Design and Preliminary Indoor Assessment of a Long-Range sub-THz VNA-Based Channel Sounder between 500 GHz and 750 GHz

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Introduction – Channel Sounding

- What is channel sounding?

  Measurements of a radio channel

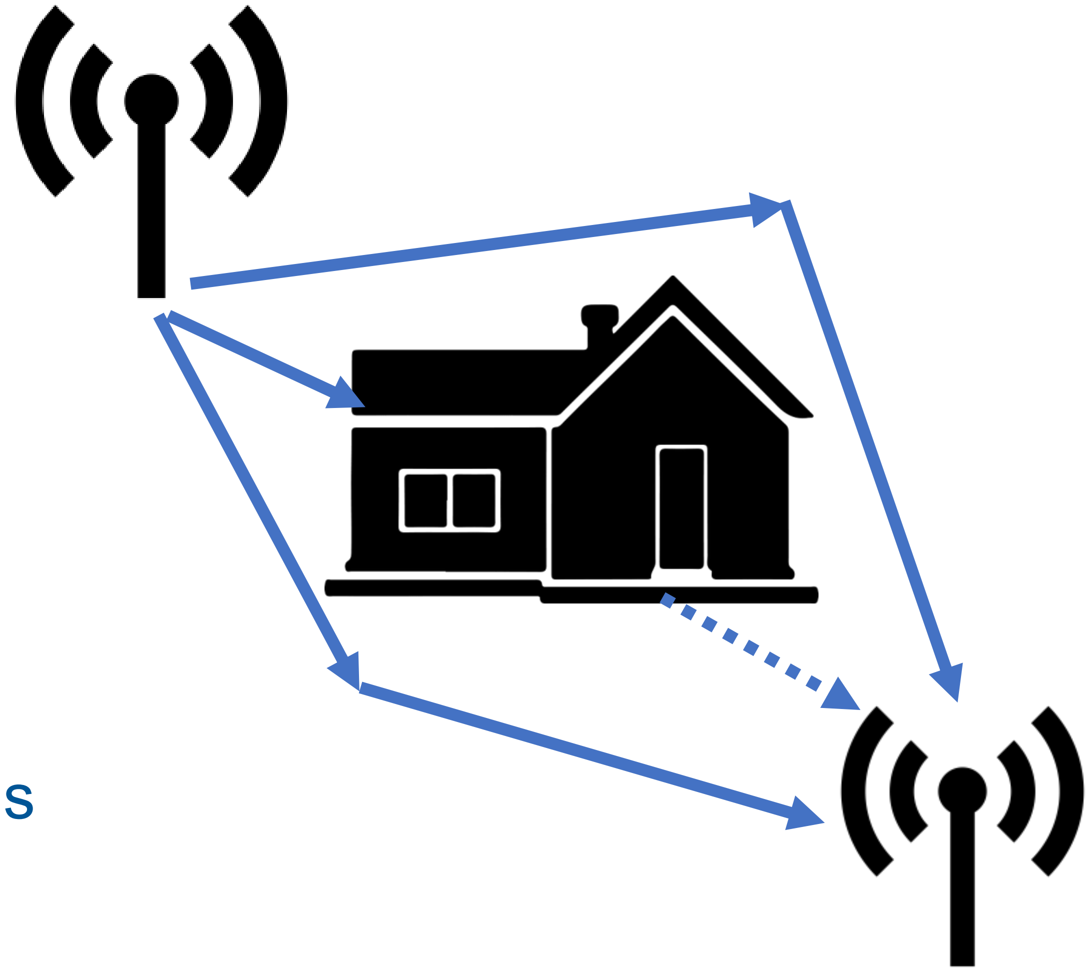
- What are the key properties?

  Path loss, delay, absorption, reflection, multipath fading and Doppler shift

- How are these measurements used?

  Design and simulation of new radio systems

  Make best use of a radio channel



Outline

- Overview design of system
  - Types of channel sounding hardware
  - Radio-over-fiber
  - Phase Compensation
- Measurement setup
- Measurement results
- Conclusion

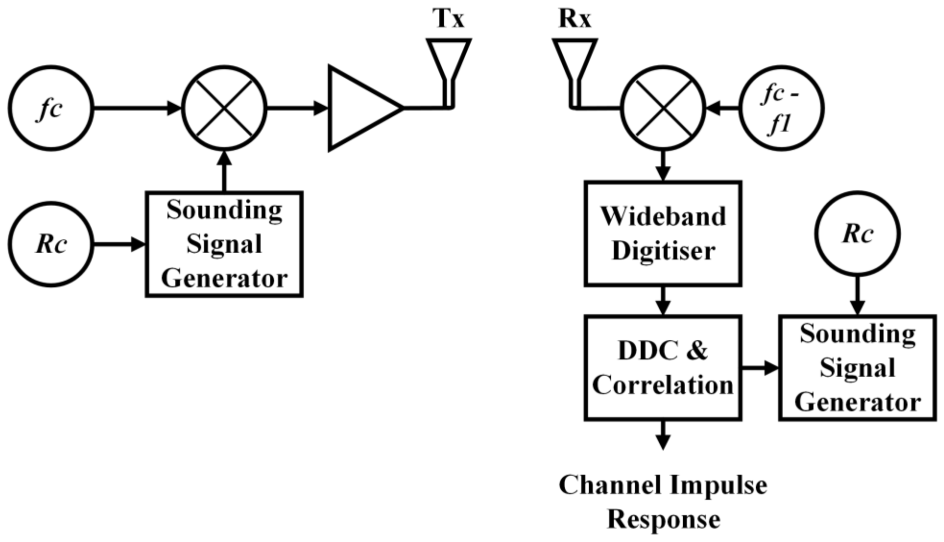
Measurement question

- Frequencies: Sub-THz 500 – 750 GHz
  - Current agreed channel models to 330 GHz
  - 250 GHz bandwidth
- Range: up to 600 m
  - Increase applicability of new applications
- Environments: Indoor and outdoor
  - Static scenarios

