Project: IEEE P802.15 Working Group for Wireless Specialty Networks (WSN)

Submission Title: D-band radio channel modelling in office environments using a VNA based channel sounder

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Abstract: The document provides the result of radio channel measurements in an office environment using a vector network analyzer based channel sounder capable of characterizing the full D-band, ranging from 110 to 170 GHz. We present Line-of-Sight path loss models, attenuation due to desk objects (partly) obstructing the LOS path and attenuation due to a screen monitor in between the two antennas.

Purpose: Information to the Standing Committee THz

D-BAND RADIO CHANNEL MODELLING IN OFFICE ENVIRONMENTS USING A VNA BASED CHANNEL SOUNDER

IEEE 802.15 SC THz Meeting

MAY 17, 2021

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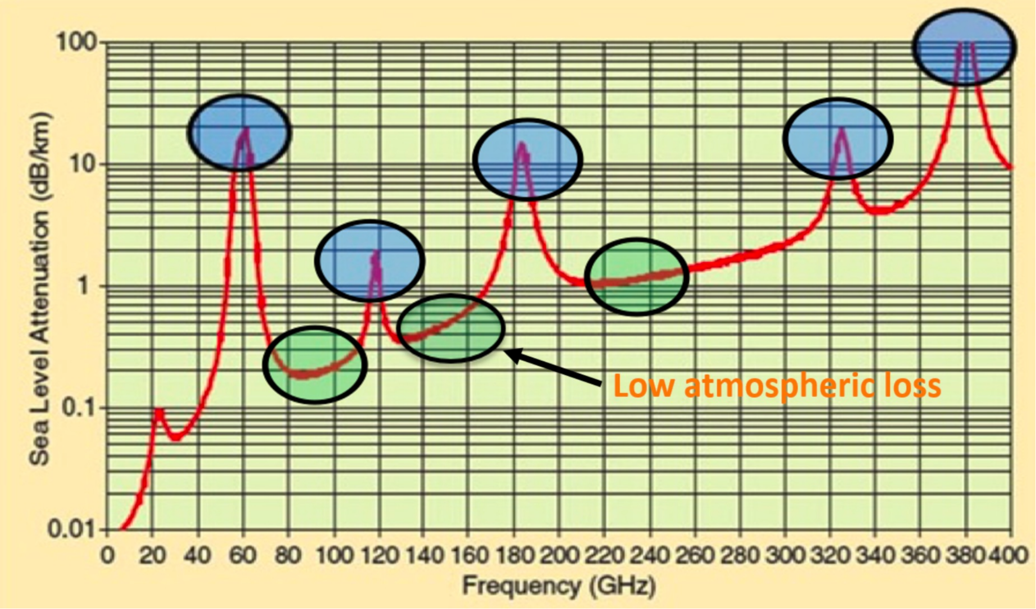
OUTLINE

- Introduction
- Channel sounder design
- Measurement setup
- Channel modelling results
  - Line-of-sight path loss
  - Object attenuation
  - Screen obstruction
- Future and related research
- Conclusion

INTRODUCTION

D-BAND RADIO CHANNEL

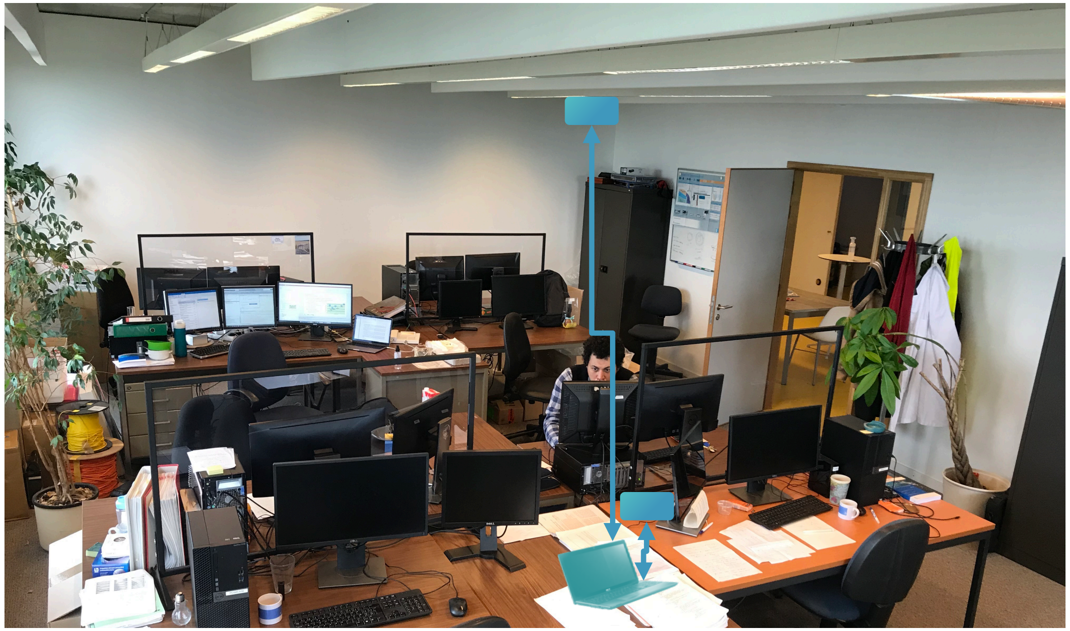
- Characterize radio propagation in D-band (110-170 GHz)
- 60 GHz of spectrum available for high-throughput applications
  - Short and medium range wireless communication
- Channel modelling
  - Office room environment
  - Line-of-sight (LOS) measurements
  - Object attenuation
  - LOS vs NLOS path
- Radio channel sounding
  - VNA based channel sounder
  - Distances up to 8.5 m



Y. Xing and T. S. Rappaport, “Propagation Measurement System and Approach at 140 GHz–Moving to 6G and Above 100 GHz,” 2018 *IEEE GLOBECOM*

INTRODUCTION

OFFICE ROOM CHANNEL MODELLING



- Office room with typical furniture
  - Desks
  - Desktop computers and monitors
  - Plasterboard and drywall walls
- High-throughput applications
  - Data kiosk – wireless hub
  - Access point
- State-of-the-art
  - J. Ryan, G. R. MacCartney, and T. S. Rappaport, "Indoor office wideband penetration loss measurements at 73 ghz," in *2017 IEEE International Conference on Communications Workshops (ICC Workshops)*, 2017, pp. 228–233.
  - G. R. Maccartney, T. S. Rappaport, S. Sun, and S. Deng, "Indoor office wideband millimeter-wave propagation measurements and channel models at 28 and 73 ghz for ultra-dense 5g wireless networks," *IEEE Access*, vol. 3, pp. 2388–2424, 2015.
  - S. Kim, W. T. Khan, A. Zajic, and J. Papapolymerou, "D-band channel measurements and characterization for indoor applications," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 7, pp. 3198–3207, 2015.
  - B.-E. Olsson, C. Larsson, M. N. Johansson, and S. L. H. Nguyen, "Radio propagation in an office environment at 140 ghz and 28 ghz," in *2021 15th European Conference on Antennas and Propagation (EuCAP)*, 2021, pp. 1–5.

