} \approx 1.5W$

  $R_{Rx} \approx 1.53W$
- Measured IF Bandwidth > 12 GHz



240 GHz wireless data transmission studies

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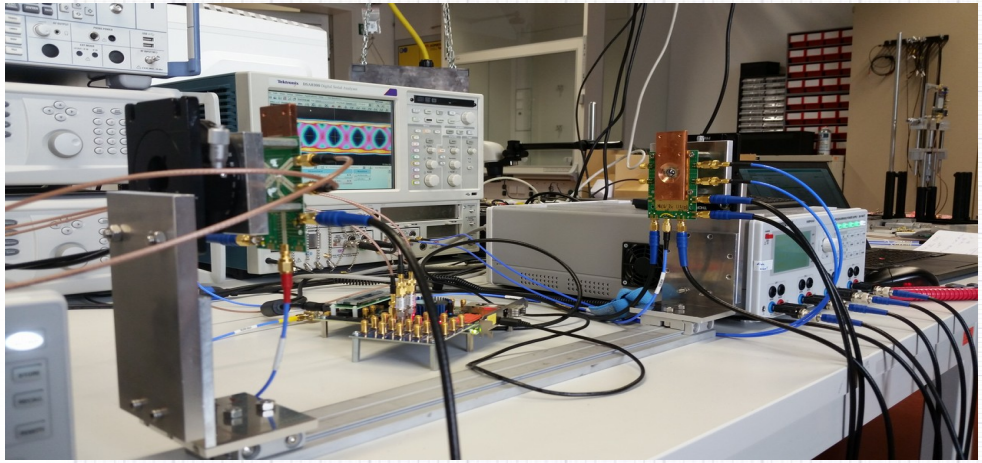
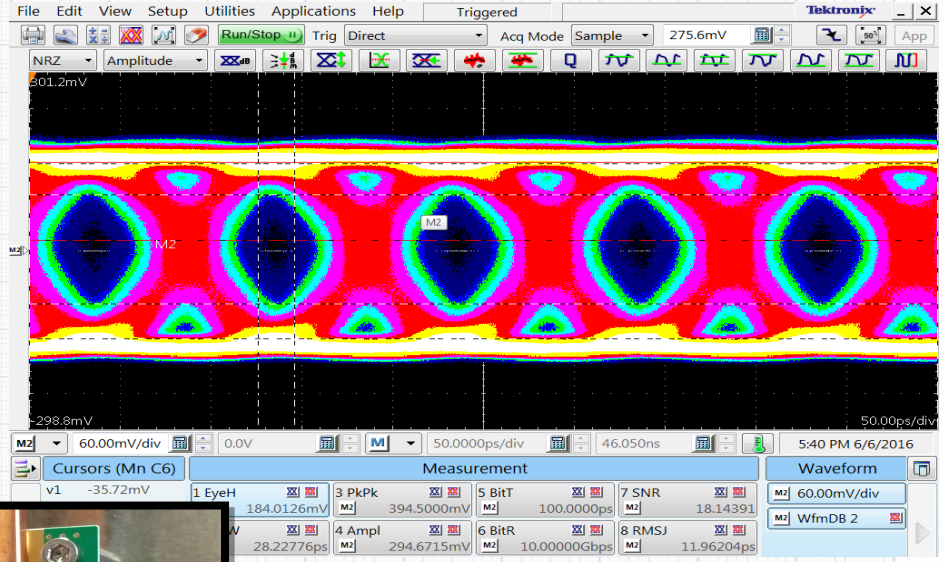
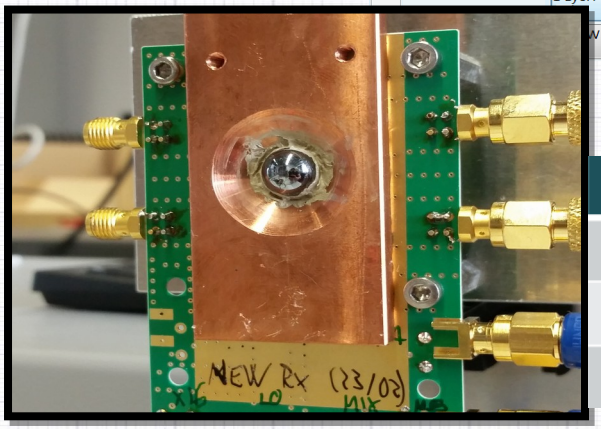
Setup in the laboratory at PI Heidelberg



10 Gb/s pseudo random data stream (PRBS7)



- Transmission distance ≈ 40 cm
- Silicon lenses G ≥ 25 dBi
- Binary Phase Shift Keying



Data rate [Gb/s]	Bit error rate
8.0	$\leq 5 \cdot 10^{-13}$
10.0	$3 \cdot 10^{-14}$
12.0	$5 \cdot 10^{-10}$