Types of channel sounder

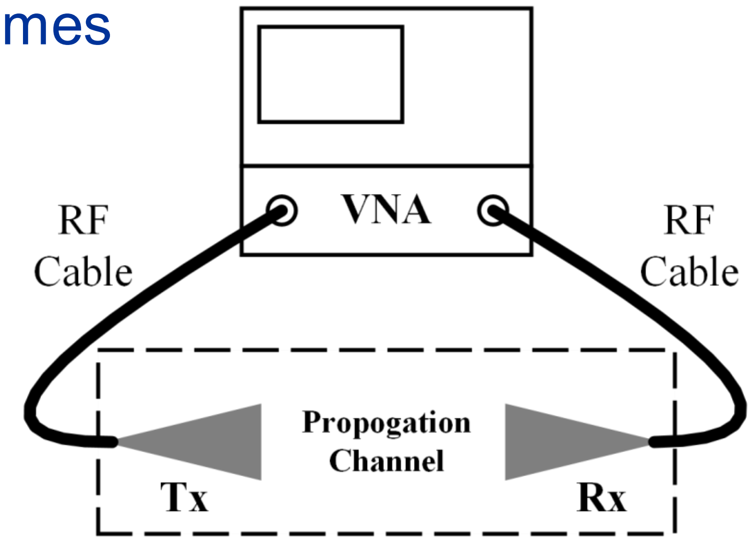
Time-domain

- A radio signal is transmitted
- Correlated at the receiver with the known signal to recover channel impulse response
- Requires wideband RF transmitter and receiver
- Short sweep times



Frequency-domain

- VNA measures the S21 of the radio channel with a frequency sweep
- Use the inverse discrete Fourier transform to recover the channel impulse response
- Can sweep over a very wide bandwidth
- Long sweep times



Sub-Thz Channel sounding design

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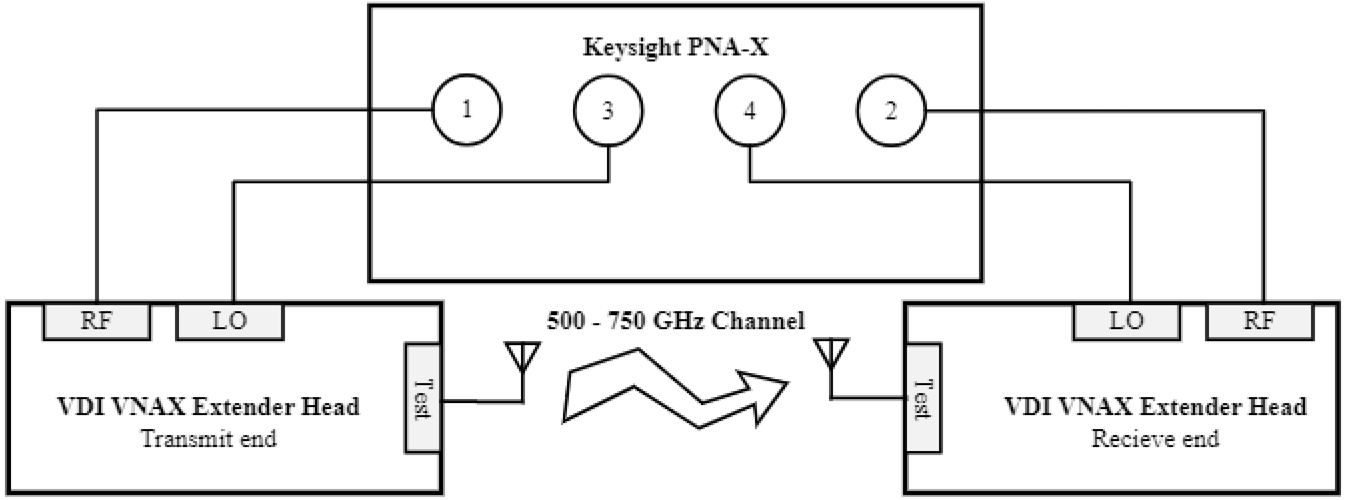
- Starting design: VNA (up to 67 GHz) + Extender heads

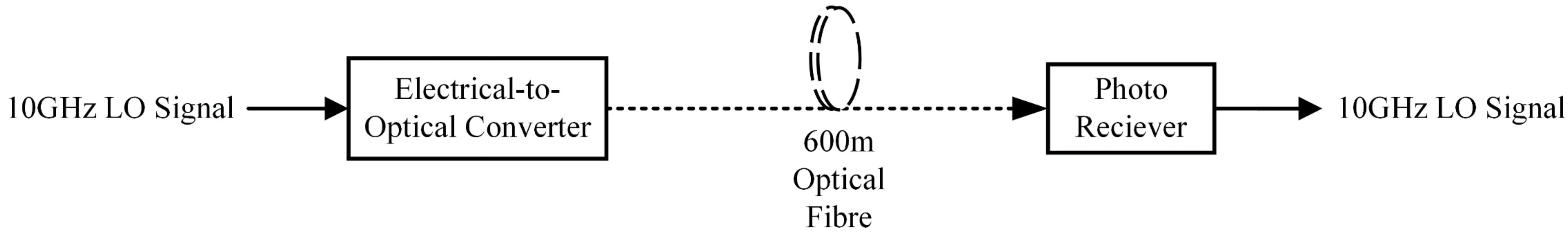


- 500-750 GHz ✓
- Distances up to ~10 m ❌

  Losses in the RF cables are too large (RF signals at 10 GHz)