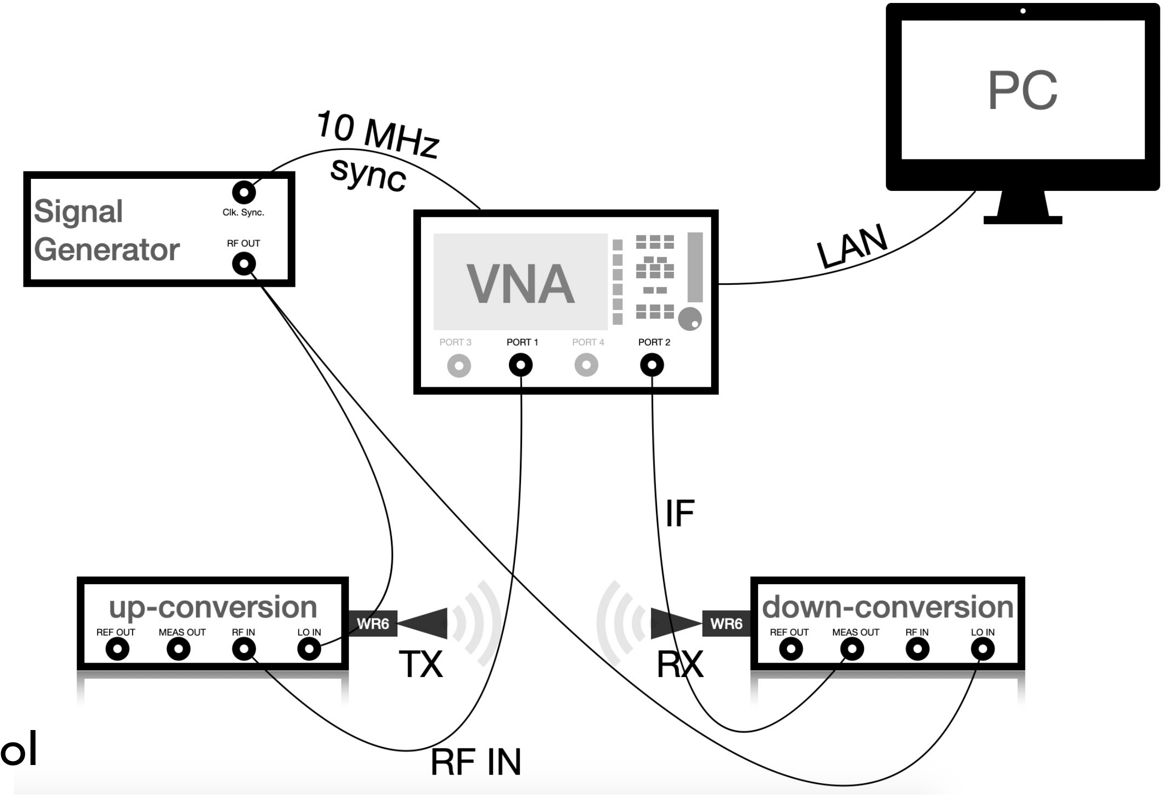
CHANNEL SOUNDER DESIGN

CHANNEL SOUNDER DESIGN

ARCHITECTURE

Equipment

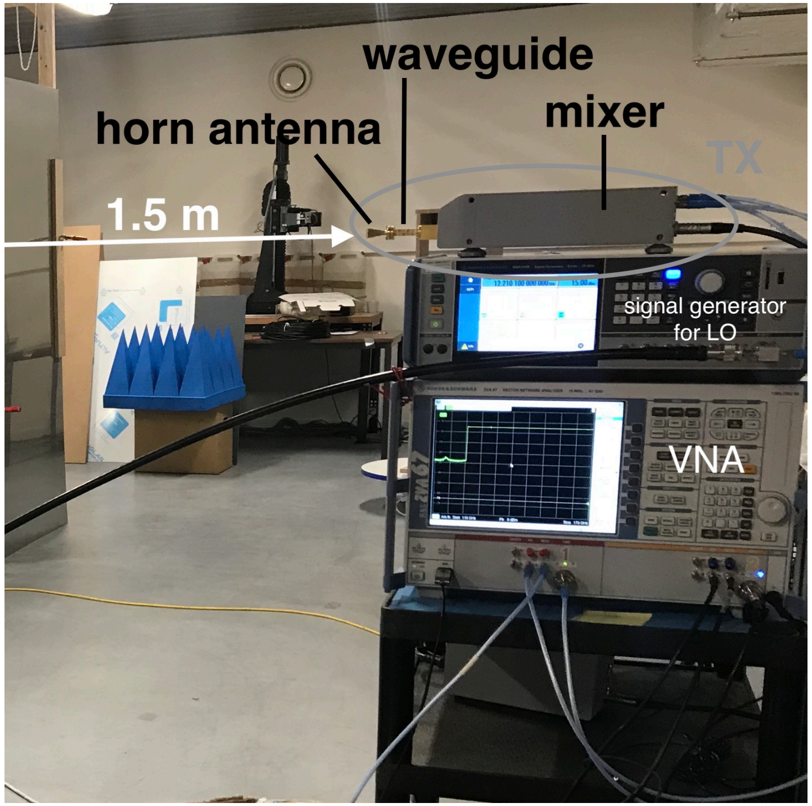
- R&S ZVA67 VNA
  - RF source input 9.167 to 14.167 GHz
- R&S SMA100B signal generator
  - LO IN signal 10.972 to 16.9782 GHz
- R&S ZC170 mixers
  - LO multiplication 10
- QuinStar horn antennas
  - operational from 110 to 170 GHz
  - HPBW = 12 to 8.8 degrees
  - Gain ranging from 22.2 dBi for 110 GHz to 23.2 dBi for 170 GHz
- PC for remote VNA and turntable control



CHANNEL SOUNDER DESIGN

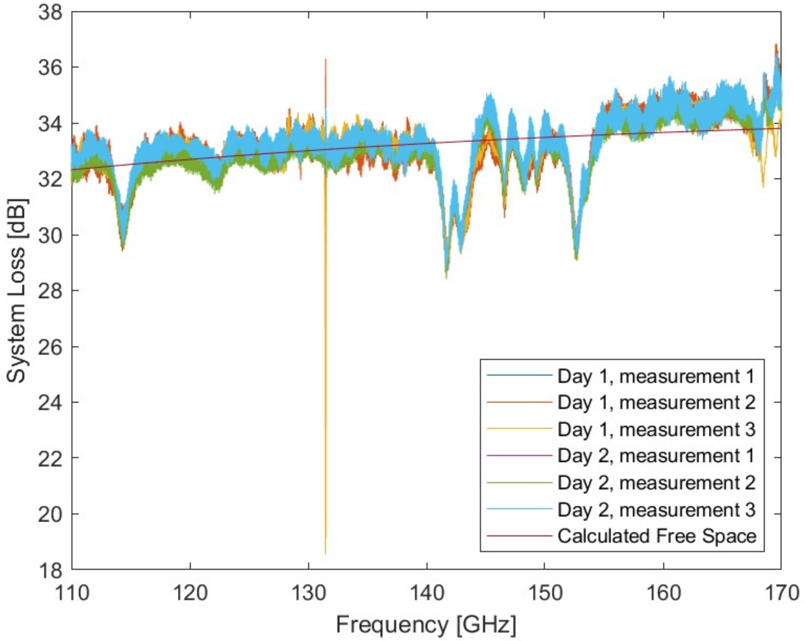
SETTINGS AND CHARACTERISTICS

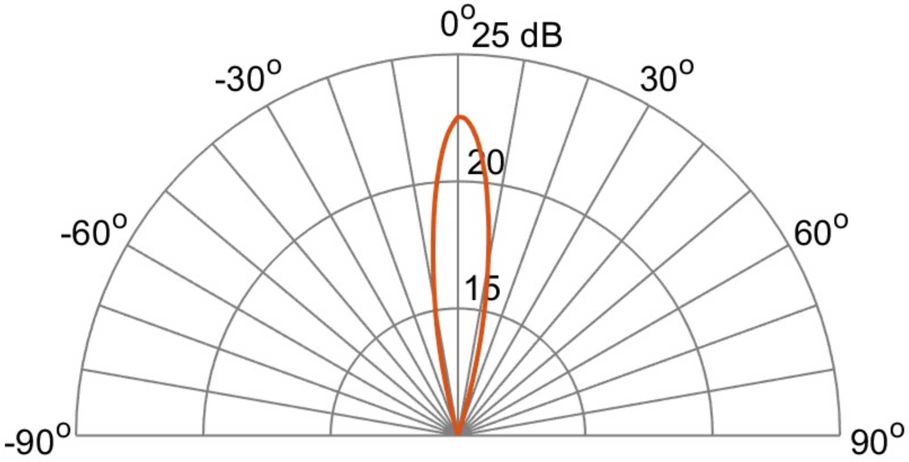
- Vector Network Analyzer settings
  - 110 to 170 GHz
  - 3001 frequency points
  - 20 MHz interspacing
  - Averaging via post-processing
  - IF Bandwidth 100 Hz
- Performed a normalized through calibration
- Channel sounder characteristics
  - Dynamic range of the VNA is 60 dB
  - 2x antenna gain of 22.5 dBi
    ➔ we can measure PL up to 105 dB
  - Sweep time 45 seconds



CHANNEL SOUNDER DESIGN

VALIDATION



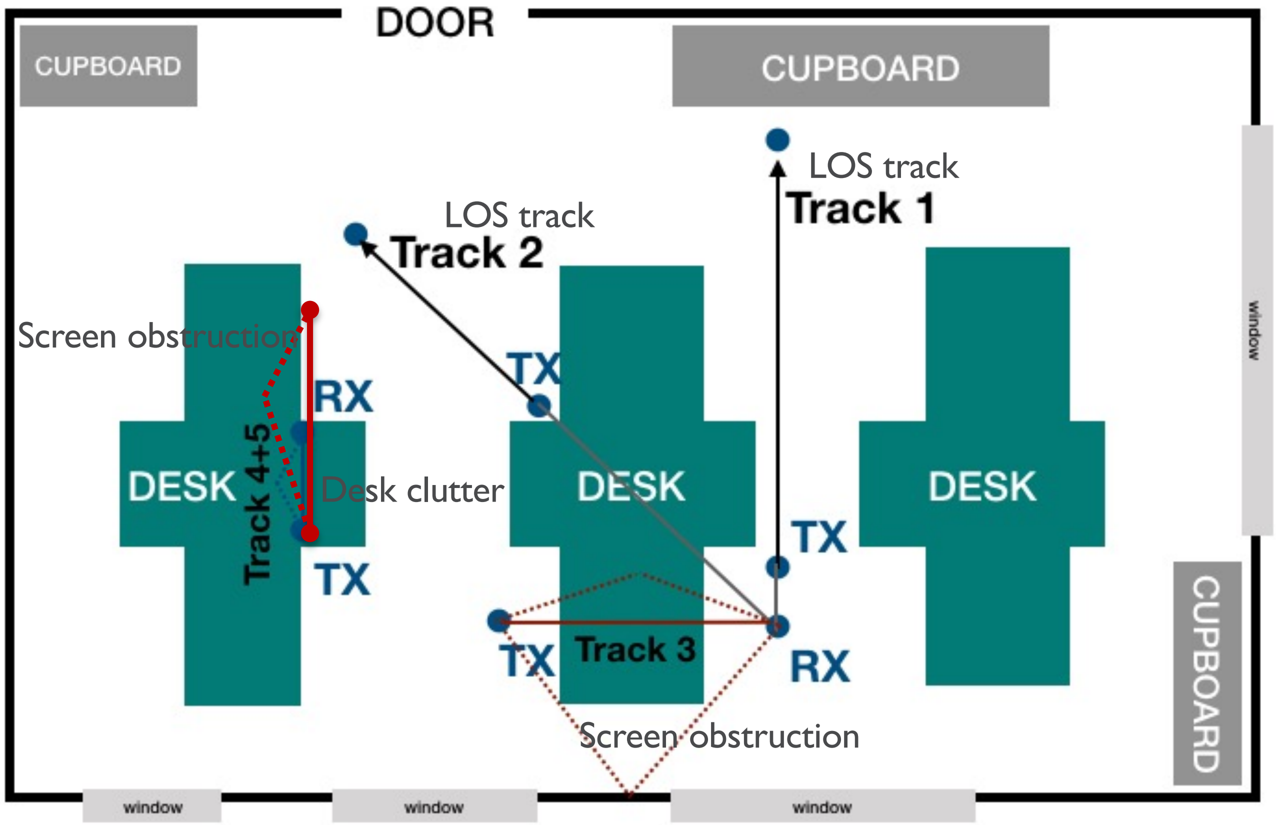


Channel sounder design and validation presented in B. De Beelde, D. Plets, E. Tanghe and W. Joseph, "Directional Sub-THz Antenna-Channel Modelling for Indoor Scenarios," *2021 15th European Conference on Antennas and Propagation (EuCAP)*, 2021, pp. 1-4, doi: 10.23919/EuCAP51087.2021.9411207.

