Radial transfer of tracking data with wireless links

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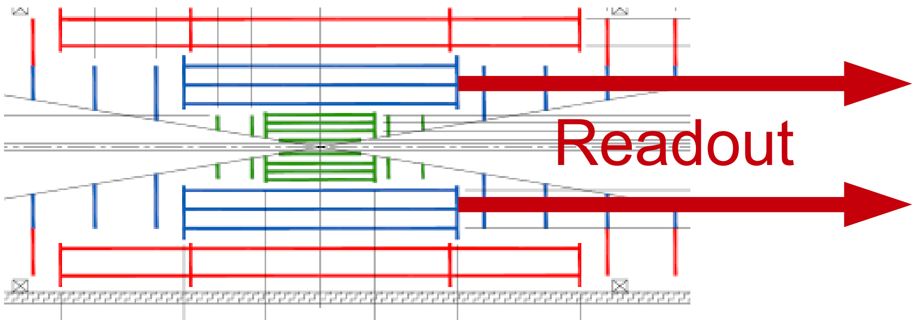
Introduction

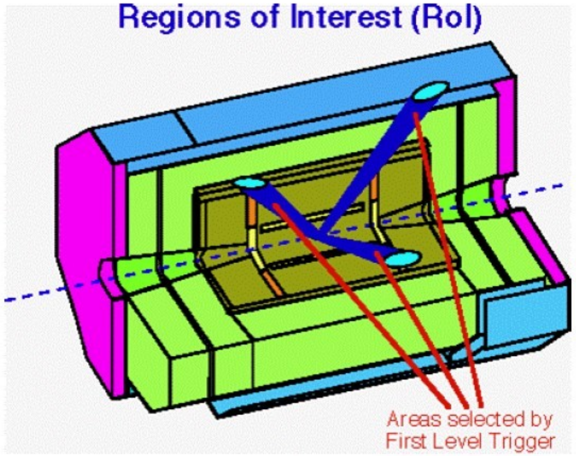
- Why wireless in the track triggers
- 60 GHz technology
- What can we do with it?
- Design of antennas
- Passive data transfer through a tracker
- Summary & Outlook

Why wireless in the track trigger

- The current readout is not optimal to build a track trigger.

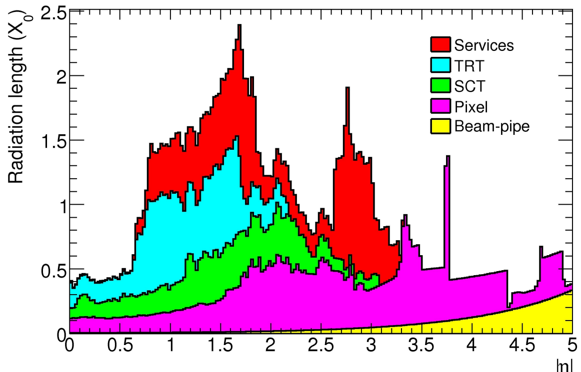


Axial tracker readout resulting in long paths, long latency etc.



Physics events are triggered in RoI that are conical regions radial from the interaction point in Φ and η.

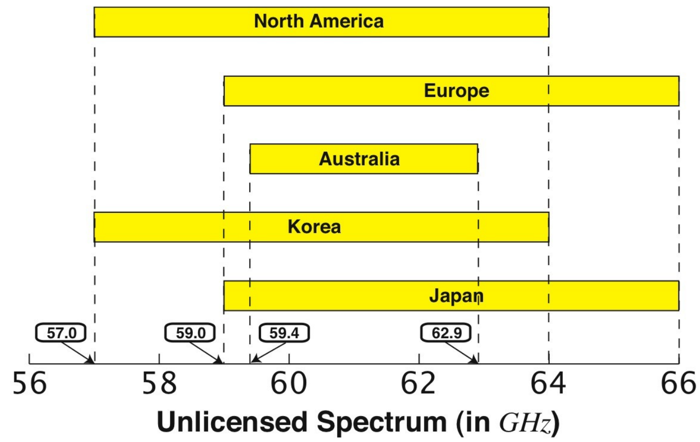
- **How can wireless technology help to solve the problem?**
  - Radial data transfer becomes possible.
    - No cables and connectors needed for data transfer.
    - Topological readout.
    - Build in intelligence into tracking.
  - Small and low mass components.
  - Low power and cost.
  - High bandwidth >5 Gbits/s.

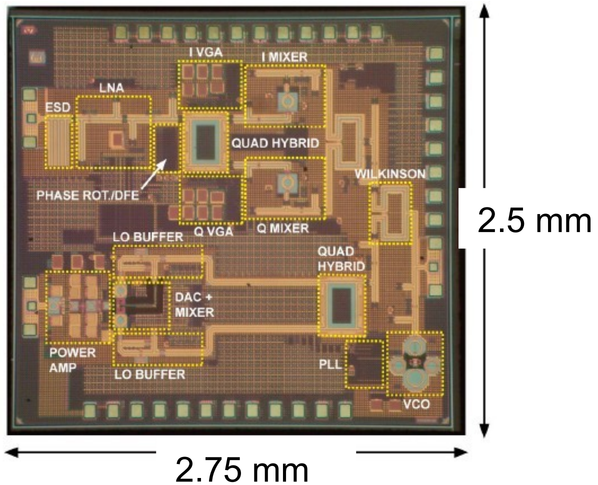


With wireless we can avoid this region if we can transmit through silicon layers.

60 GHz technology

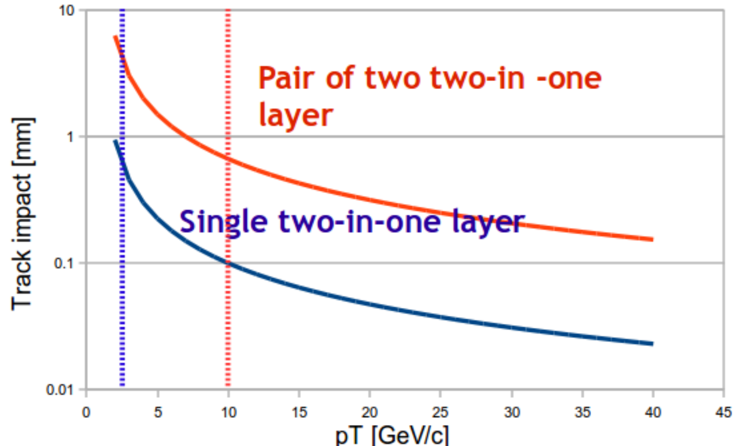
- mm waves
  - Small structures
- Up to 7 GHz unlicensed frequency spectrum.
  - Enormous bandwidth for data transfer.
- Fast developing technology.
  - First implementations are commercially available.
  - A lot of products are expected in the consumer marked, wireless uncompressed video connections...
  - Low power.
  - Achievable in 65nm CMOS.



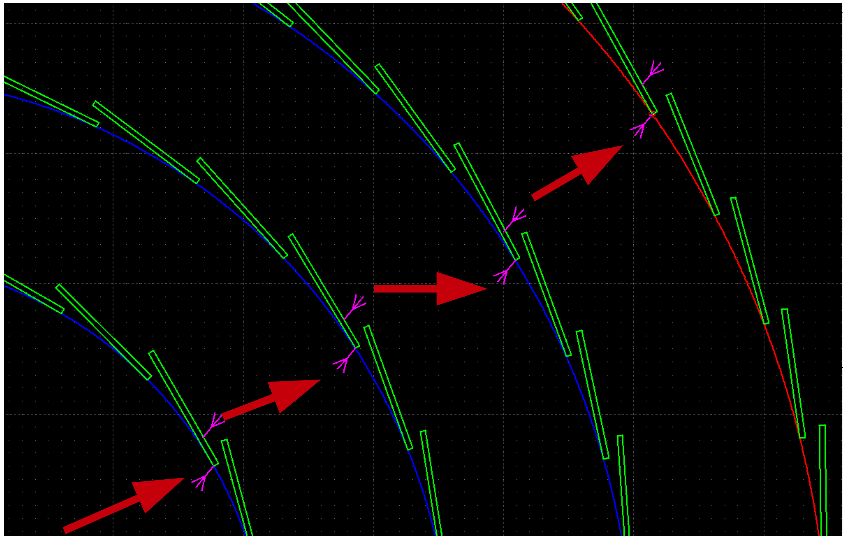


What can we do with it?

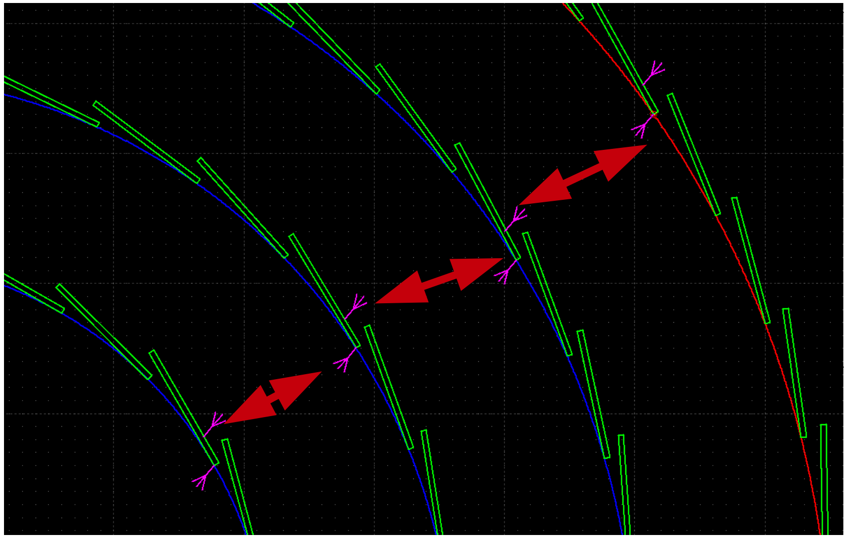
- Build up radial data transfer links.
  - Low latency.
- Different frequencies per layer:
  - 60 GHz does not penetrate through the detector layers.
- Pre analysis already on the layer.
  - Use multiple layer's correlation to reduce fakes.