Radio-over-fibre solution

- RF signals are converted to optical to allow transmission along fibre optic cables
- 0.1 dB/km losses ✓



- Not phase stable ❌

  Fibre optic cables drift in phase due to temperature and bending

  VNA calibration cannot be maintained

Phase Compensated Radio-over-fibre

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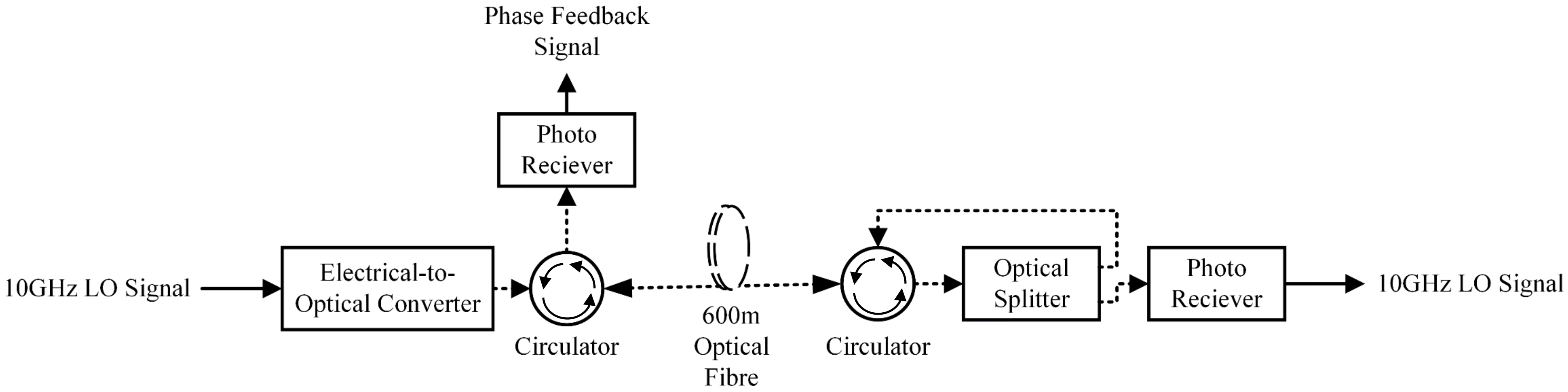
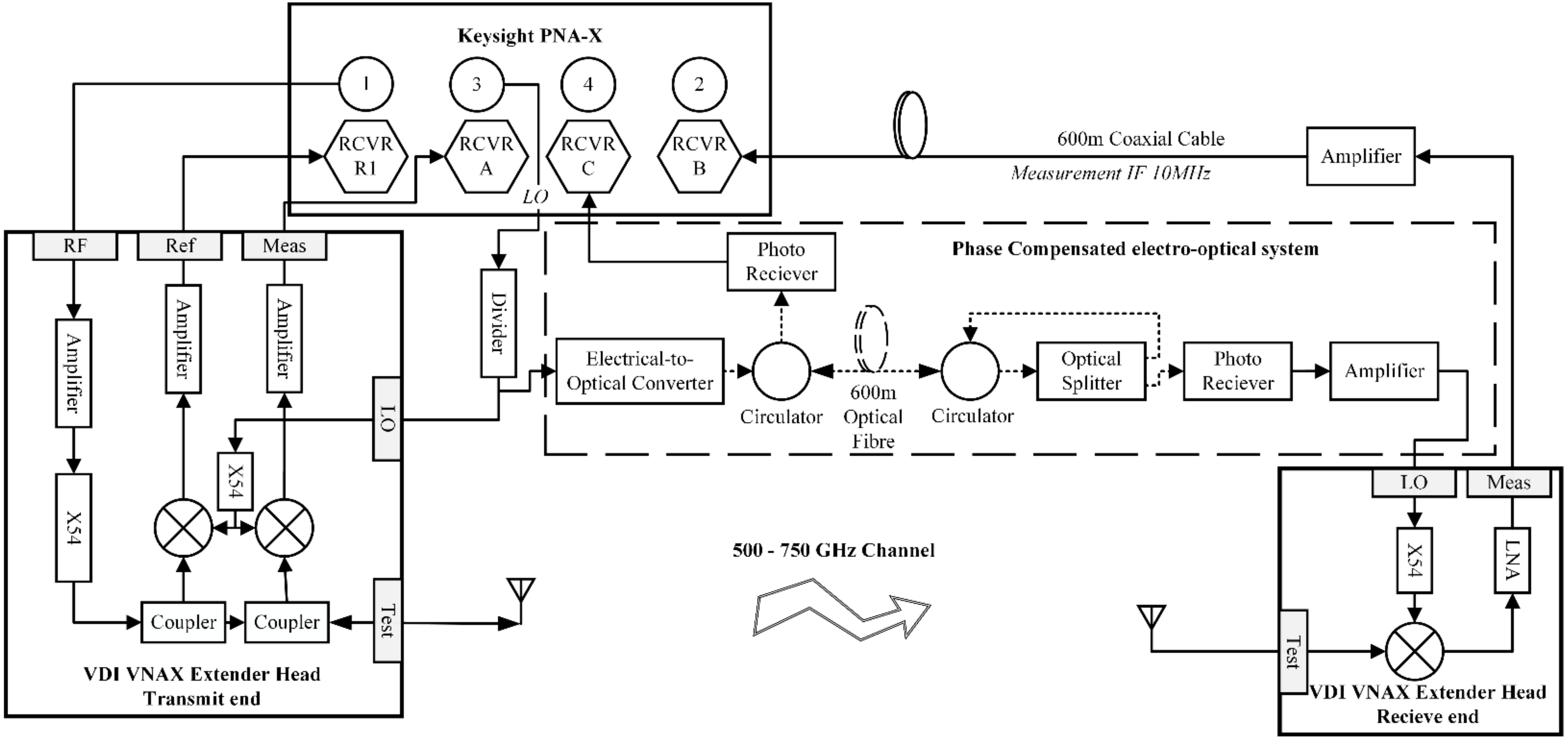
- Optical signal is partially reflected back through the fibre optic cable and sensed to monitor the change in phase over time