MEASUREMENT SETUP

MEASUREMENT SETUP

OVERVIEW



MEASUREMENT SETUP

LINE-OF-SIGHT MEASUREMENTS

- Two measurement tracks
- Distance increassing from 0.3 to 3.5 m
- Steps of 10 cm
- Antenna height above desk height
- Unbstructed Line-of-Sight (LOS)

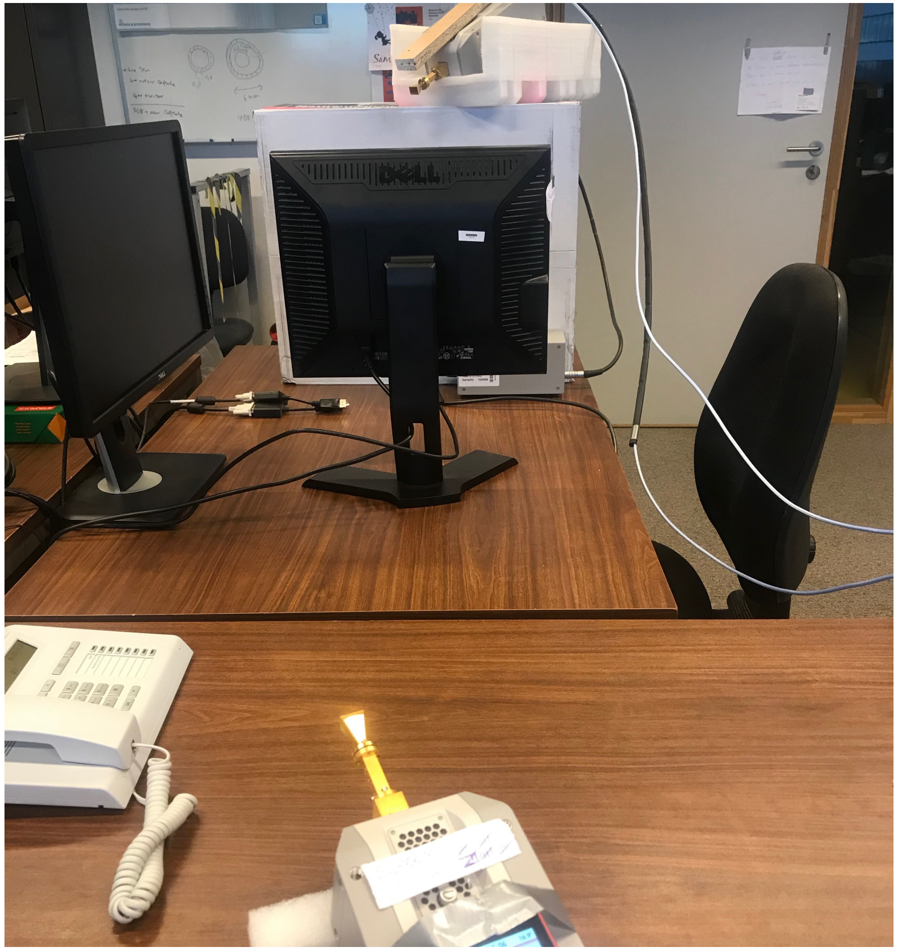
MEASUREMENT SETUP

OBJECT ATTENUATION

- Different desk objects obstructing LOS
  - USB or telephone cable
  - Computer mouse and keyboard
  - Desktop monitor, laptop power supply
  - Business cards and perforator
- Two distances between TX and RX
  - 20 cm
  - 50 cm
- Measured attenuation
- Compare to attenuation of reflected NLOS path

MEASUREMENT SETUP
SCREEN OBSTRUCTION

- Line-of-Sight path (partly) obstructed by a screen in between
- Measurements with different screen heights
- Fixed distance between TX and RX
- Two scenarios
  - TX and RX at same height
  - At different heights, pointing towards each other
- Reflected NLOS path
  - Wall reflection
  - Reflection on a nearby screen monitor

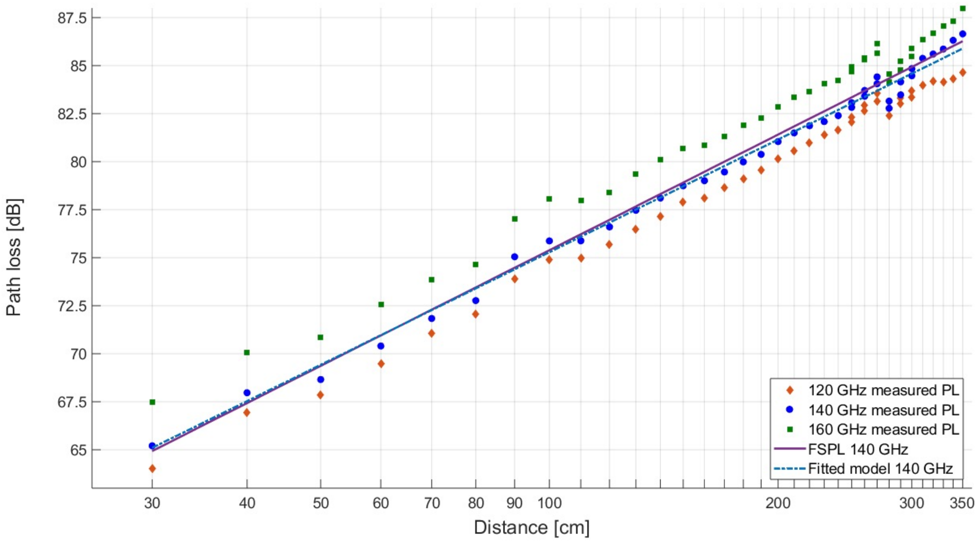


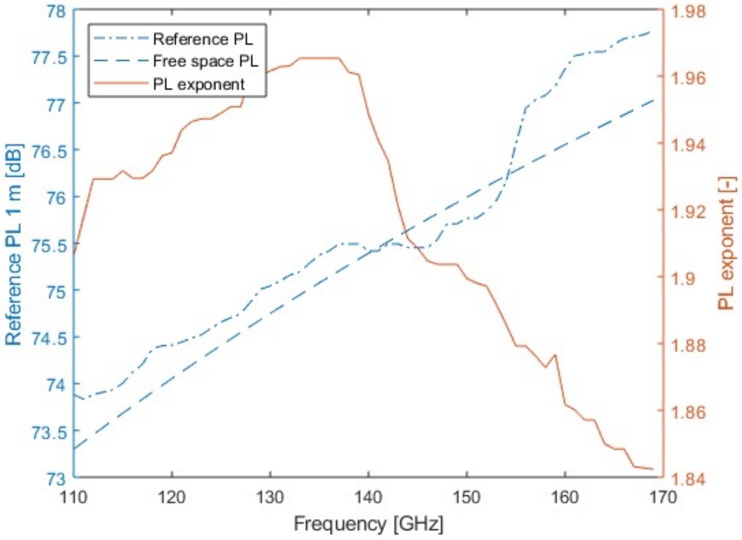
CHANNEL MODELLING

CHANNEL MODELLING

LINE-OF-SIGHT PATH LOSS

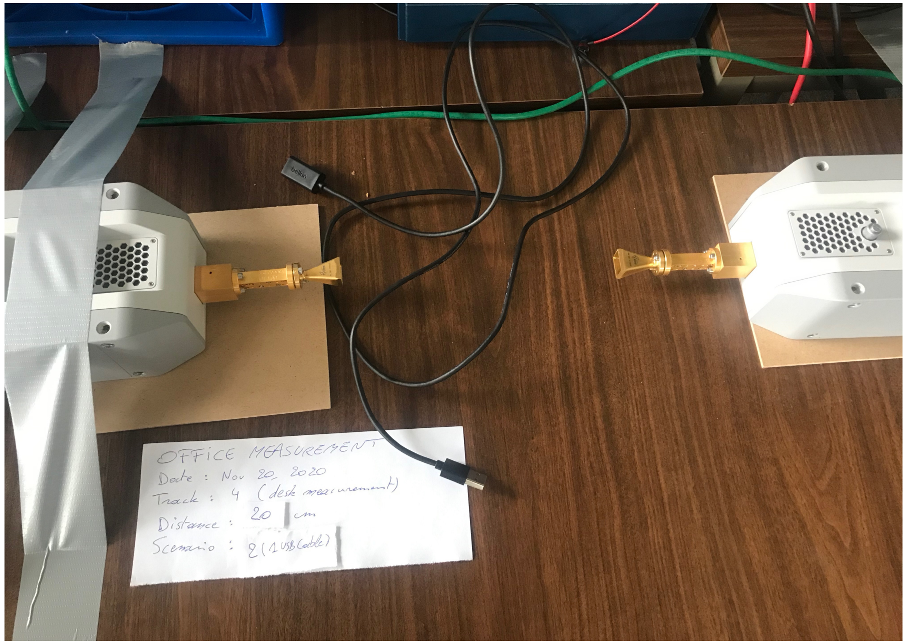
- LOS path loss models
- FI model
  - $PL(d) = PL_0 + 10\,n\,\log_{10}\frac{d}{1\,m} + \chi$
  - Reference path loss PL_0 in dB at 1 m
  - Path loss exponent n
  - Fitted for each 1 GHz subband
  - Coefficient of determination R^2 is above 0.995
- ABG model
  - $PL(d,f) = \alpha + 10\beta\log_{10}\frac{d}{1\,m} + 10\gamma\log_{10}\frac{f}{1\,GHz}$
  - Intercept value α is 32.65 dB
  - PL exponent β is 1.92
  - Frequency dependence γ is 2.0
  - Coefficient of determination R^2 is 0.93