Two-in-one layer separated by 3 mm
→ pT cut on a few GeV possible in ATLAS.
Two two-in-one layer separated by 20cm
→ pT cut ~10 GeV possible



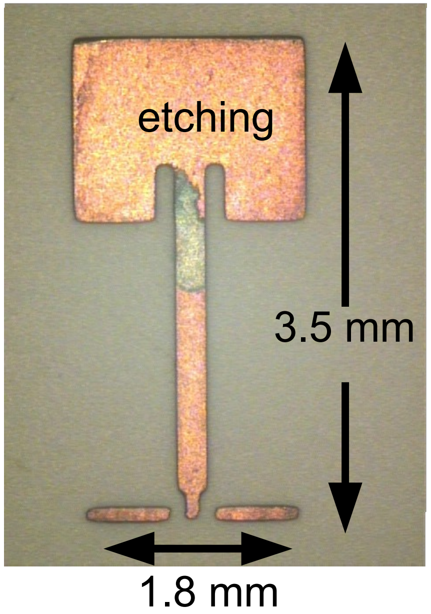
Radial readout



Correlation between layers

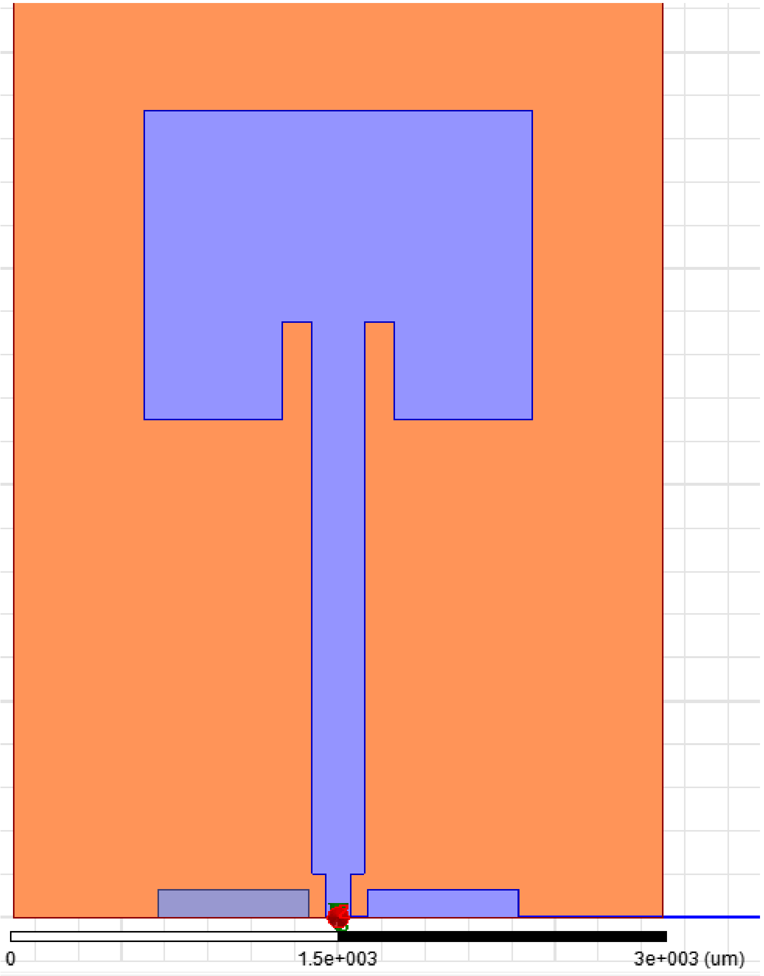
Antenna design

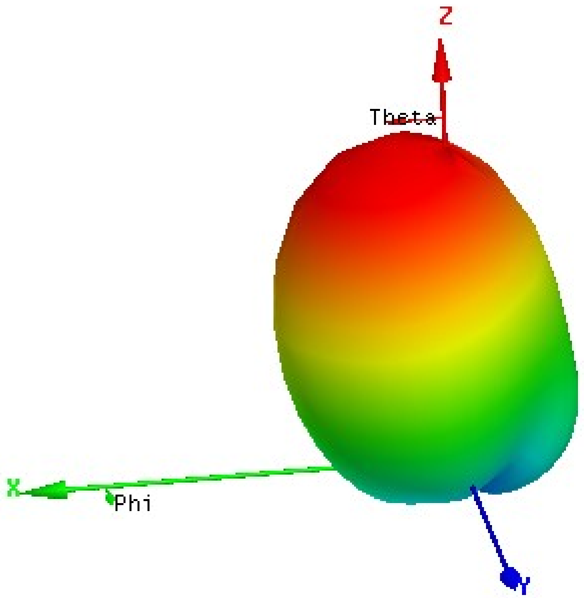
- We have started to design and produce patch antennas.
  - Single and antenna arrays.
  - Can be produced on PCB material.
    - Etching and milling.
    - Rogers, DuPont PCB material
  - Very small structure sizes.



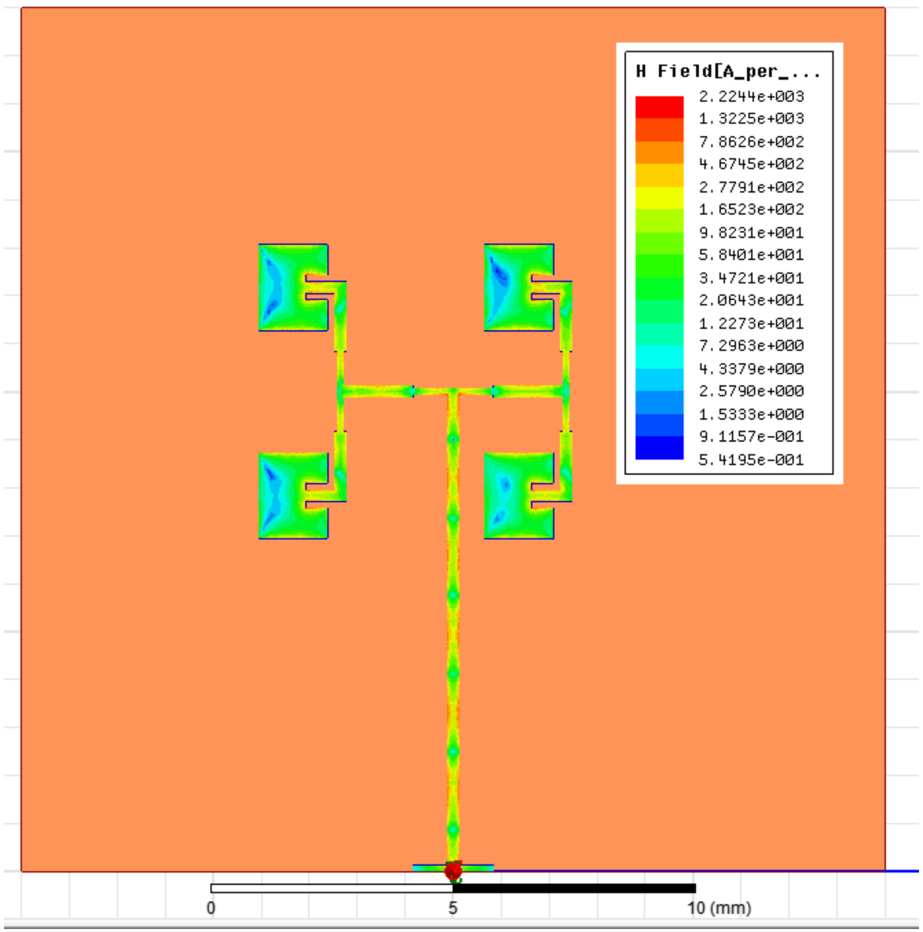
Antenna design - simulation

- Single patch

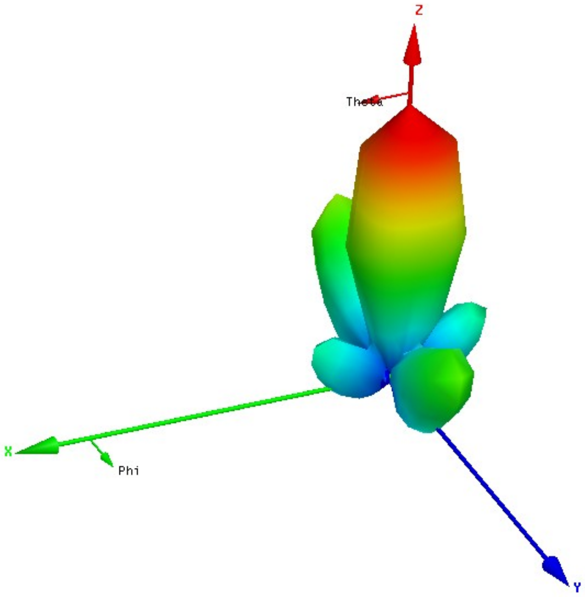




Antenna design - simulation



- Designs for multi patch antennas.
  - 4 Patch design.
  - More focused radiation pattern.
    - reduced cross talk,
    - denser packing of links,
    - higher gain =lower power