- Phase Stability is maintained by adjusting for the measured phase change at the feedback point

Sub-Thz Channel sounder design

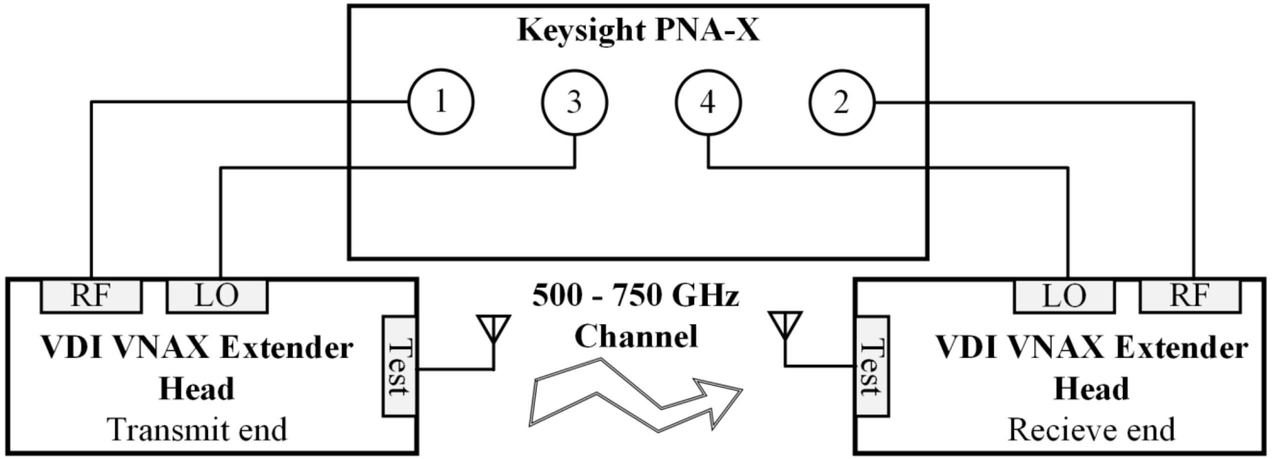
- Combining the VNA, extender heads and radio-over-fibre components:
  Additionally, LO divider and VNA direct receiver access



Preliminary measurements

- Test for consequences from the addition of radio-over-fibre components
- Measurements up to 250 mm performed with:
    1. VNA and extender heads only (co-axial connections)
    2. VNA, extender heads and 600 m radio-over-fibre with phase compensation

A.



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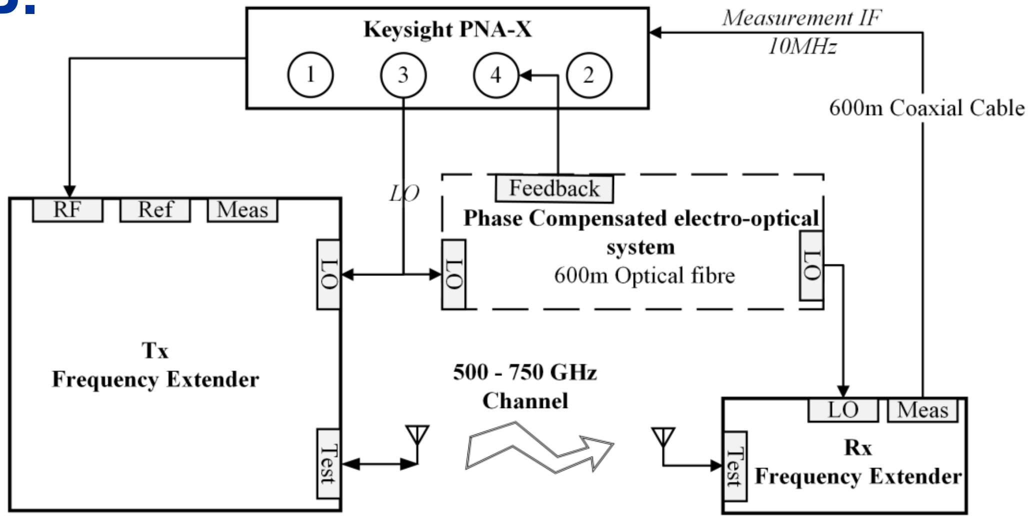
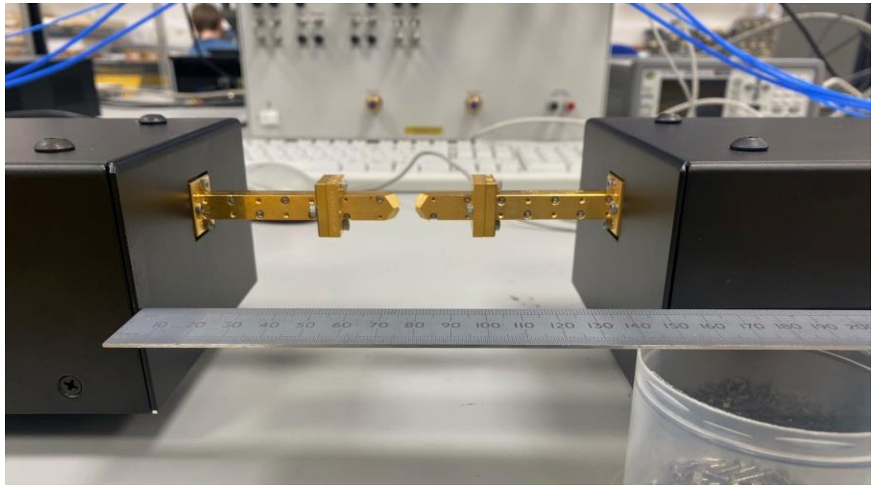