Summary and outlook

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- Wireless data transmission with mm-waves (60 GHz and higher) is an attractive option for tracking detectors.
- GBT data transfer has been demonstrated
- Link spacing of 10 cm and below has been demonstrated
- Antenna-system designs can be easily tailored fit tracker
- Potential to build topological systems
- First compact low power GBT for use in trackers are being developed
- Technology to build links with carrier frequencies higher than 60 GHz will allow for even higher data transfer
- WADAPT is welcoming more ethusiastic collaborators on this technology - more information on program in https://arxiv.org/pdf/1511.05807.pdf

VERTEX 1992

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Back-up

Bit-energy efficiency @ 60 GHz

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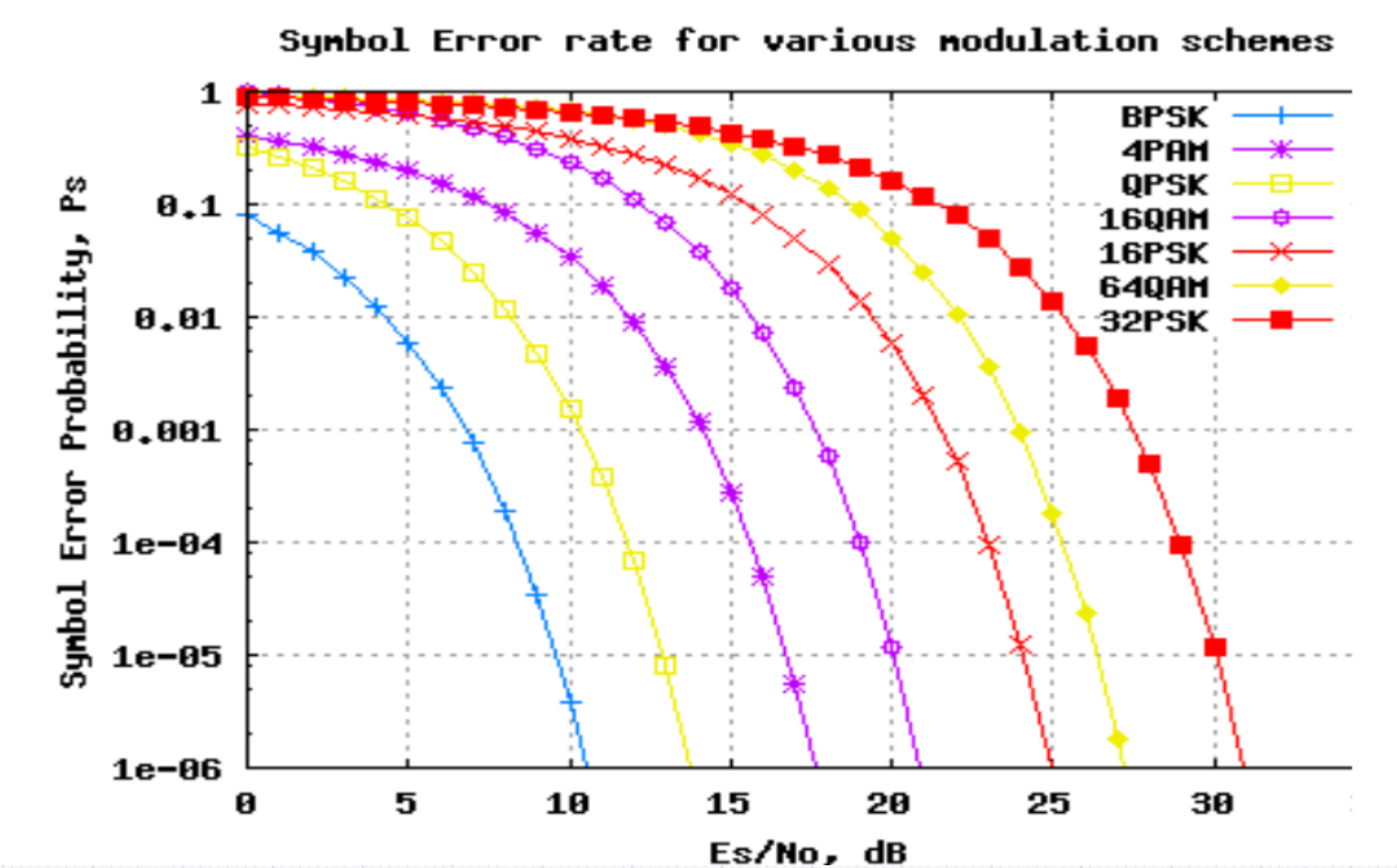
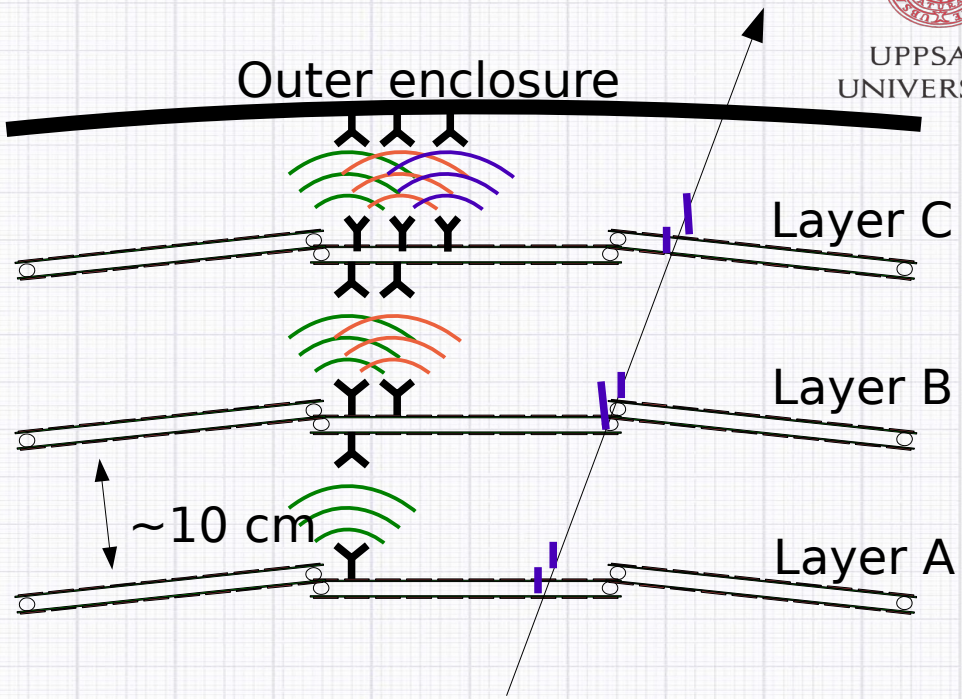
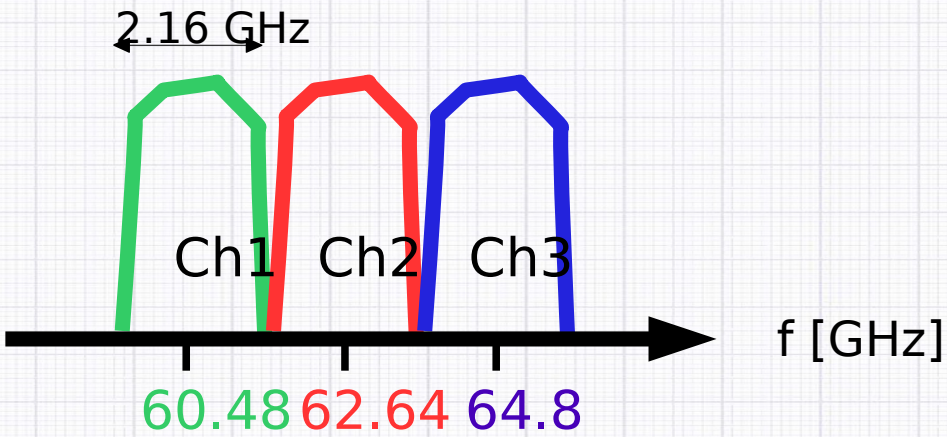
TABLE I. COMPARISON OF HIGH-SPEED 60-GHZ-BAND OOK DEMODULATORS