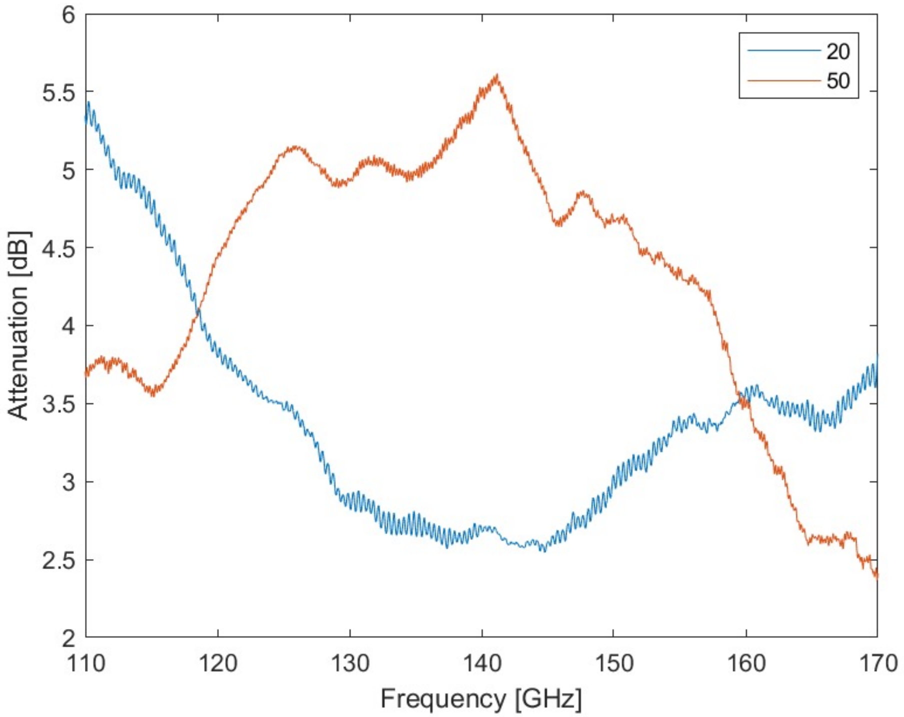




CHANNEL MODELLING

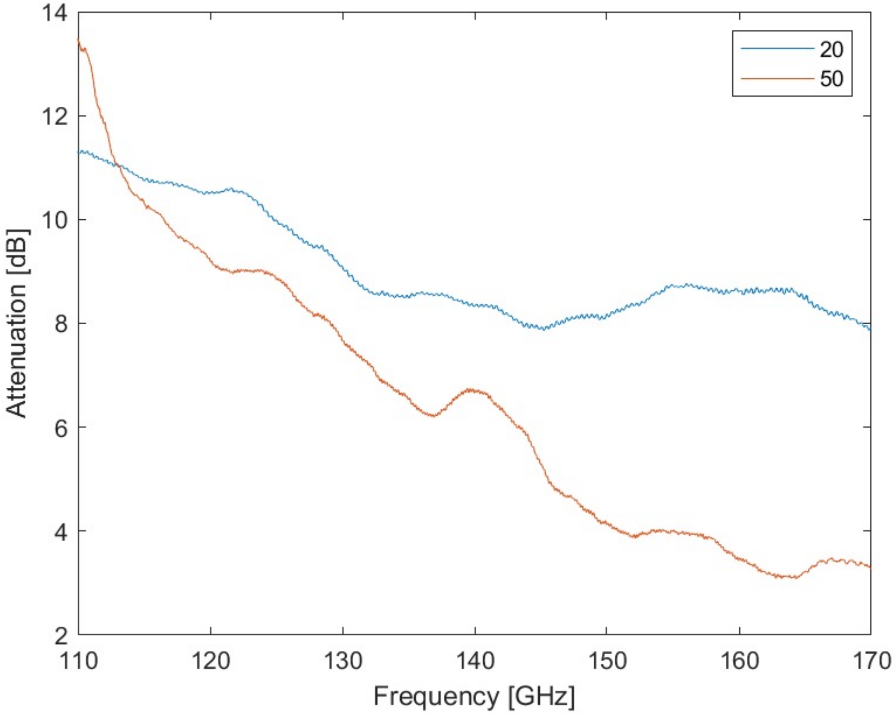
OBJECT ATTENUATION (1/9) – SINGLE USB CABLE





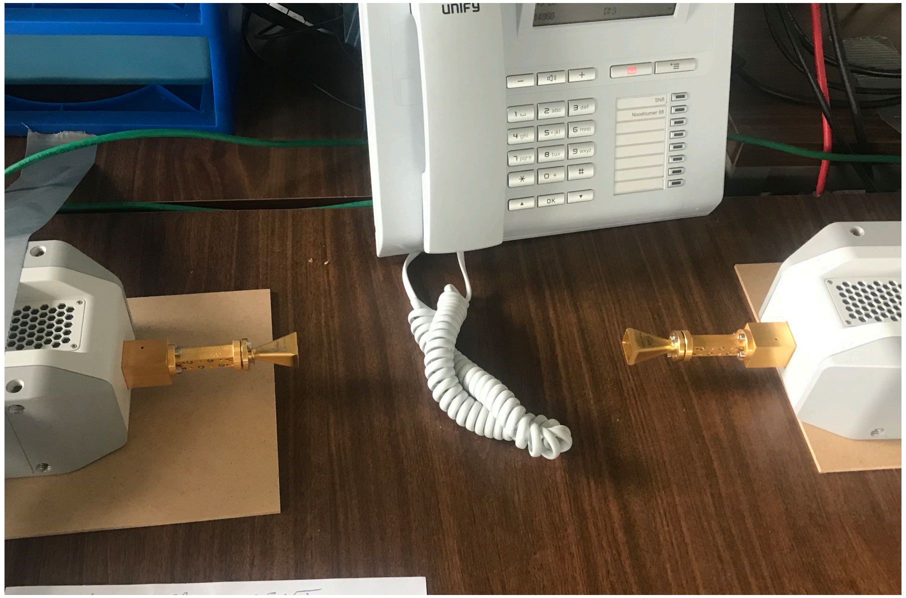
CHANNEL MODELLING

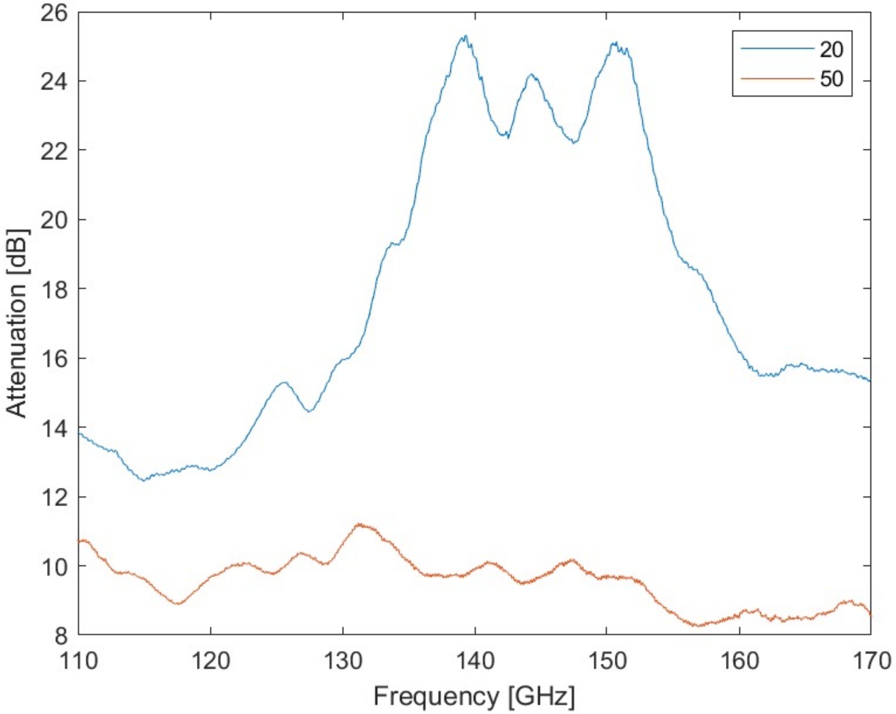
OBJECT ATTENUATION (2/9) – MULTIPLE USB CABLES



CHANNEL MODELLING

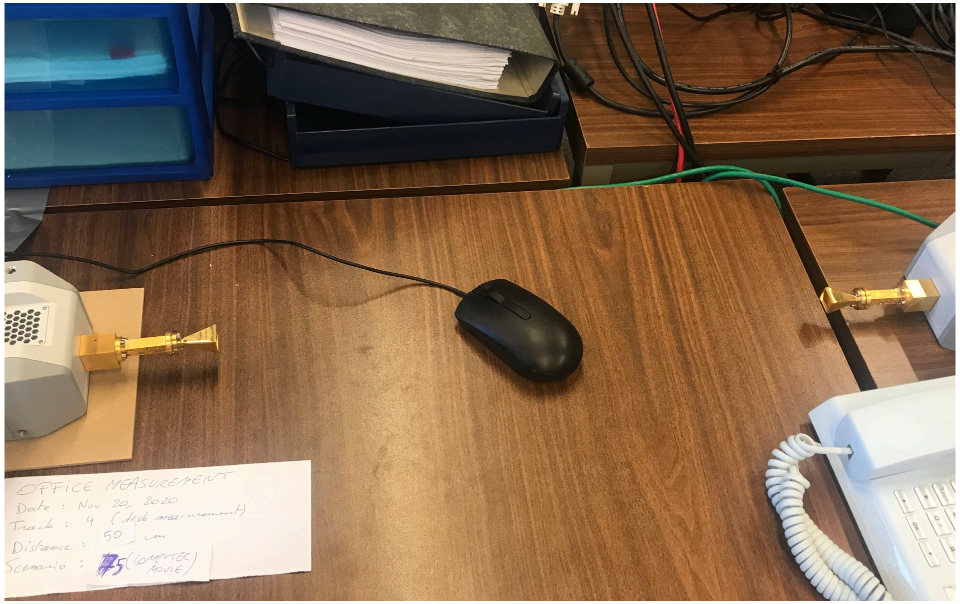
OBJECT ATTENUATION (3/9) – TELEPHONE CABLE

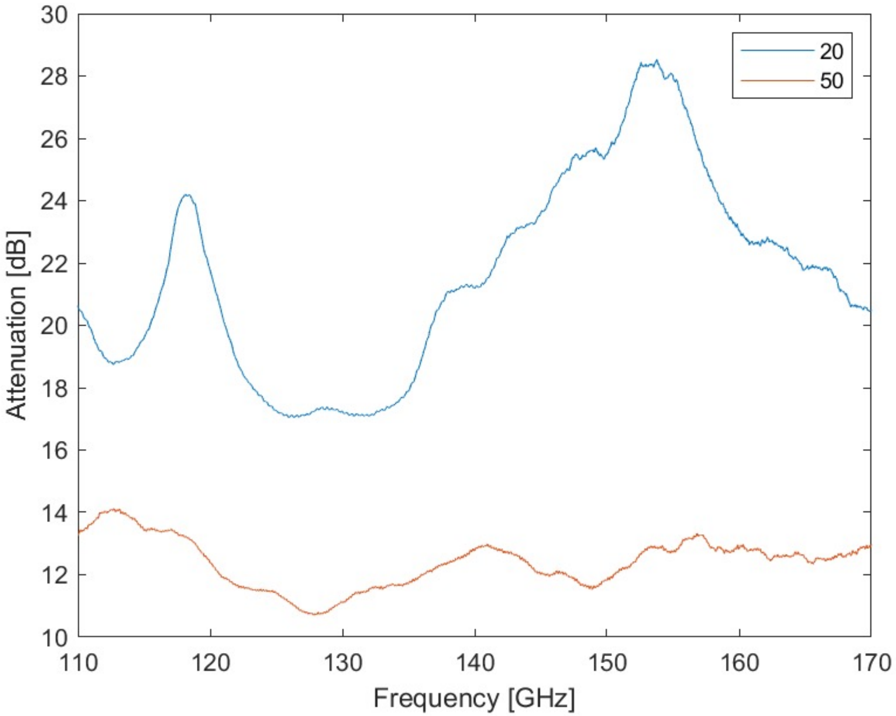




CHANNEL MODELLING

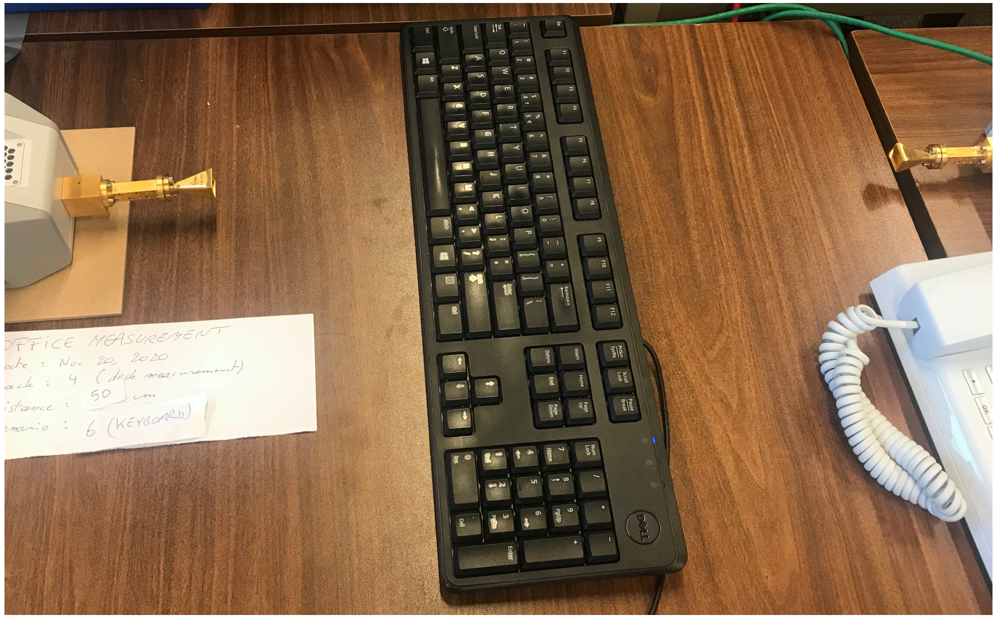
OBJECT ATTENUATION (4/9) – COMPUTER MOUSE