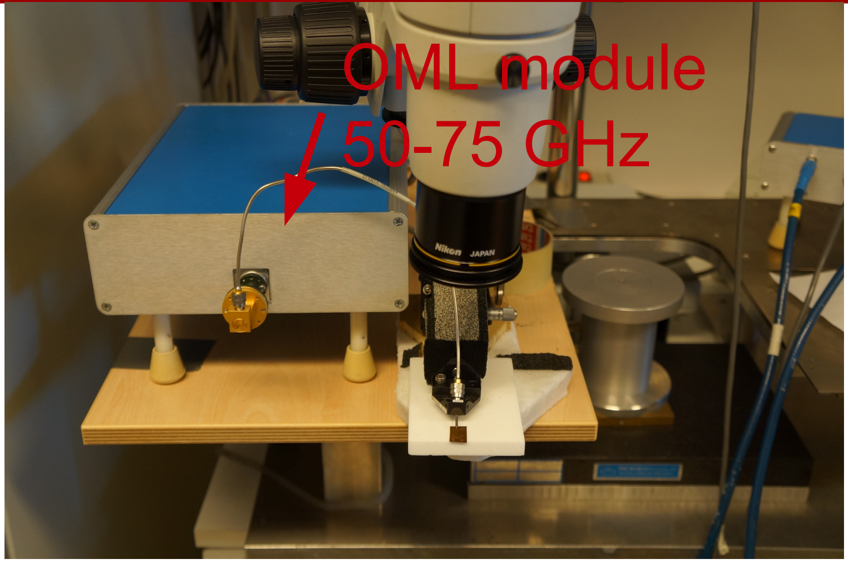


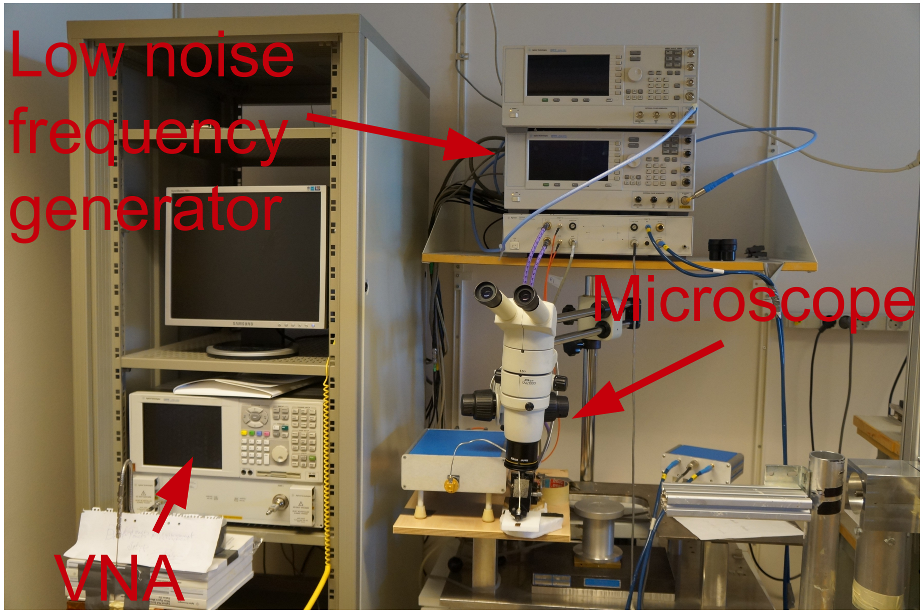
S-parameters

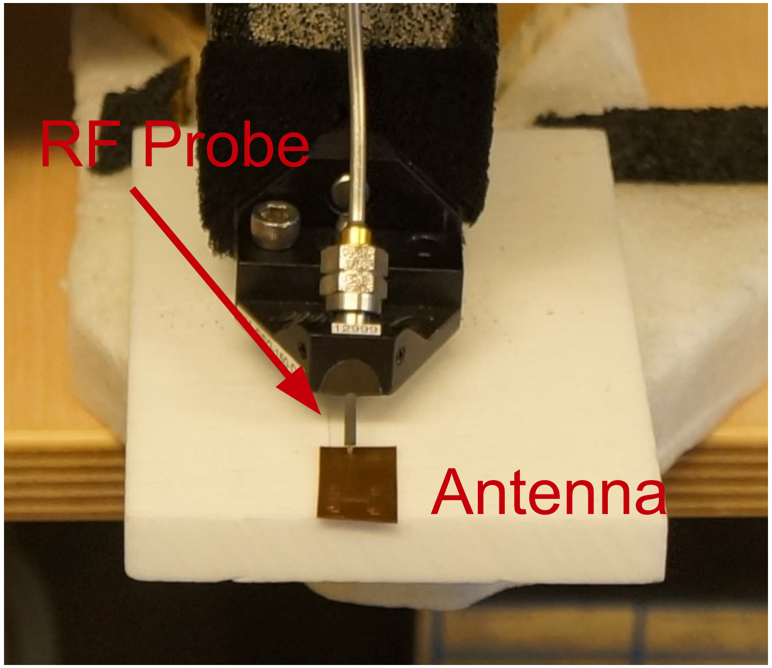
- **S-parameters**:
  - Describe the input-output relationship between ports in an electrical system.
  - Ex.: 2 ports (Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1.
  - Having a transmitter with an antenna connected:
    - S11 is the reflected power Port 1 is trying to deliver to antenna 1.
    - 0dB all power is reflected
    - - 30dB and below almost no power is reflected
      → good matching
  - Frequency depending variable.

Antenna design Simulation vs Real

- Agilent Technology Signal Generator and Vector Network Analyser

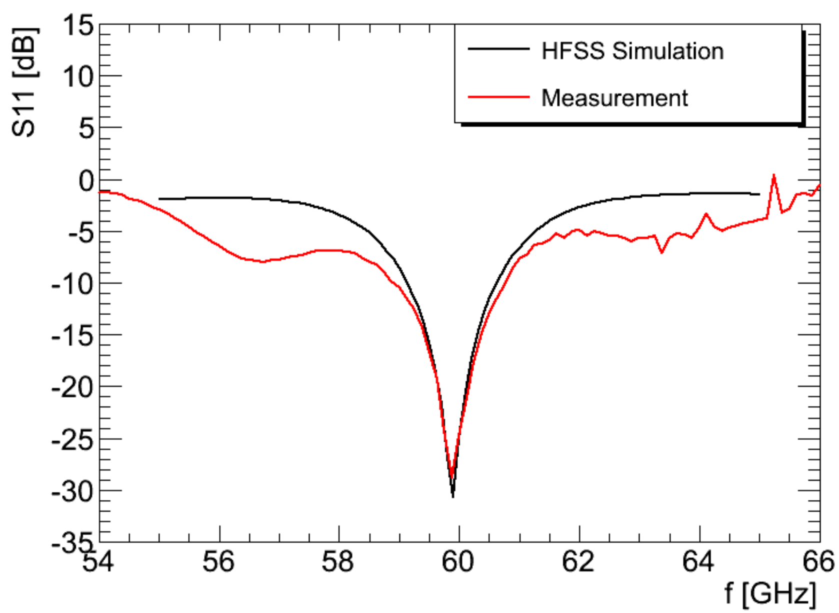




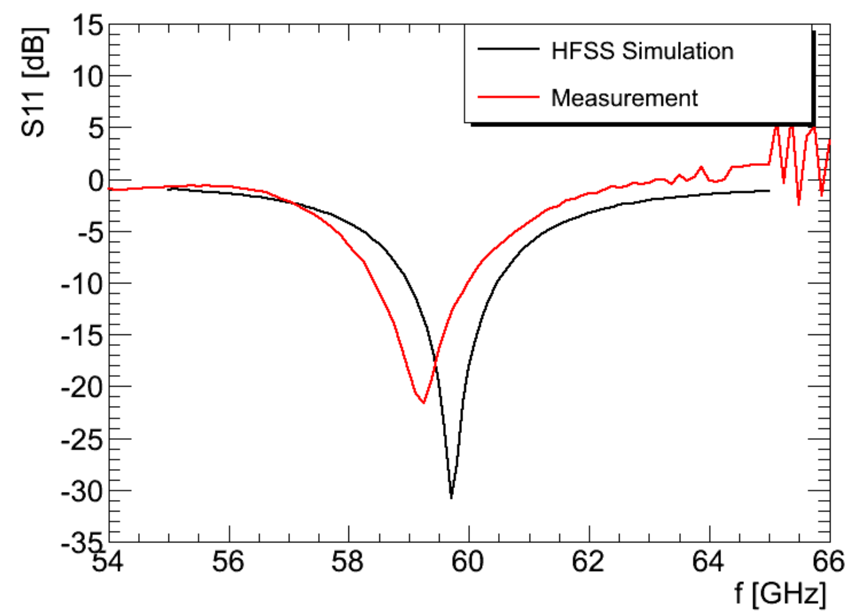


Antenna design Simulation vs Real

- Compare simulation with a manufactured antenna.
  - This gives feedback how well simulation matches reality.
  - Etched antennas were used (PCB etching process).
    - 4 Patch antenna array: very good agreement with simulation.
    - 1 Patch antenna: a shift of ~500MHz.
      - This is good result and shows that antenna production is feasible.



4 Patch design



single patch design

Required fabrication precision

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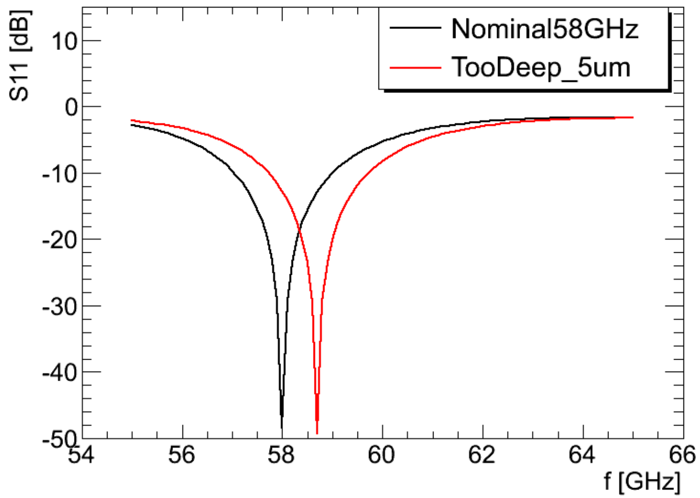
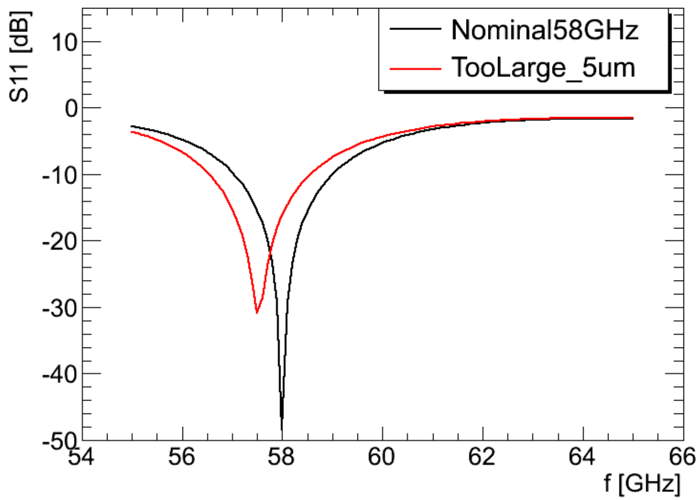
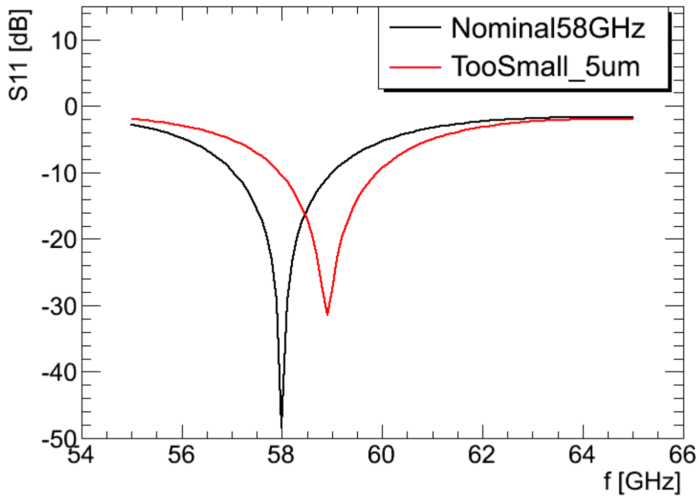