Ref.	Technology	Freq. (GHz)	Data rate (Gbps)	BER	P_{diss} (mW)	Energy/ bit (pJ/bit)
[4](1a)	40-nm CMOS	56	11	$< 10^{-11}$	41(1b)	3.7
[12](2a)	0.13-μm SiGe BiCMOS	60	10	N/A(2b)	21	2.1
[9](3a)	0.12-μm SiGe BiCMOS	55	6	10^{-12}	11(3b)	1.8(3b)
[8](4a)	0.13-μm CMOS	60	5	N/A	14.7(4b)	2.9(4b)
[10](5)	90-nm CMOS	62	5	N/A	49	9.8
This(6) work	0.25-μm SiGe BiCMOS	60	11.5	10^{-12}	27.5	2.4

(1a) wireless test using $2^7 - 1$ PRBS at 1.4 cm, transmitted power = 0 dBm, LNA is included, (1b) receiver only
(2a) tested with input power of -28 dBm, input amplifier is included but without limiting amplifier, (2b) BER is not clearly defined in the paper
(3a) wireless test using $2^{31} - 1$ PRBS, input power = -36 dBm, LNA is included, (3b) single-ended topology, without on-chip limiting amplifier (off-chip coaxial amplifier consumes 150 mA)
(4a) tested using $2^{31} - 1$ PRBS, no LNA, limiting amplifier is included, (4b) single-ended topology
(5) tested using $2^{31} - 1$ PRBS, no LNA, limiting amplifier is included
(6) tested with input power of -10.6 dBm using $2^7 - 1$ PRBS, no LNA, limiting amplifier is included

BER vs. modulation



- For maximum simplicity, keep all modules independent.
- Each layer transmit with different frequencies
- Signal from inside is forwarded unchanged through layer by repeater electronics