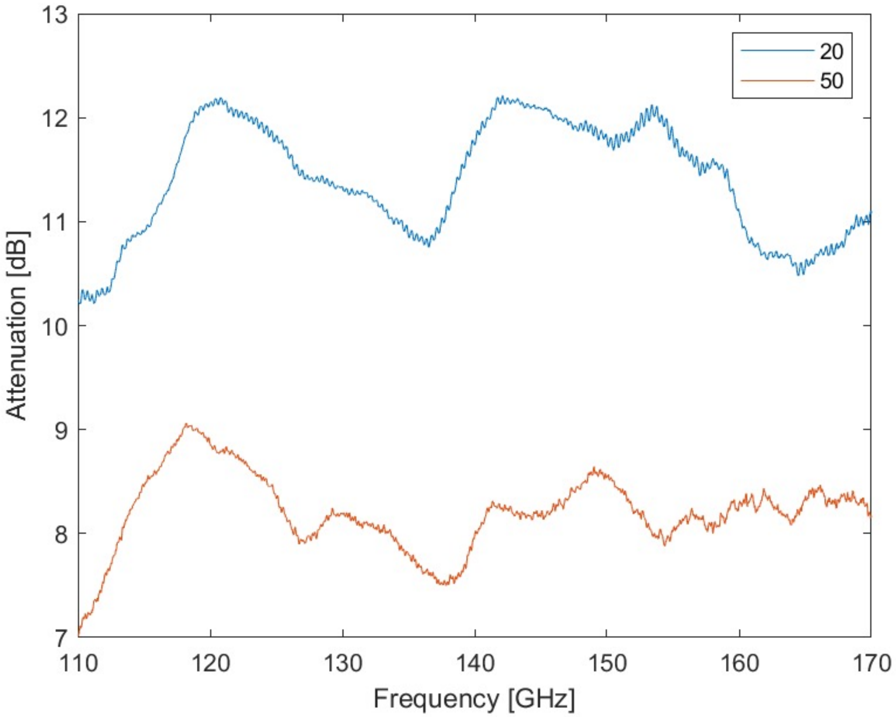




CHANNEL MODELLING

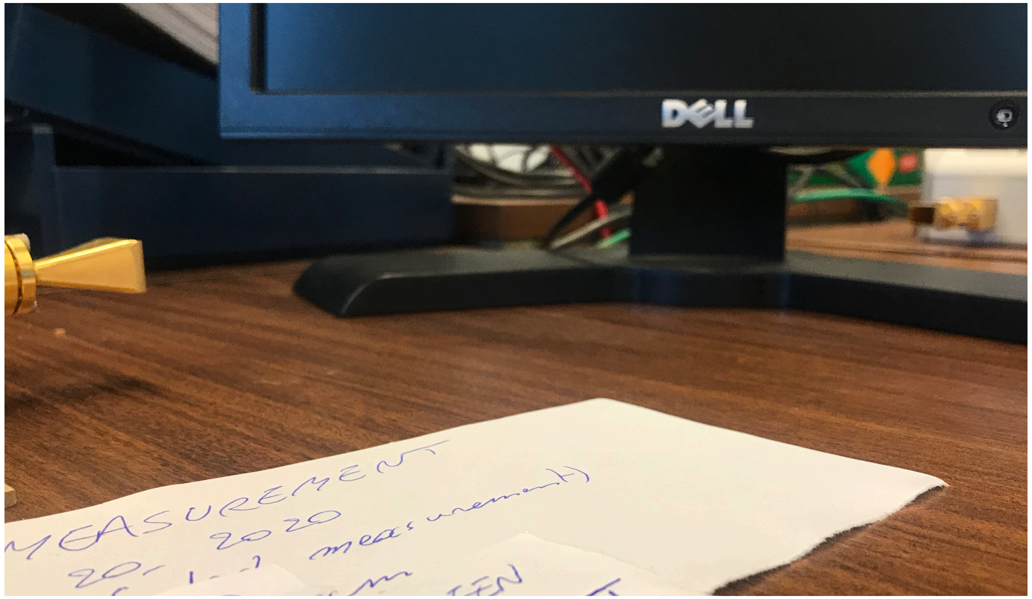
OBJECT ATTENUATION (5/9) – COMPUTER KEYBOARD

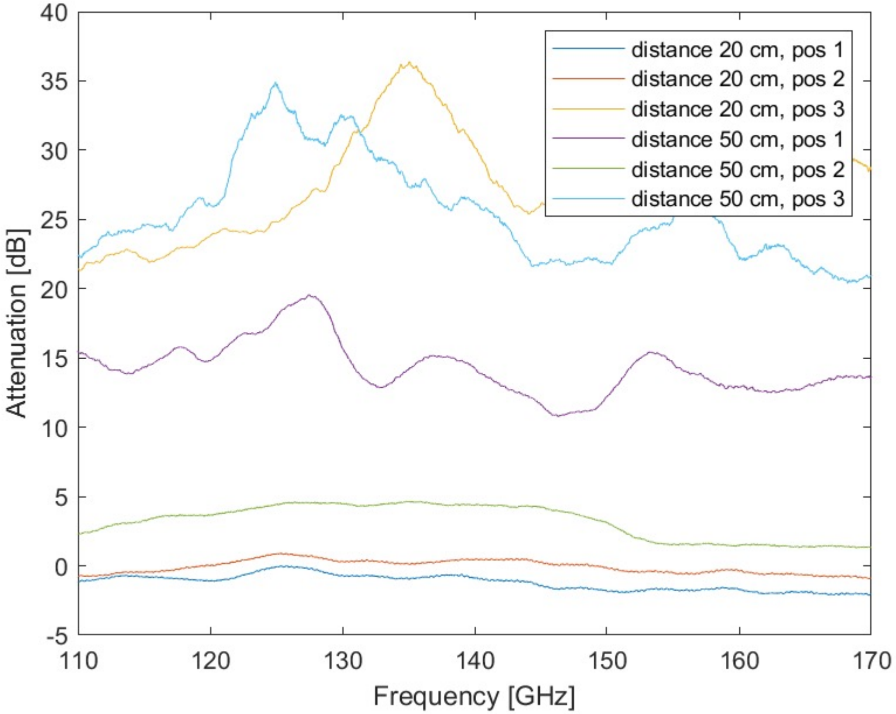




CHANNEL MODELLING

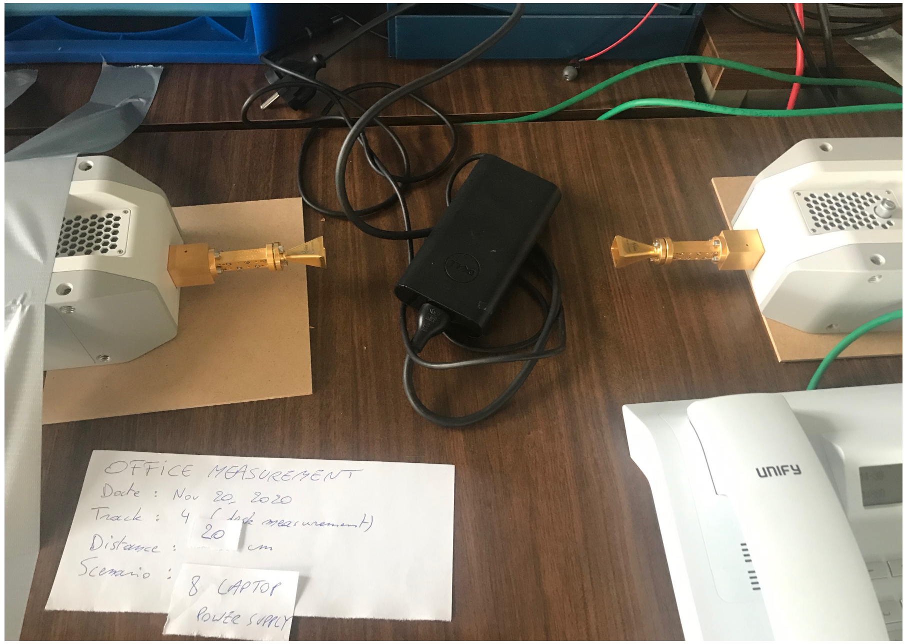
OBJECT ATTENUATION (6/9) – DESKTOP MONITOR SCREEN BASE

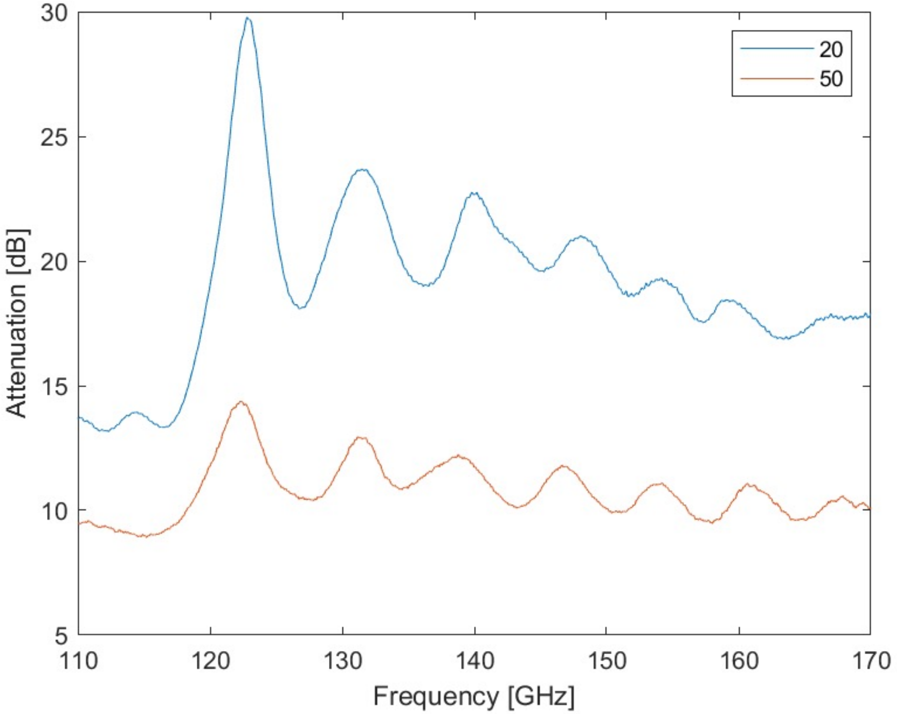




CHANNEL MODELLING

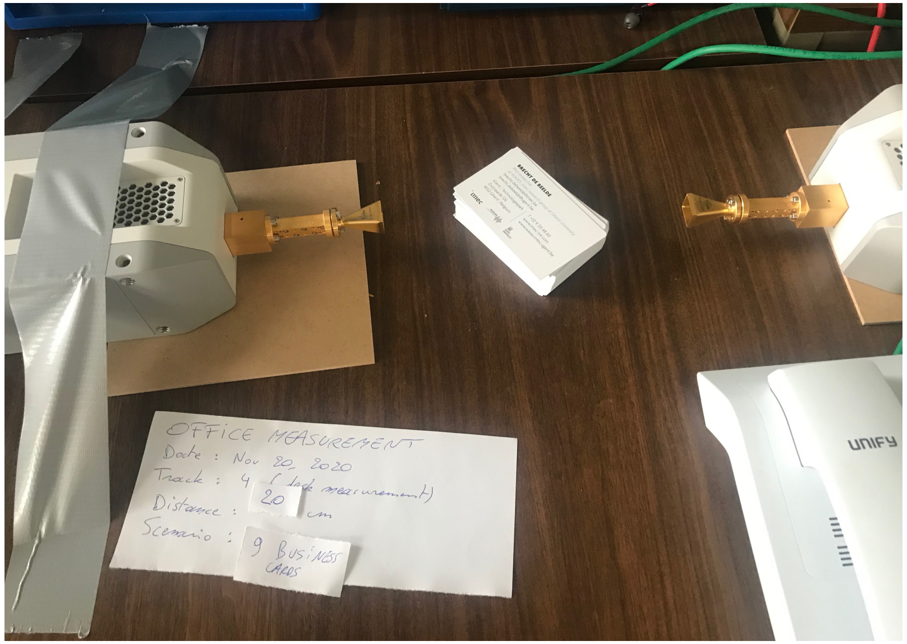
OBJECT ATTENUATION (7/9) – LAPTOP POWER SUPPLY UNIT

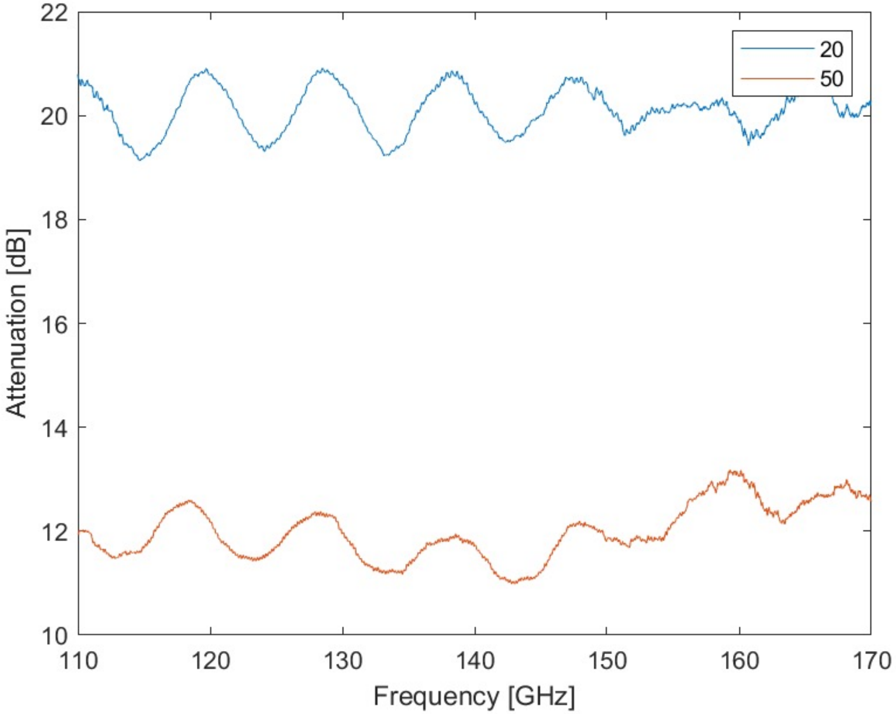