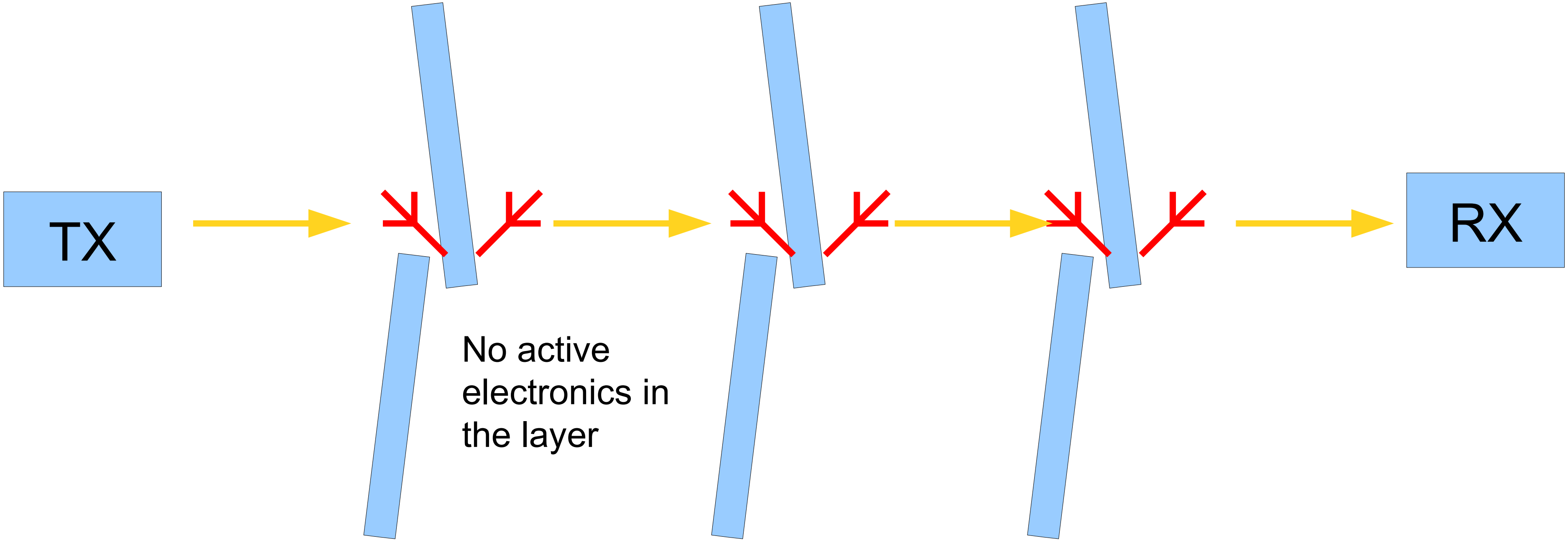


- The effect of fabrication tolerances were studied:
  - Mill too deep through the cooper (remove substrate)
    - → frequency shift to higher f
  - Antenna outer edges 5 um too large
    - → frequency shift to lower f
  - Antenna outer edges 5 um too small
    - → frequency shift to high f
- → Tolerances as small as 5μm can cause shift of ~1GHz



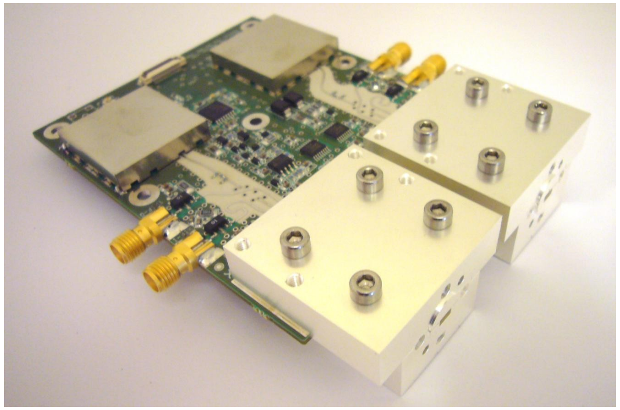
Passive data transfer through layers

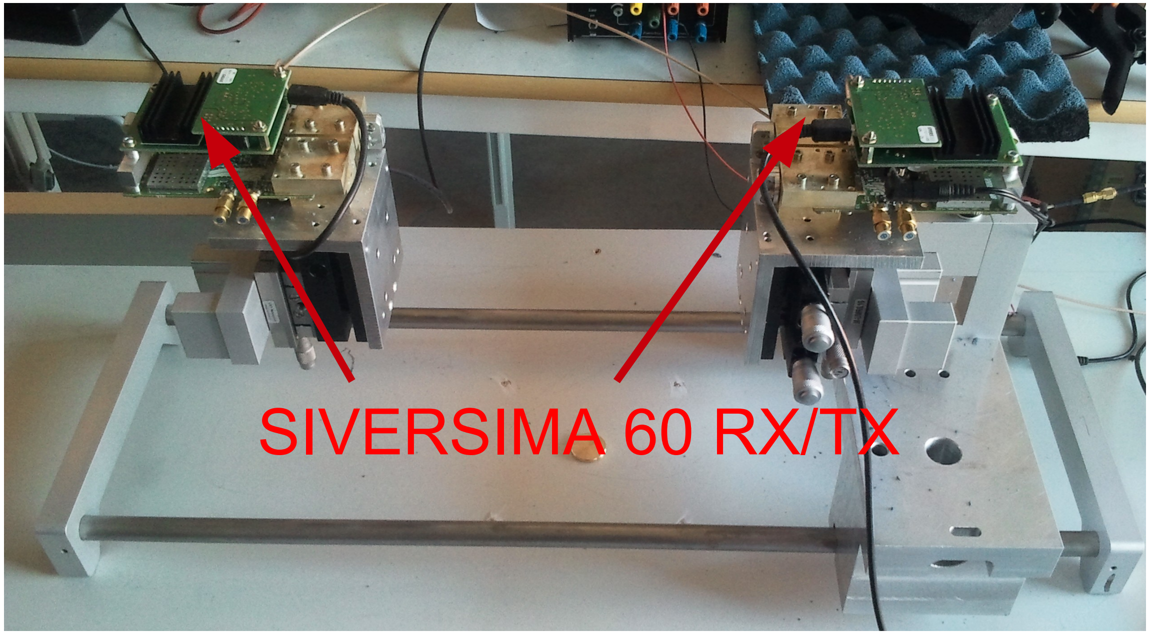
- The amount of electronics could be reduced significantly if one could radiate through detector layers.
  - No active hardware would be needed as a repeater.
  - The links are spread out uniformly around detector and do not have to be routed to the extremely dense gap at η~0.8
- Simple approach:
  - One receiver antenna on one side and a transmitter antenna on the other side.
  - Antennas are connected by a micro strip, no active electronics.



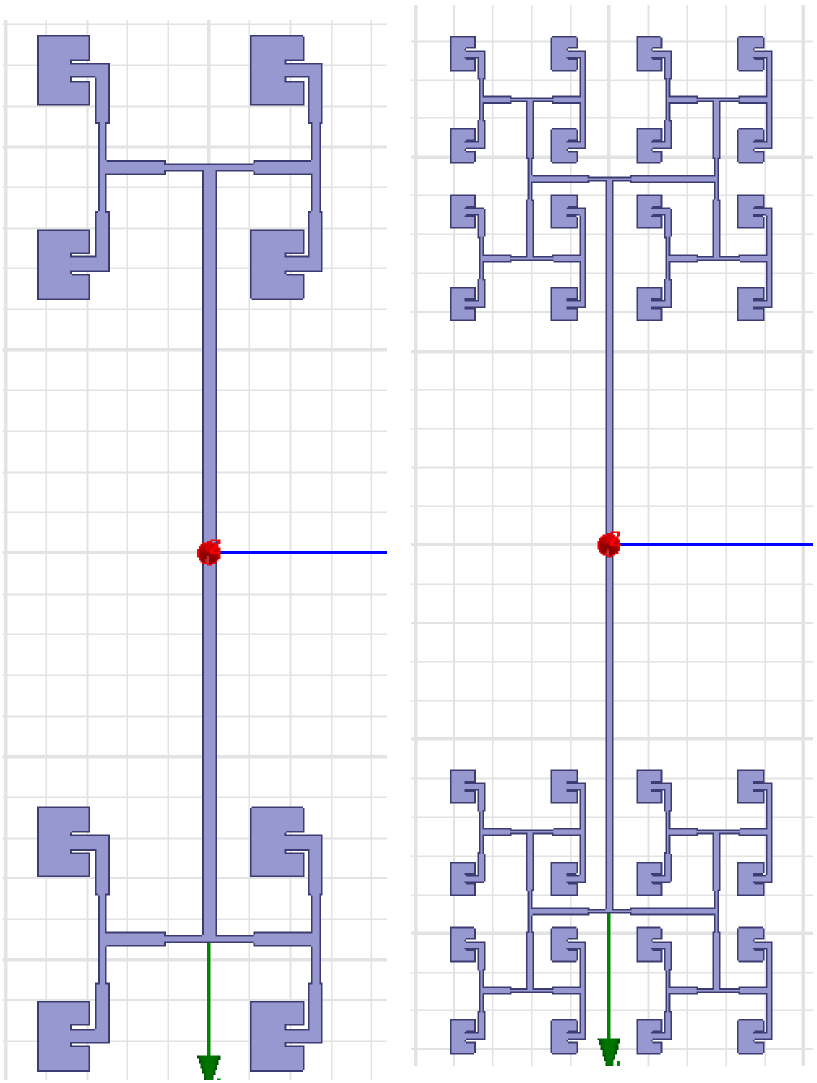
Passive data transfer through layers

- The test setup
  - SIVERSIMA 60 GHz up down converter cards.
    - Duplex card RX and TX.
    - I and Q separately available.
    - Connected horn antennas.