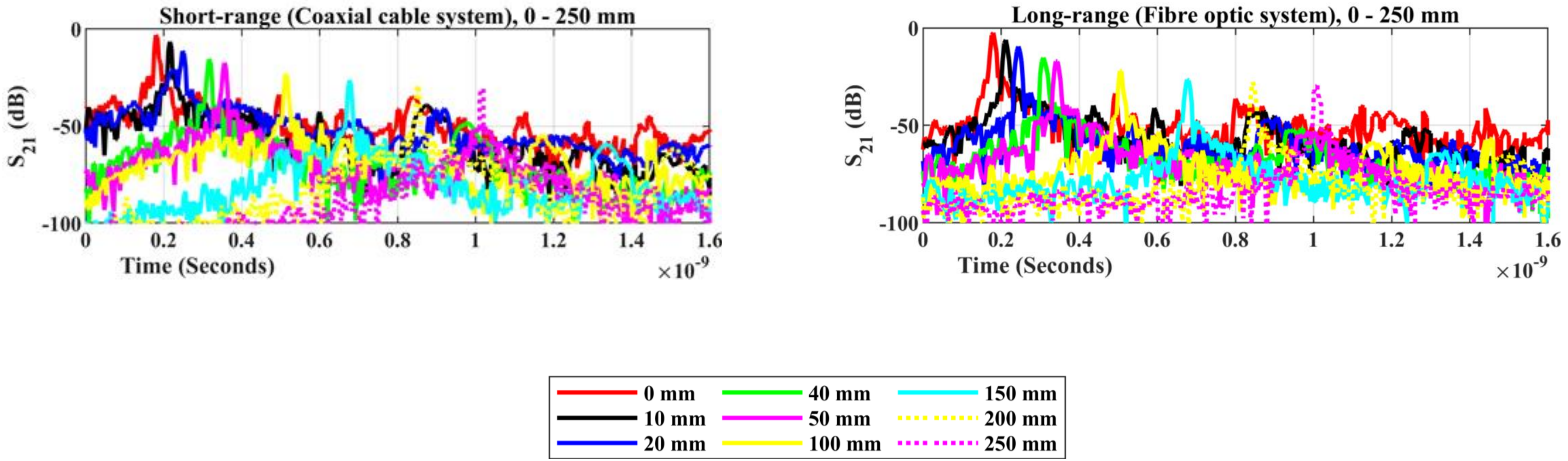
Measurement set up – up to 250 mm

- Each system setup according to diagrams
- VNA Calibration performed
  - Two-port Thru-Reflect-Line (TRL) for the co-axial system
  - Enhanced response for the 600 m fibre compensated system
- Horn antennas attached and Tx and Rx placed directly in-line
  - Antenna separation distances of 0, 10, 20, 40, 50, 100, 150, 200, and 250 mm