CHANNEL MODELLING

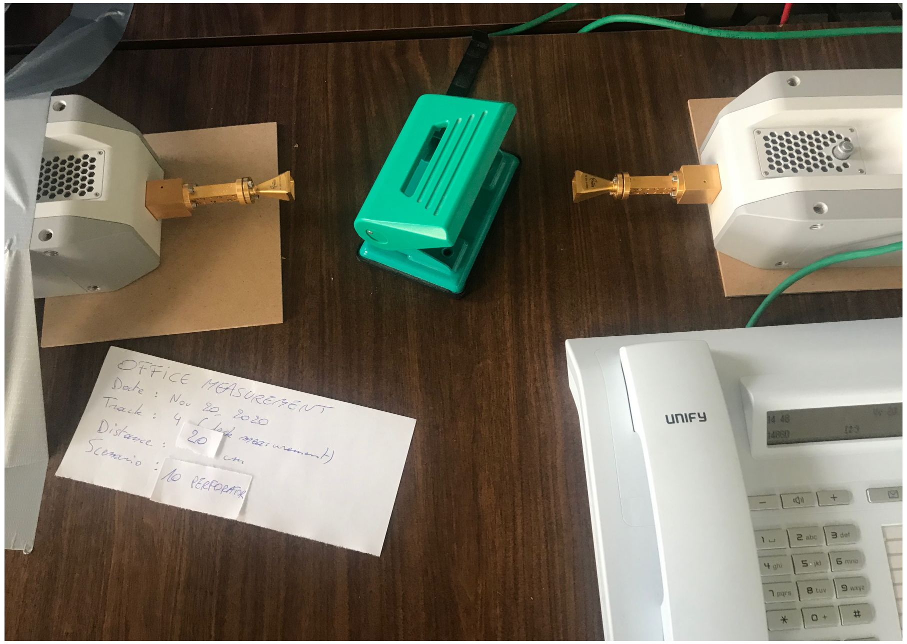
OBJECT ATTENUATION (8/9) – BUSINESS CARDS STACK



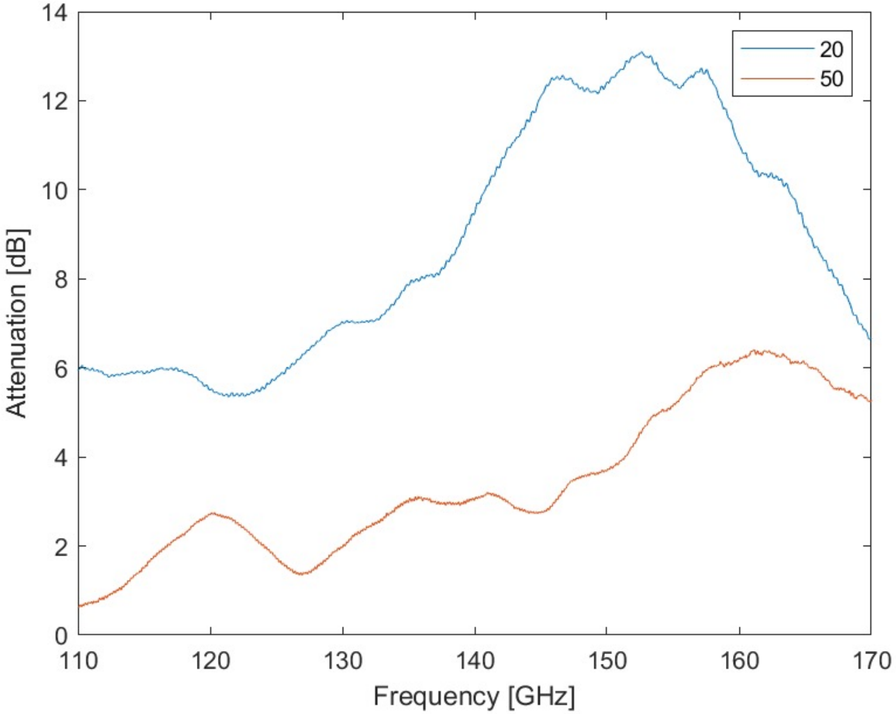


CHANNEL MODELLING

OBJECT ATTENUATION (9/9) – PERFORATOR

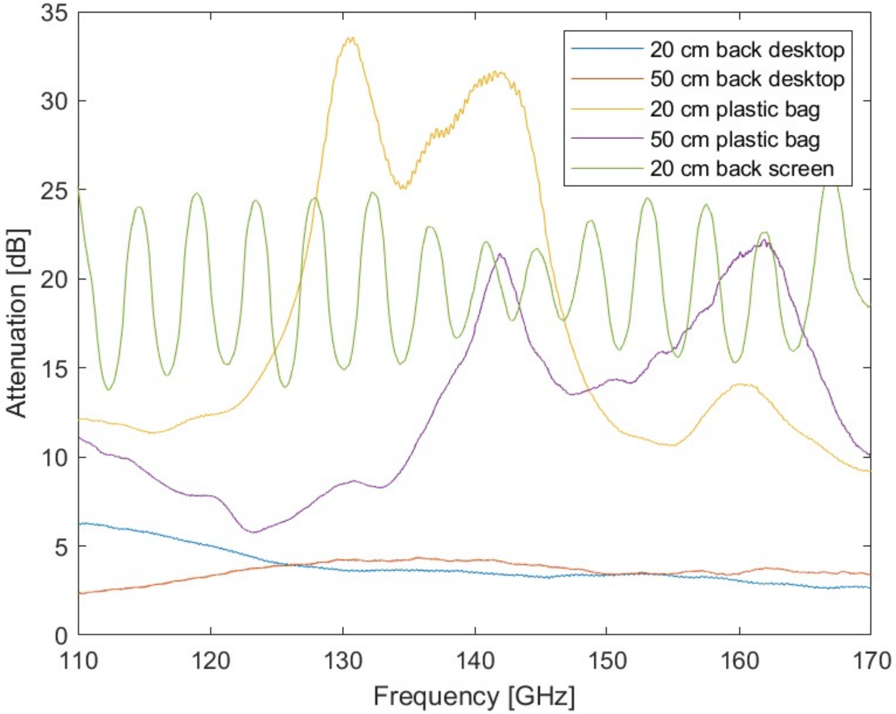


OFFICE MEASUREMENT
Date : Nov 20, 2020
Track : 4 (last measurement)
Distance : 20 cm
Scenario : 10 PERFORATOR



CHANNEL MODELLING

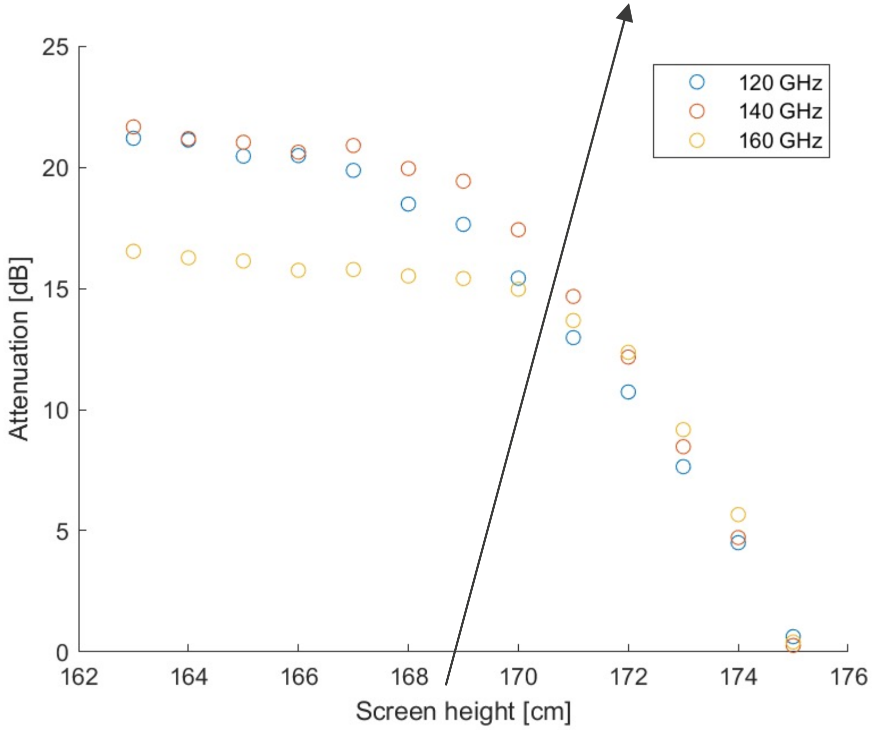
OBJECT ATTENUATION – REFLECTED NLOS PATH



CHANNEL MODELLING

SCREEN OBSTRUCTION (1/3)

- TX and RX at same height