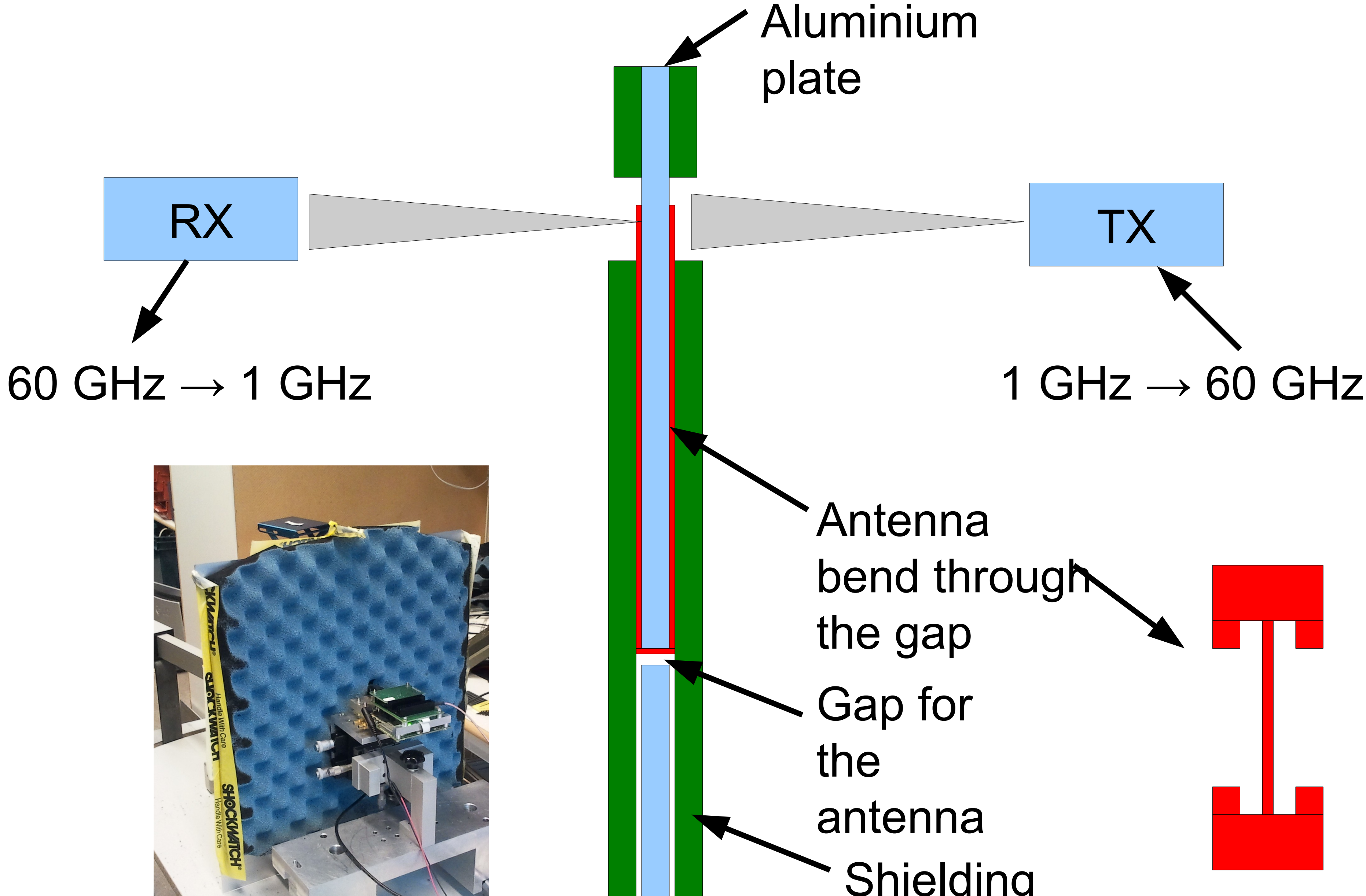


Passive data transfer through layers

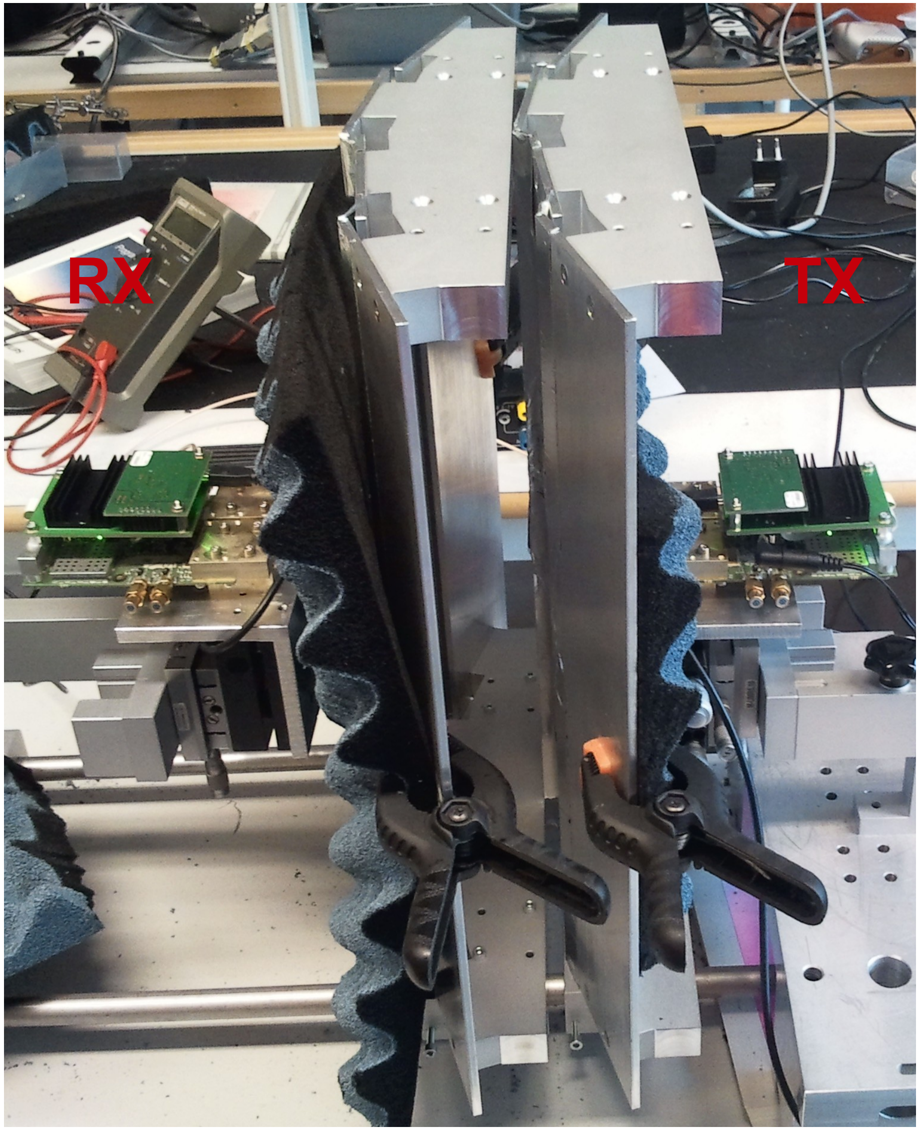


- 1, 4 and 16 Patch design.
  - Patches are connected by micro strip transformers (needed for impedance matching).
  - Antenna arrays are connected by a micro strip.