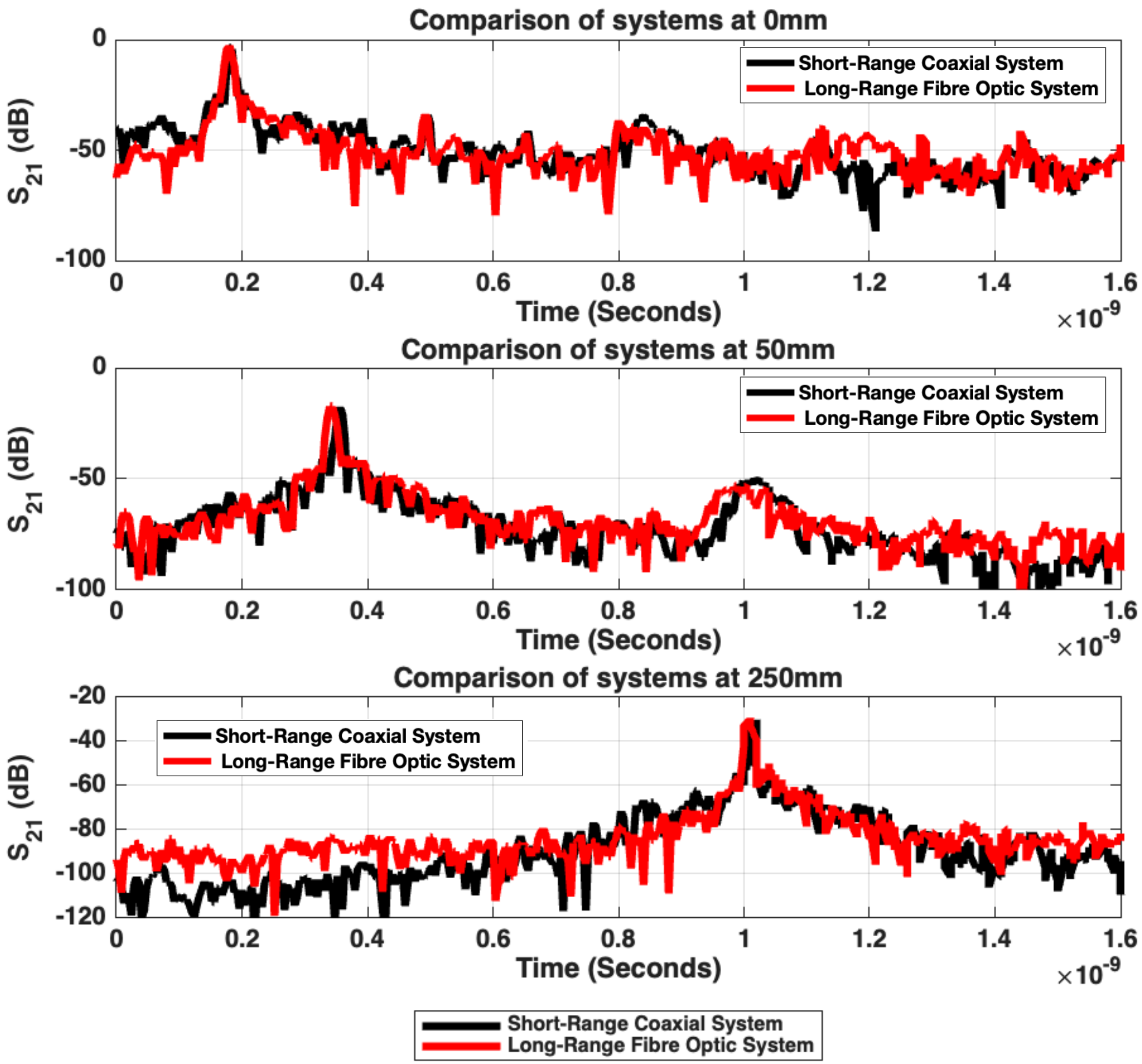
Measurement results – 250 mm

- Results are closely matched between systems
- The location and amplitude of the peaks show good consistency



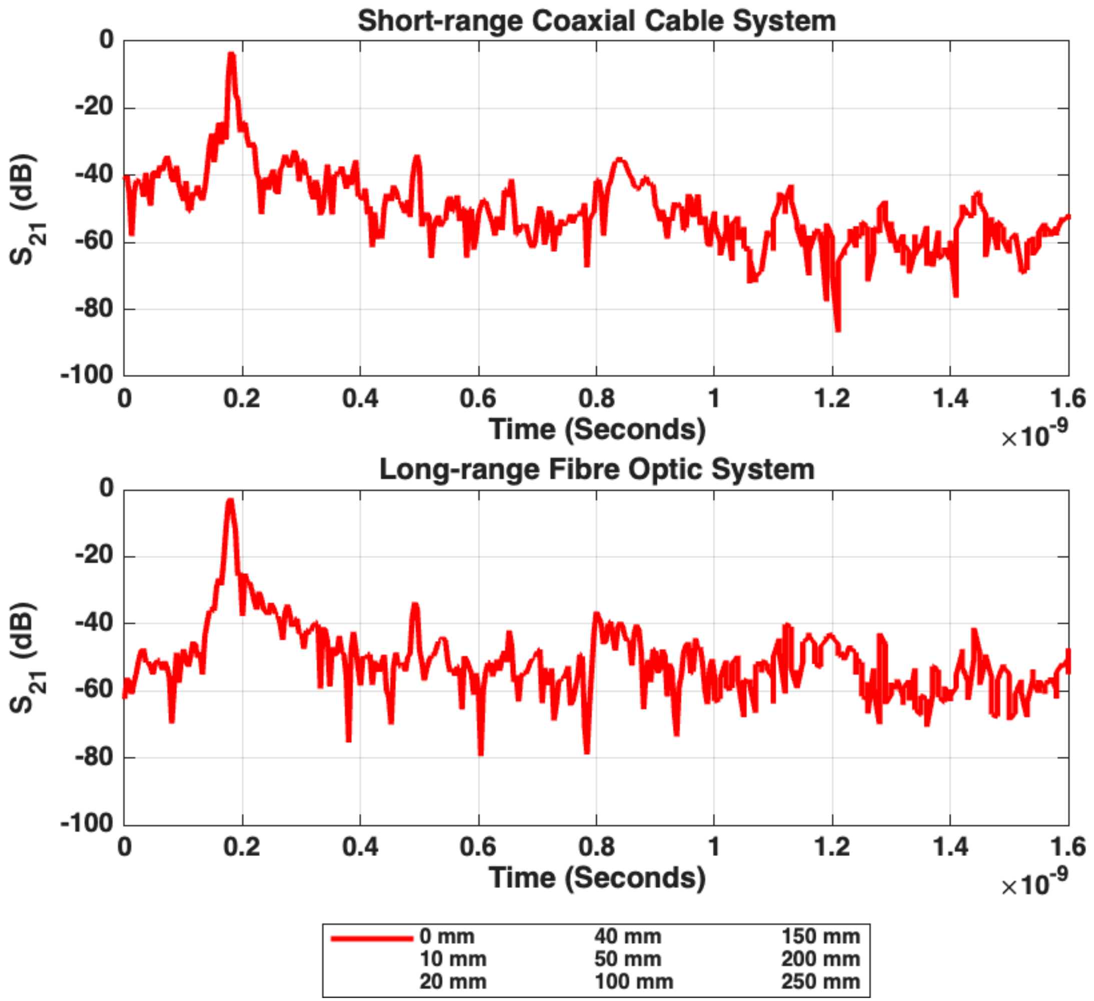
Measurement results - 250 mm - Noise

- Overall: Equal noise level from the two systems
- At 250 mm: Increased noise in the radio-over-fibre solution due to the additional active components (Optical converters and amplifiers)