- Obstructed LOS path

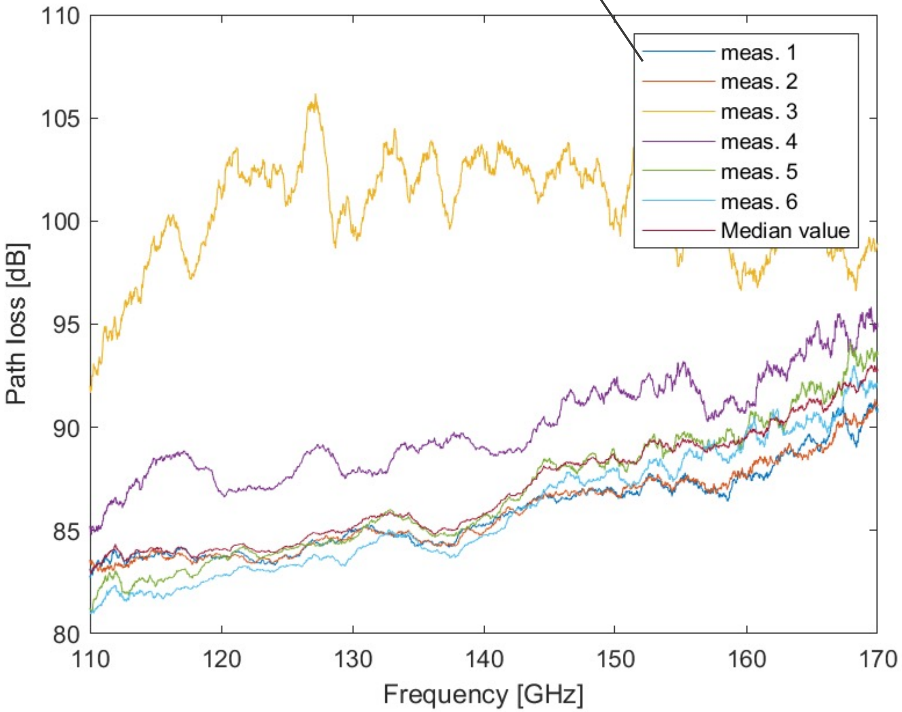


Height from the top of the screen to the ceiling

CHANNEL MODELLING
SCREEN OBSTRUCTION (1/3)

- TX and RX at same height
- Reflected NLOS path via nearby screen monitor

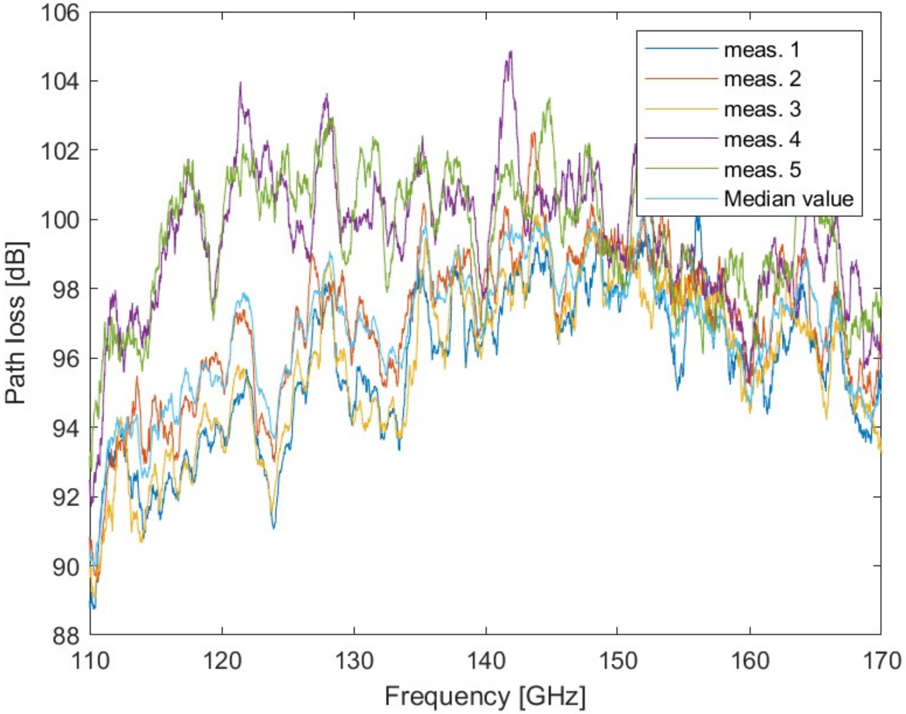
Different measurements with slight TX angle adjustments
Measurements 3 and 4 show severe misalignments



CHANNEL MODELLING

SCREEN OBSTRUCTION (2/3)

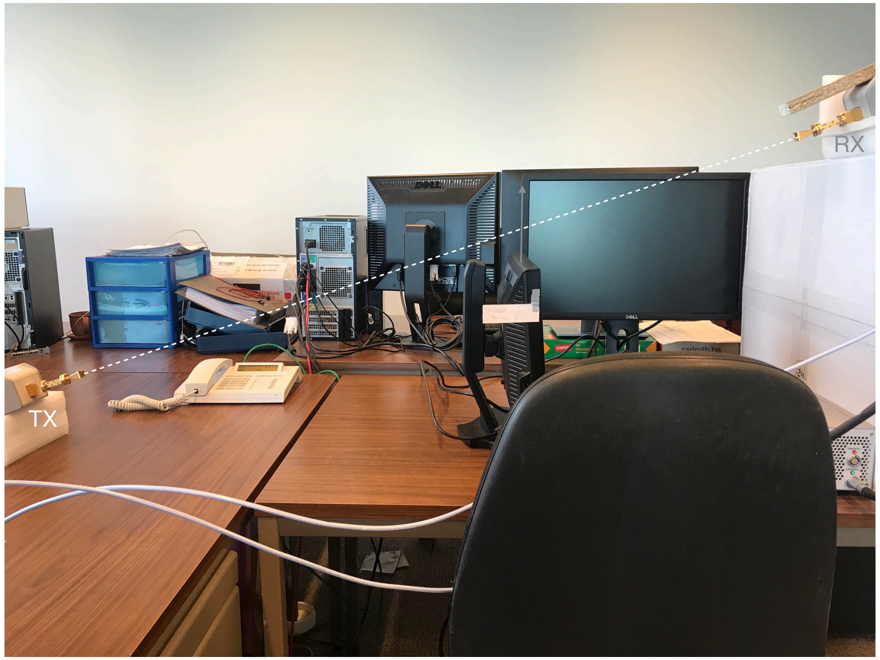
- TX and RX at same height
- Reflected NLOS path via wall