Passive data transfer through layers

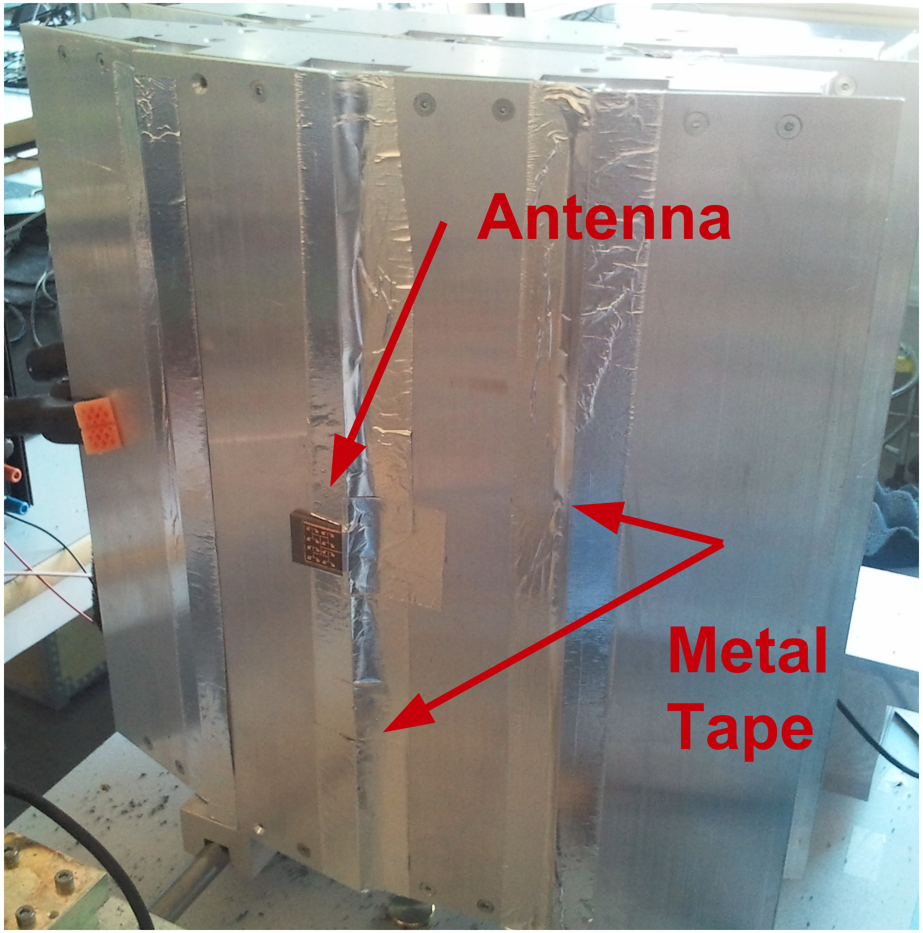


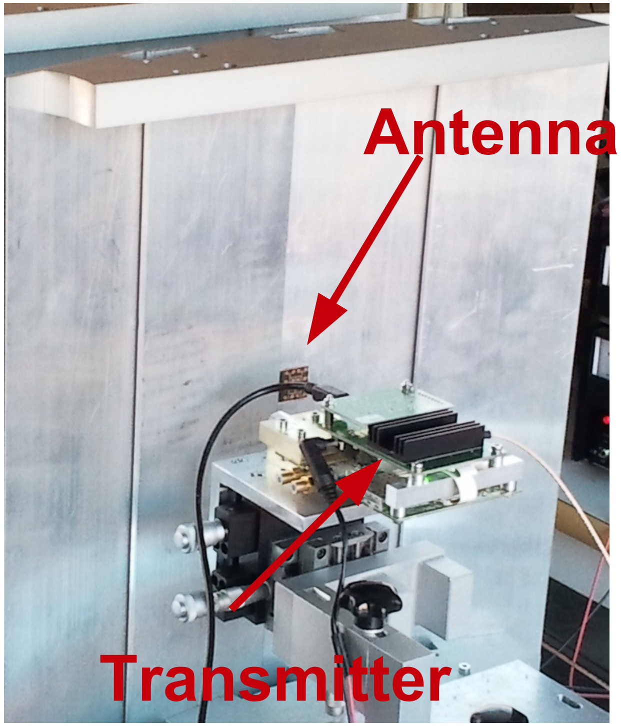
Passive data transfer through layers



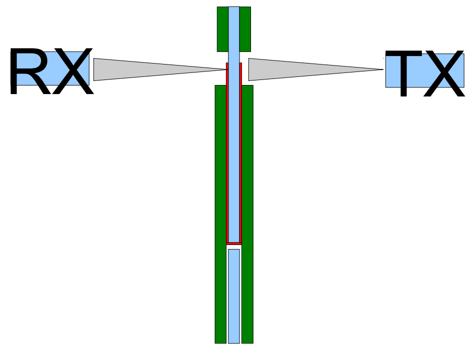
- Two setup
  - Aluminium Plate with small gap to bring though the antenna.
    - Gap is closed by metal tape.
  - Aluminium detector model.
    - 2 detector layers.
- **We are coming trough both setup with just the passive antennas**
  - A BPSK modulated digital signal was send through one detector layer without observing problems.

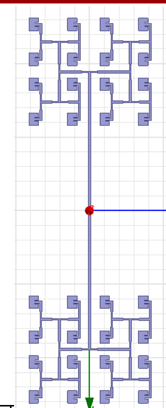
Passive data transfer through layers

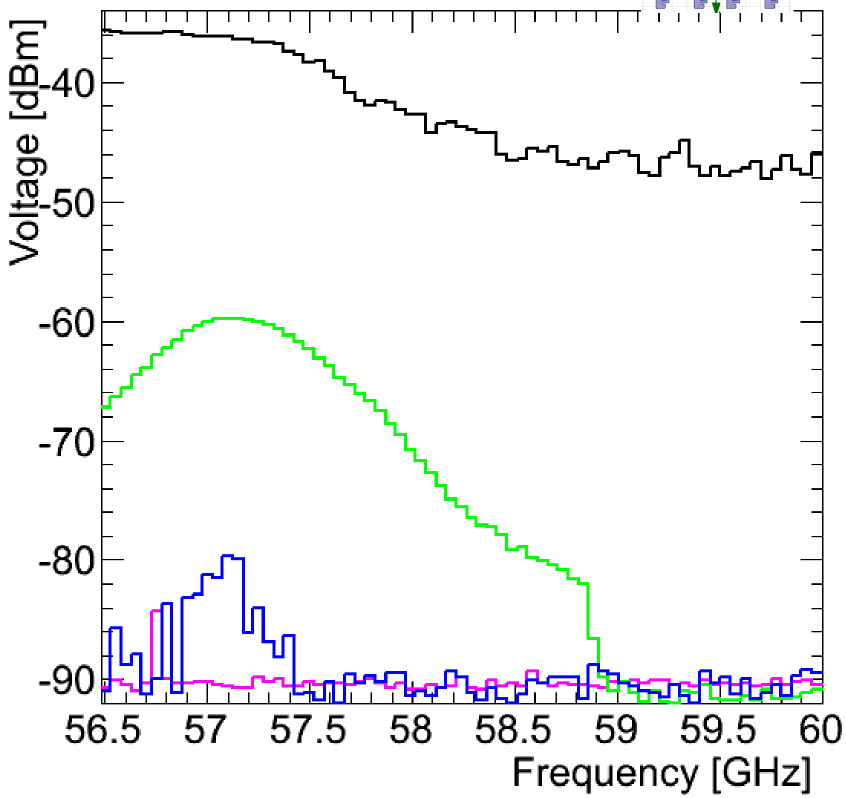




Power loss in the detector layers







- Frequency dependence of the antenna can be observed
- 16 Patch – 16 Patch antenna were used

- **Power estimate:**
  - Horn to Horn 12 cm distance:
    ~ -40 dBm @ 57.2GHz
  - Single antenna : ~ -60dBm
  - Two antennas : ~ -80dBm
  - Background
  - We have ~20dB insertion loss per detector layer.
  - The test was performed with 0.001 W output power
    - +10 dB gain on RX side

Summary & Outlook

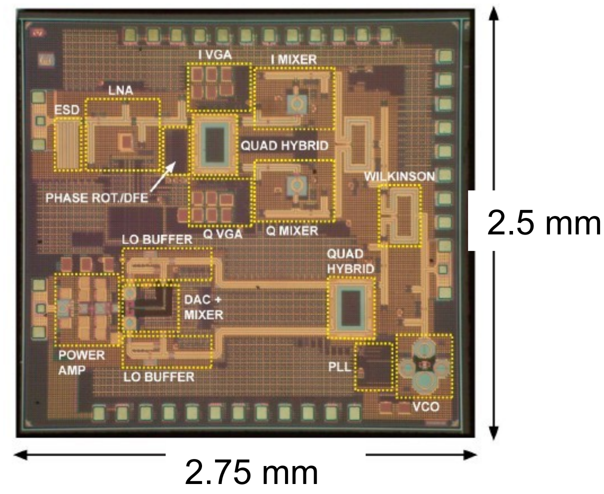
- Summary
  - Wireless data transfer inside a detector system would open up a lot of new possibilities.
    - A key ingredient for a fast track trigger.
  - We have designed antennas with feature size and performance compatible with high bandwidth read out of data from tracking detectors.
  - We have shown that we can bring data through silicon layers radially with passive repeater structures.
- Outlook:
  - We will study data transfer and modulation schemes.
  - An interesting thing is if each readout ASIC can transmit individually to avoid having to collect all read out data to a separate MUX-transeiver chip on hybrid.

Backup

- Backup

Power consumption

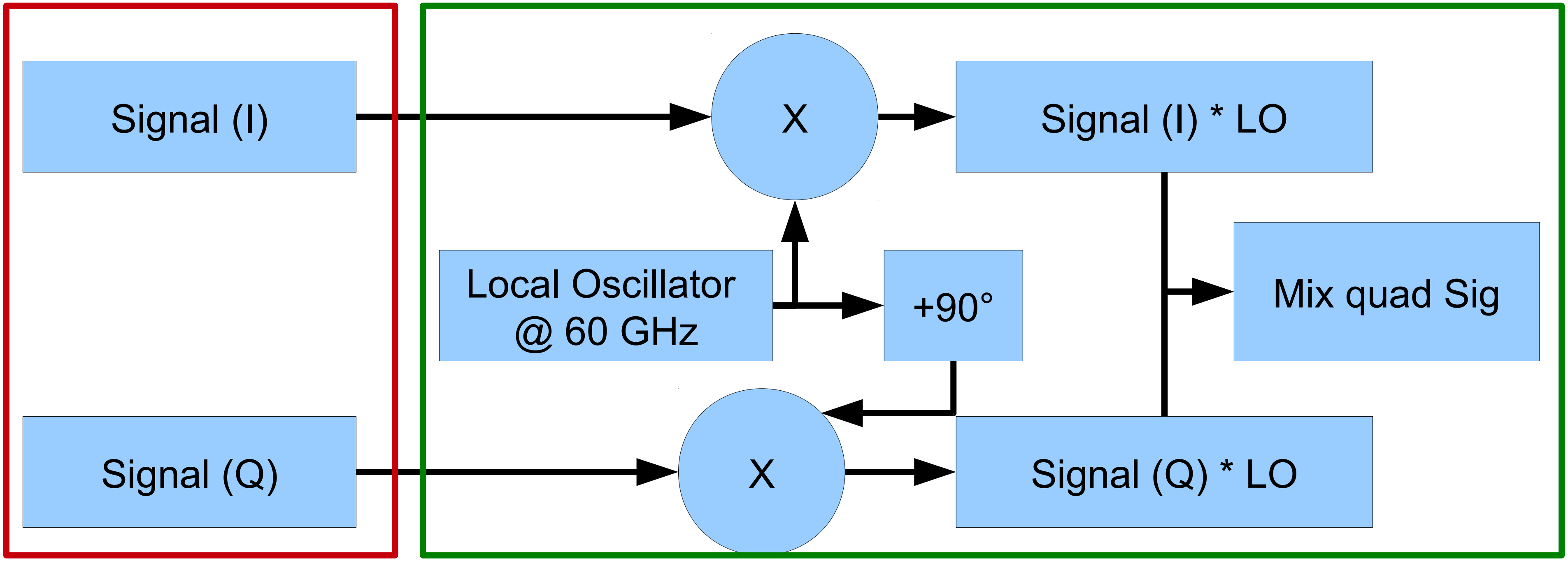
- Low power 60 GHz transceiver that includes **RF, LO, PLL and base band** signal paths integrated into a single chip
- Fabricated in a standard 90 nm CMOS
- With a **1.2 V supply** the chip consumes **170 mW while transmitting 10 dBm (10mW) and 138 mW while receiving.**
- Designed for 10 Gb/s communication using QPSK modulation