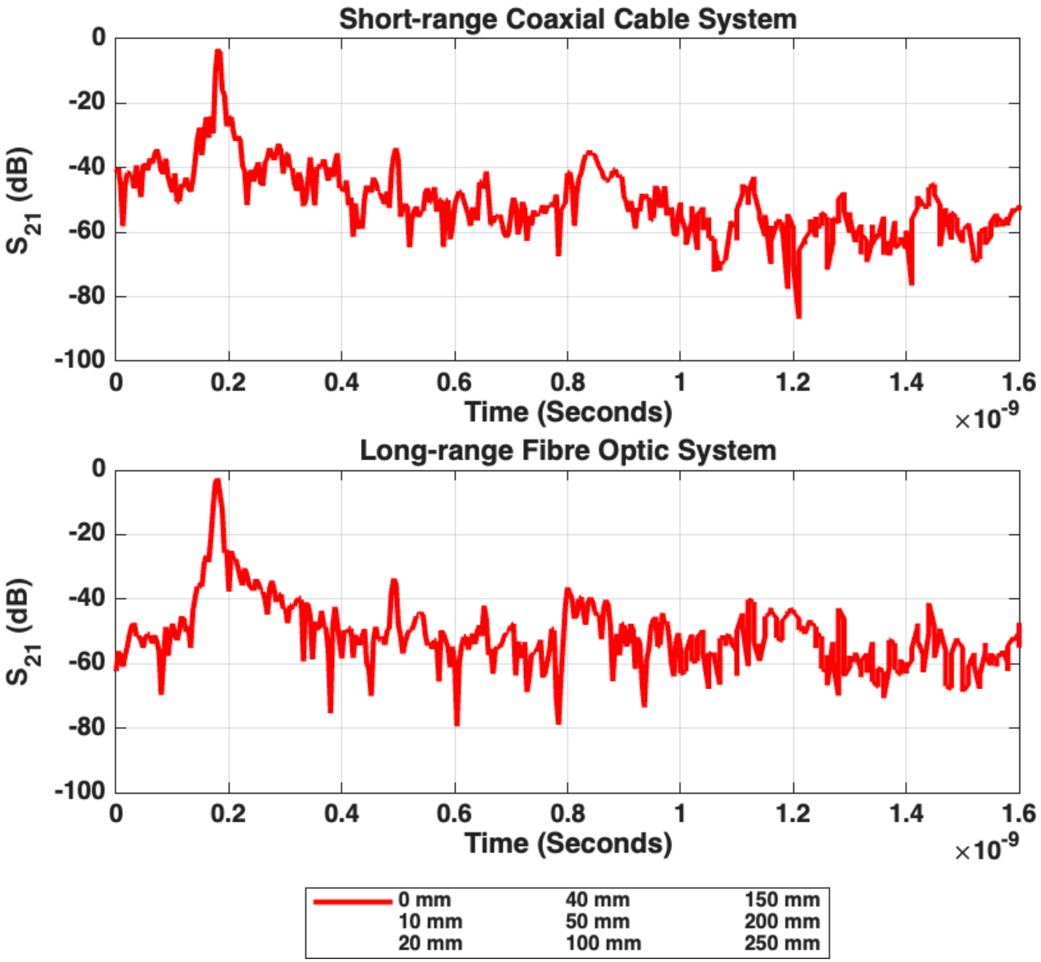
Measurement results analysis – 250 mm

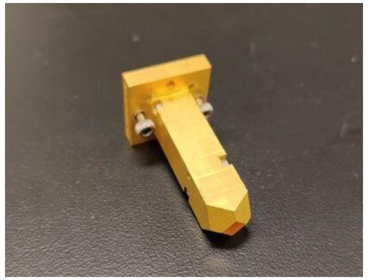
- Peaks for each distance match the expected line-of-sight case
- There is one strong peak for each indicating there is low multipath effect
- As the antennas are separated:
  - Peaks increase in time, expected due to the longer propagation time
  - Peaks decrease in amplitude, expected due to free-space path loss



Measurement results analysis – 250 mm

- Non-zero propagation time for 0 mm case as the calibration is performed at the waveguide interface not antenna phase centre
  - Approximate delay is 0.180 ns
  - Equivalent to 54 mm at the speed of light
- Matches the physical length of the horn antennas each 24 mm





Measurement method – up to 4.5 meters

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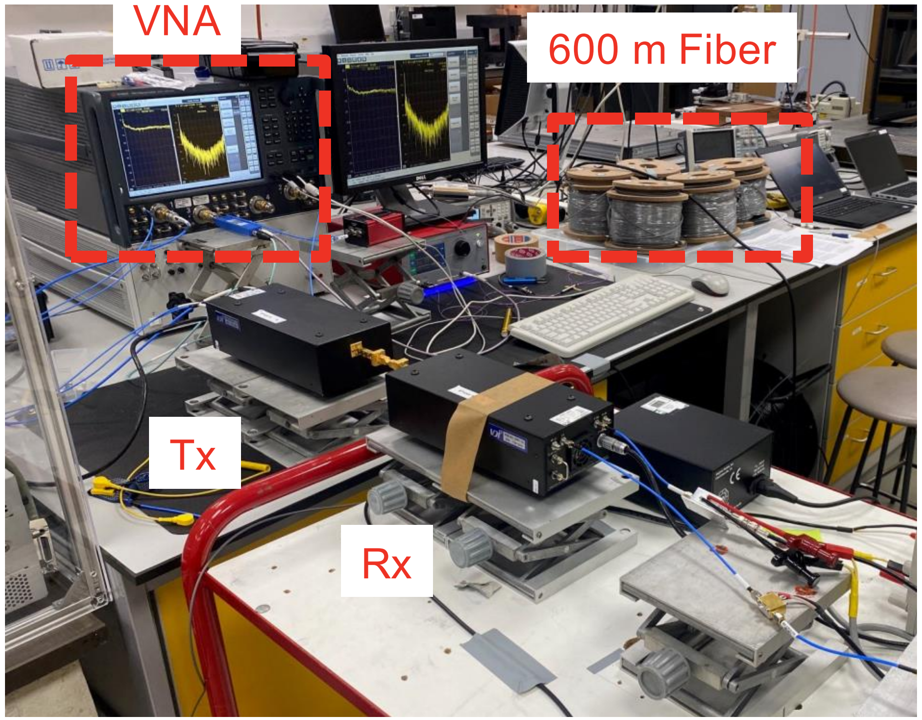
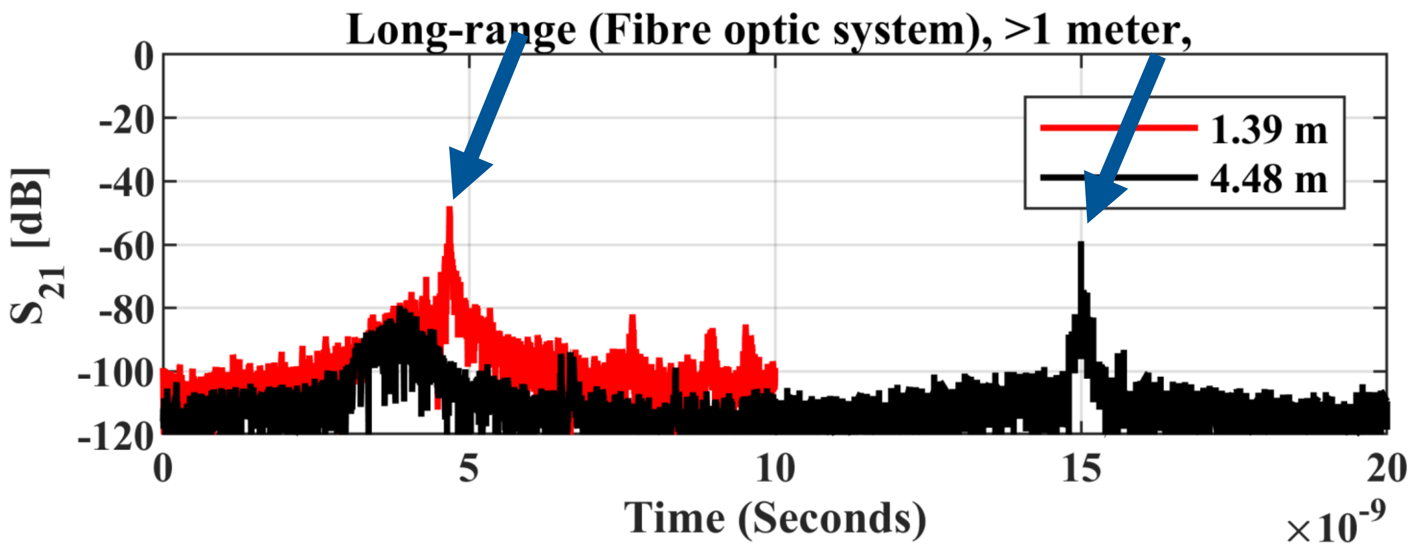
- 750 GHz channel sounding at 1.4 m and 4.48 m
- Measurements were performed using the same methods as the 250 mm measurement with 600 m of fibre cable

  Calibrate, attach antennas and perform VNA frequency sweep
- Number of frequency points within the sweep was increased to allow for a greater measurement time span when converted to the time domain



Measurement results – up to 5 meters

- The peaks in each separation result show correlation with the calculated line-of-sight path delays,
- For the 1.39 m and 4.48 m separations, 4.64 ns and 14.9 ns respectively.



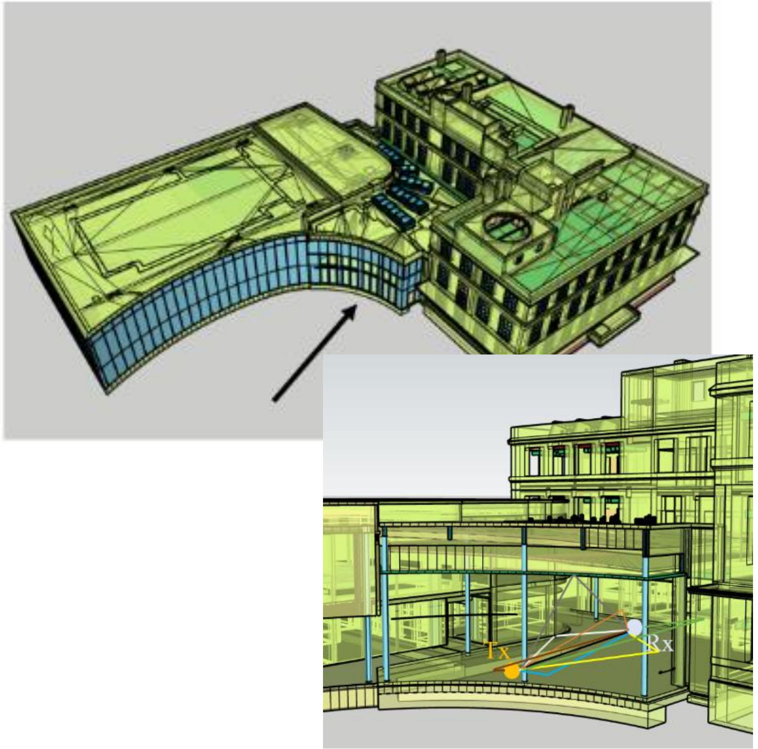
Antenna Separation	Ideal LOS propagation time	Measured peak
1.39 m	4.64 ns	4.68 ns
4.48 m	14.9 ns	15.02 ns

Conclusion

- Presented a solution for long-range sub-THz Measurements
  - Verified against existing short-range systems
- Overcome effects of phase drift within radio-over-fiber solutions
- Preliminary measurements up to 4.48m

Future Work

- Long-range channel measurements
  - System capable of 600 m separation
- Proposed indoor and outdoor measurement scenarios
- Comparison with sub-THz ray tracing tools



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