- A 90 nm CMOS Low-Power 60 GHz Transceiver With Integrated Baseband Circuitry
  - Published in : Solid-State Circuits, IEEE Journal of (Volume:44 , Issue: 12) Page: 3434 - 3447

Generation of the test frequency

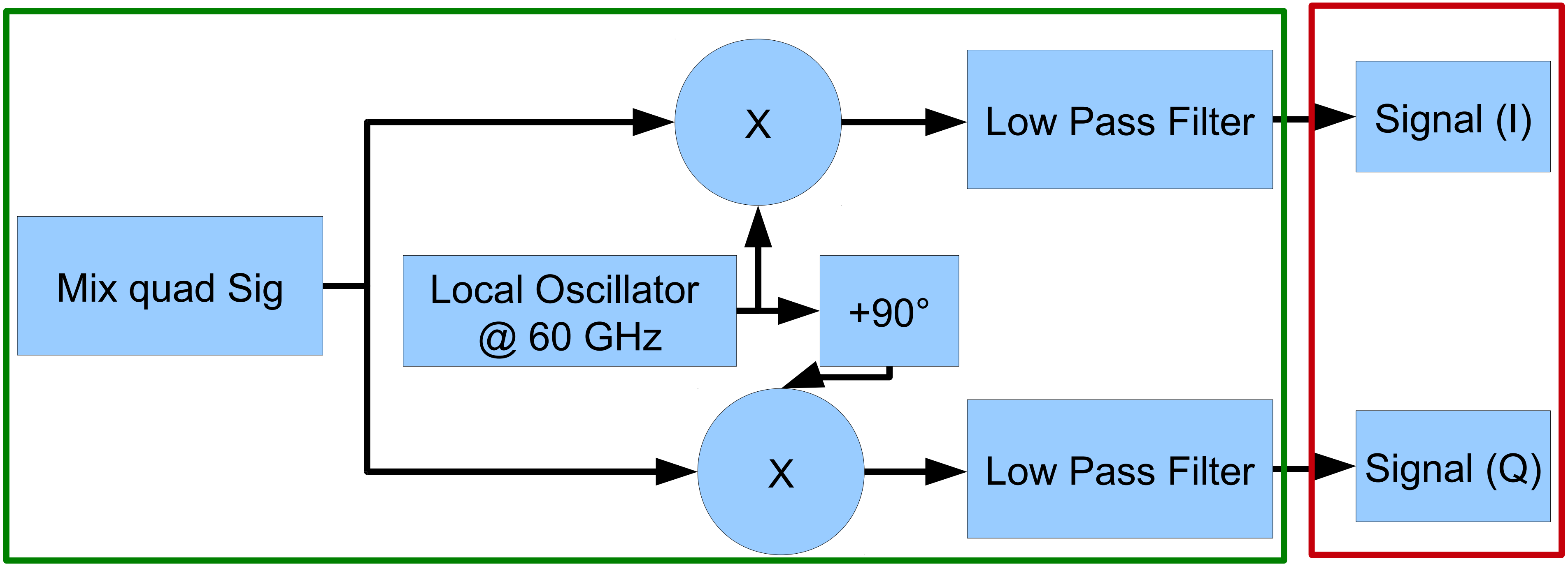
Up conversion (TX)



- I and Q part of the signal is mixed with the frequency of the Local Oscillator (LO)
  - Modulates the baseband on the carrier frequency (60 GHz ± baseband)
- The mixed I and Q part is summed and send through the antenna.

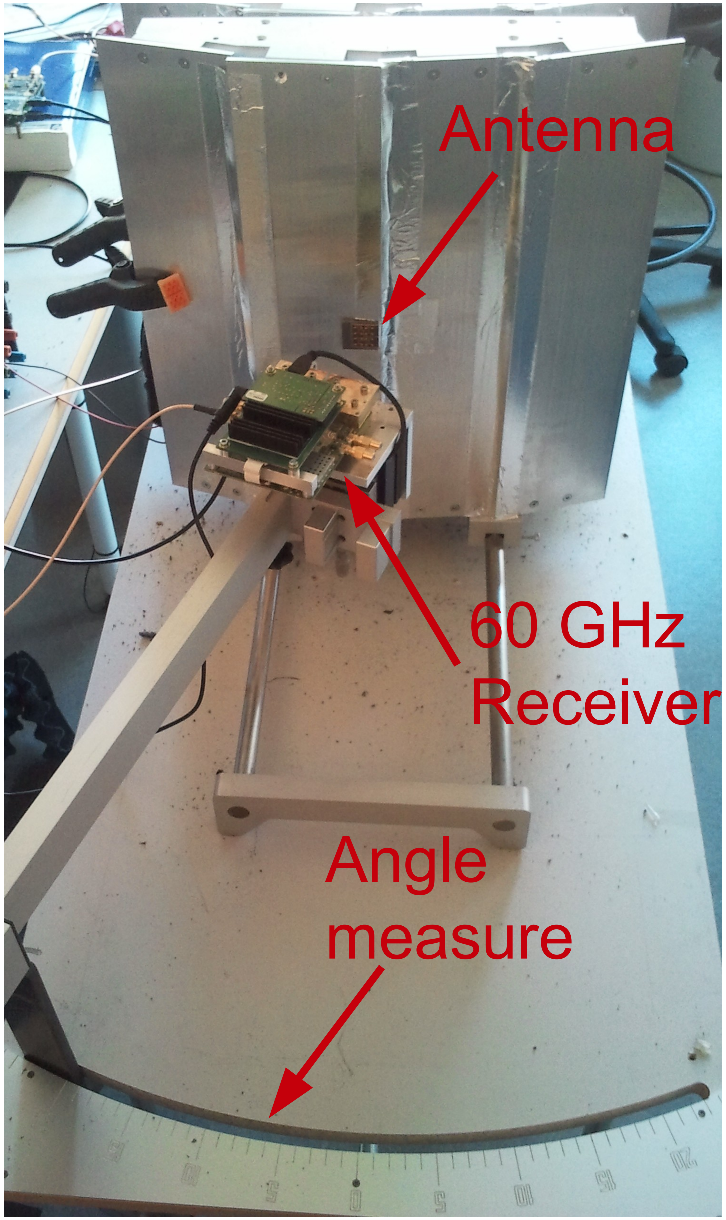
Receiving of the test frequency

Down conversion (RX)

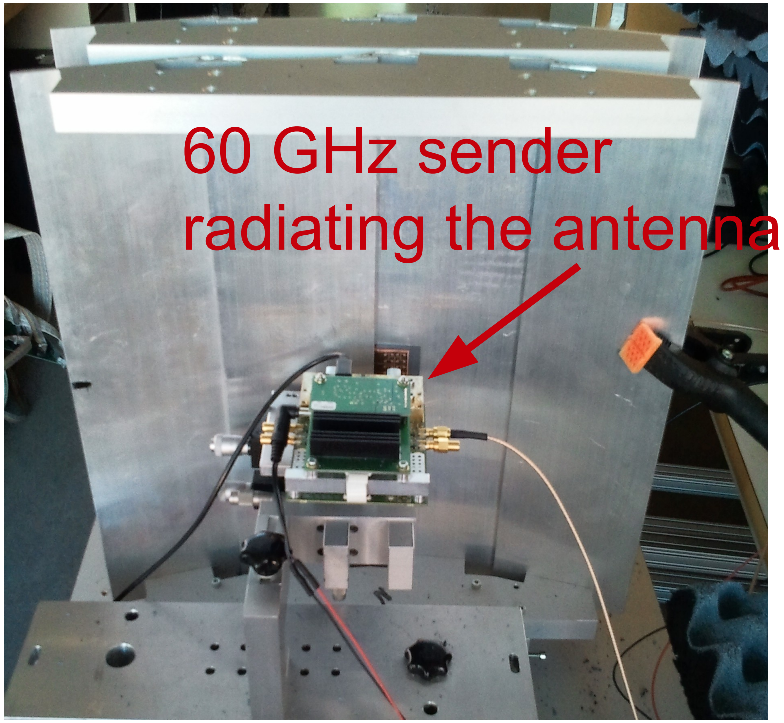


- Received signal is mixed with 60GHz carrier frequency.
  - (60 GHz ± baseband) ± 60 GHz
- With the low pass filter the baseband is extracted.

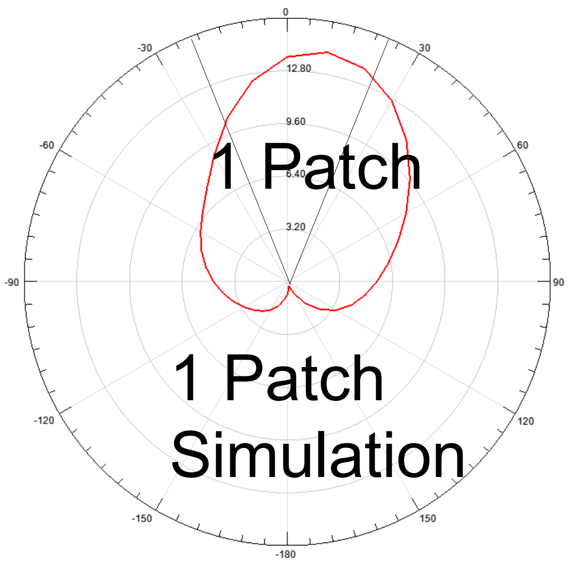
Testing the passive antennas

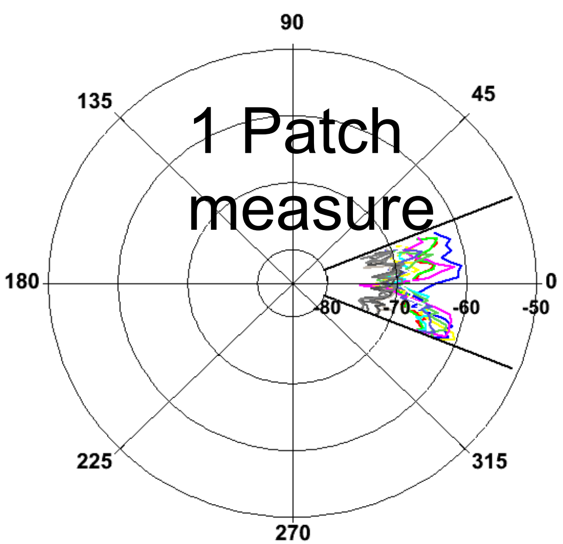


- Angular dependence measurement.



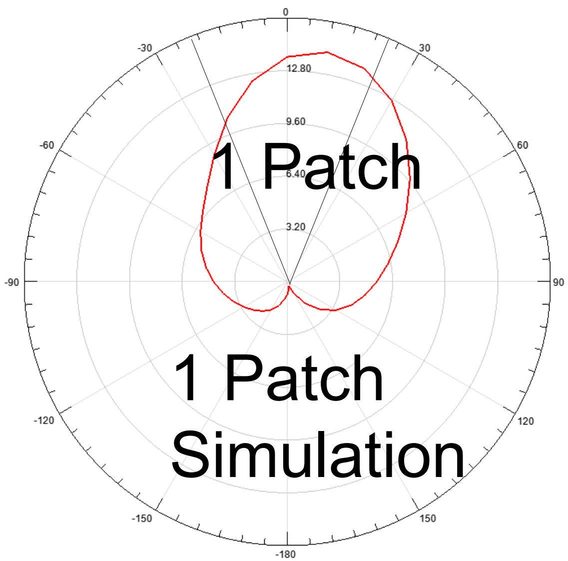
Testing the passive antennas

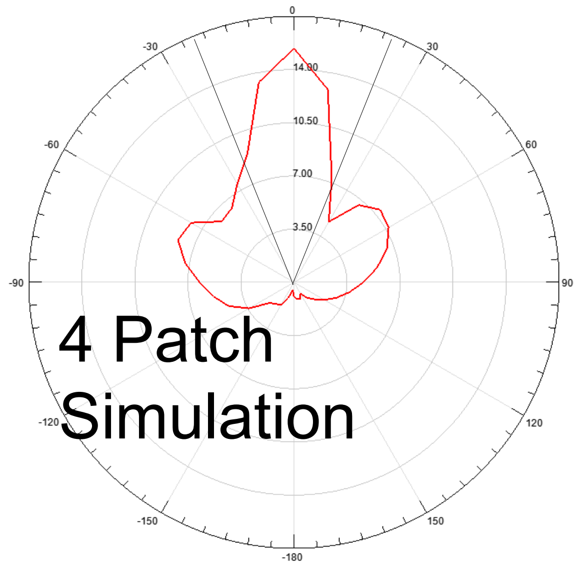


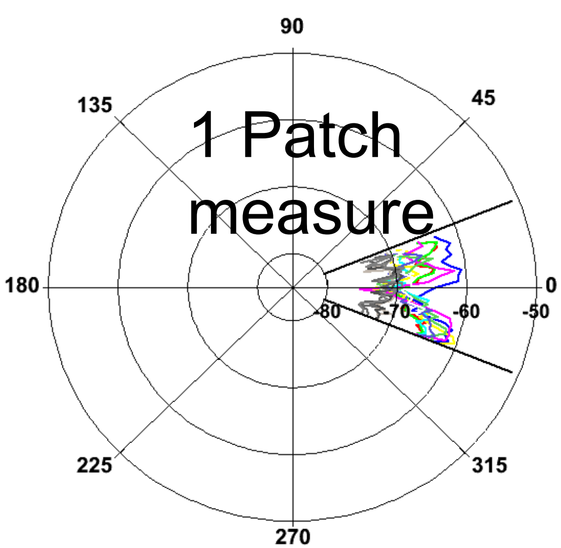


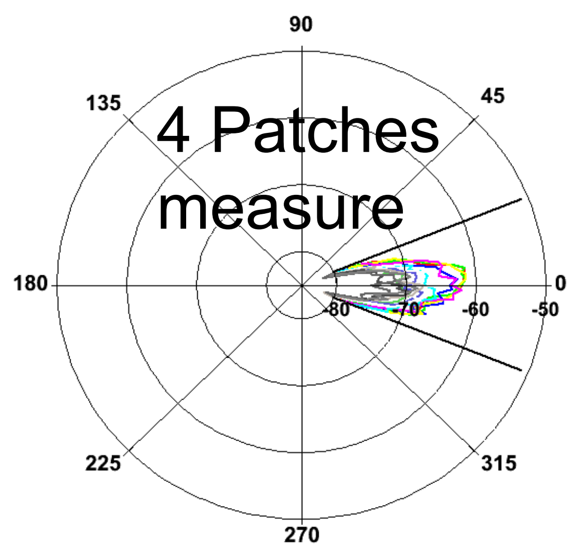
- The angular dependence of the antennas was tested measuring the transmitted power through one layer under different angles -22° to 22°.
- The more patches the more focus and gain we get.

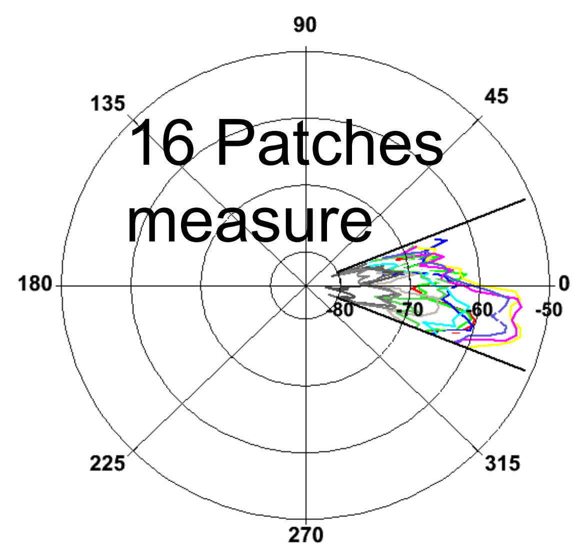
Testing the passive antennas



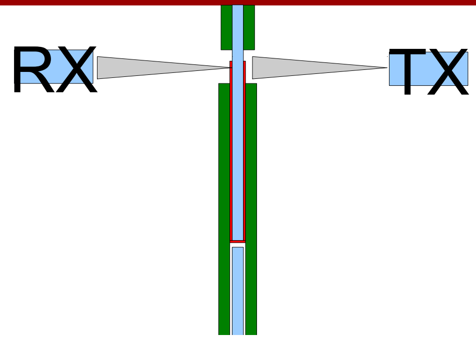


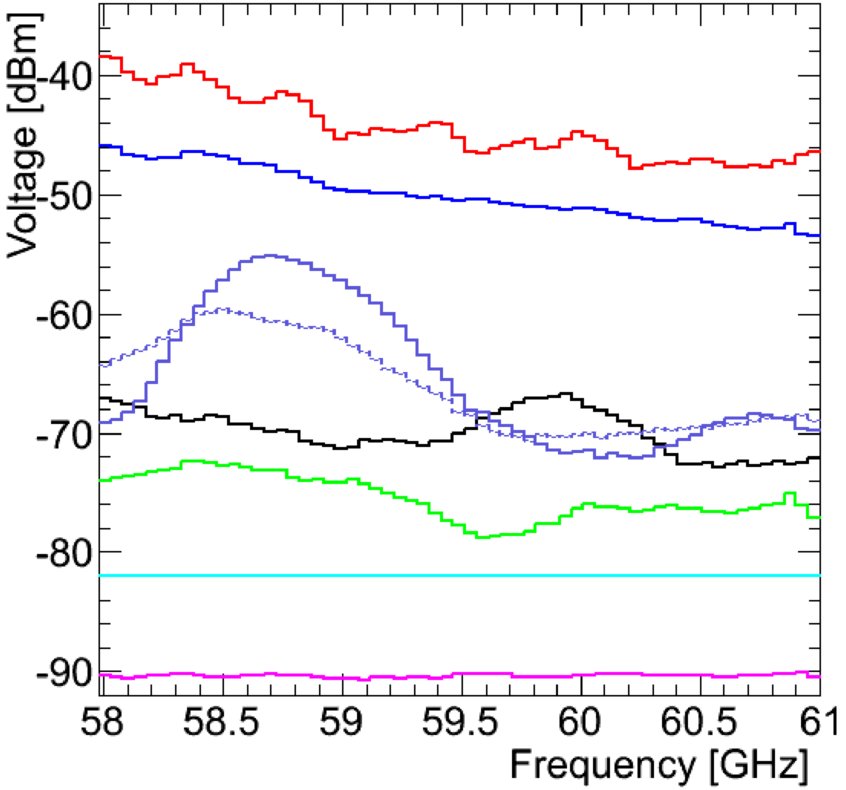






Testing the passive antennas





- Different Antennas were tested.
  - 1, 4, 16 patch
- The maximum throughput through the antenna was measured at different frequencies.
- A clear dependence on the amount of patches can be seen.
  - As well as a slight frequency dependence.

Horn-Horn 9.5cm distance
Horn-Horn 35cm distance
16 Patch (Antenna 1)
16 Patch (Antenna 2)
4 Patch
1 Patch
Cutoff
Background