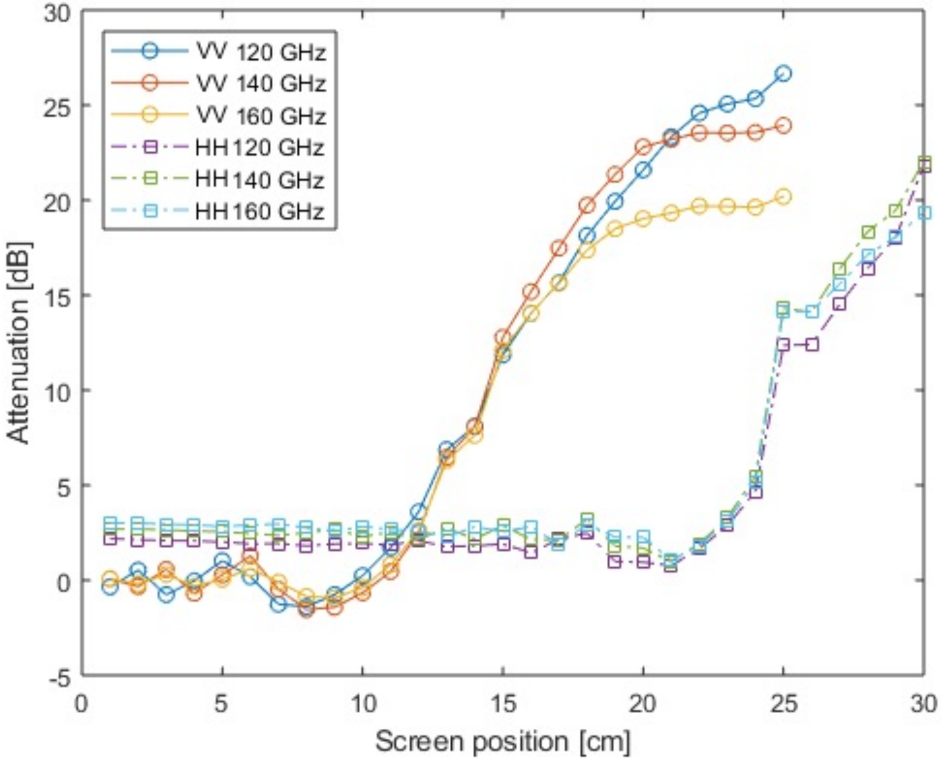


CHANNEL MODELLING

SCREEN OBSTRUCTION (3/3)

- TX and RX at different heights
- Obstructed LOS path

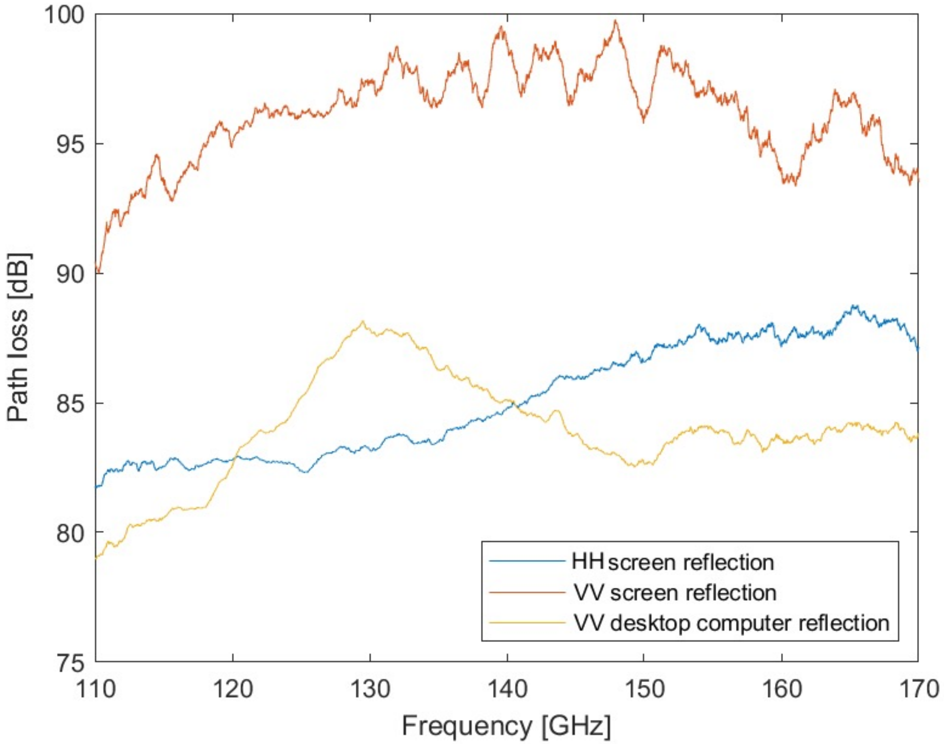




CHANNEL MODELLING

SCREEN OBSTRUCTION (3/3)

- TX and RX at different heights
- Reflected NLOS path via nearby screen monitor



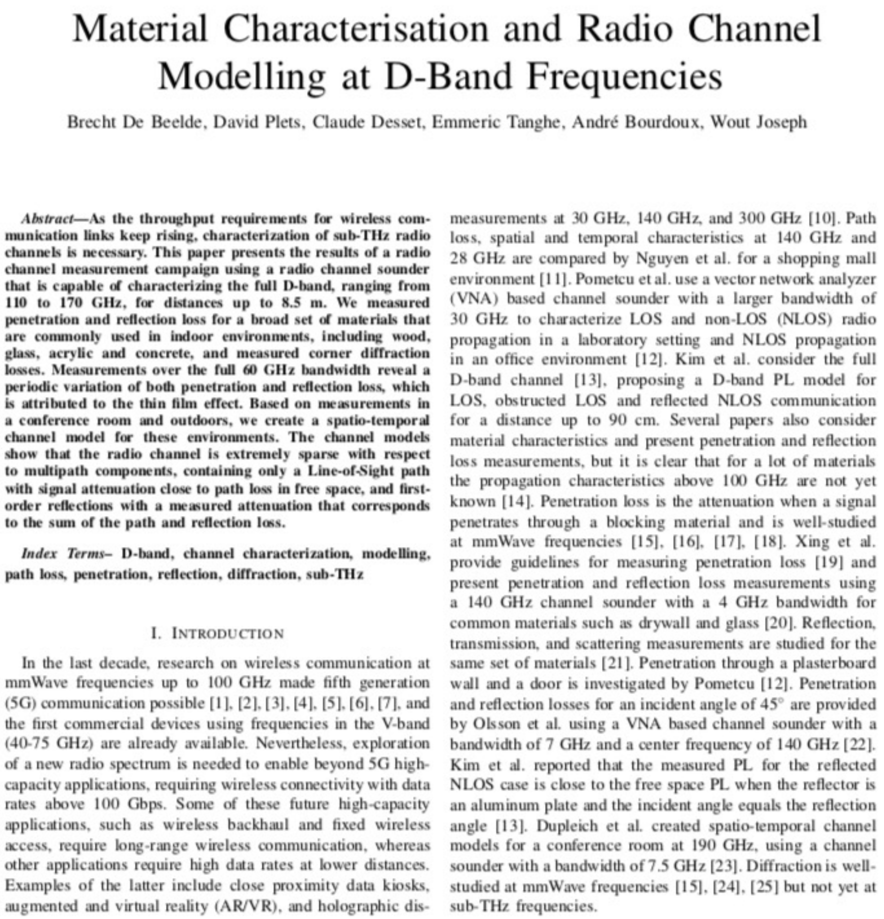
RELATED RESEARCH

D-BAND CHANNEL MODELS

RELATED RESEARCH

- Conference room channel modelling
- Reflection, penetration and diffraction loss
- Outdoor measurements

- Submitted for publication in IEEE Transactions on Antennas and Propagation



Material Characterisation and Radio Channel Modelling at D-Band Frequencies

Brecht De Beelde, David Plets, Claude Desset, Emmeric Tanghe, André Bourdoux, Wout Joseph

***Abstract*—As the throughput requirements for wireless communication links keep rising, characterization of sub-THz radio channels is necessary. This paper presents the results of a radio channel measurement campaign using a radio channel sounder that is capable of characterizing the full D-band, ranging from 110 to 170 GHz, for distances up to 8.5 m. We measured penetration and reflection loss for a broad set of materials that are commonly used in indoor environments, including wood, glass, acrylic and concrete, and measured corner diffraction losses. Measurements over the full 60 GHz bandwidth reveal a periodic variation of both penetration and reflection loss, which is attributed to the thin film effect. Based on measurements in a conference room and outdoors, we create a spatio-temporal channel model for these environments. The channel models show that the radio channel is extremely sparse with respect to multipath components, containing only a Line-of-Sight path with signal attenuation close to path loss in free space, and first-order reflections with a measured attenuation that corresponds to the sum of the path and reflection loss.**

***Index Terms*– D-band, channel characterization, modelling, path loss, penetration, reflection, diffraction, sub-THz**

I. INTRODUCTION

In the last decade, research on wireless communication at mmWave frequencies up to 100 GHz made fifth generation (5G) communication possible [1], [2], [3], [4], [5], [6], [7], and the first commercial devices using frequencies in the V-band (40-75 GHz) are already available. Nevertheless, exploration of a new radio spectrum is needed to enable beyond 5G high-capacity applications, requiring wireless connectivity with data rates above 100 Gbps. Some of these future high-capacity applications, such as wireless backhaul and fixed wireless access, require long-range wireless communication, whereas other applications require high data rates at lower distances. Examples of the latter include close proximity data kiosks, augmented and virtual reality (AR/VR), and holographic dis-

measurements at 30 GHz, 140 GHz, and 300 GHz [10]. Path loss, spatial and temporal characteristics at 140 GHz and 28 GHz are compared by Nguyen et al. for a shopping mall environment [11]. Pometcu et al. use a vector network analyzer (VNA) based channel sounder with a larger bandwidth of 30 GHz to characterize LOS and non-LOS (NLOS) radio propagation in a laboratory setting and NLOS propagation in an office environment [12]. Kim et al. consider the full D-band channel [13], proposing a D-band PL model for LOS, obstructed LOS and reflected NLOS communication for a distance up to 90 cm. Several papers also consider material characteristics and present penetration and reflection loss measurements, but it is clear that for a lot of materials the propagation characteristics above 100 GHz are not yet known [14]. Penetration loss is the attenuation when a signal penetrates through a blocking material and is well-studied at mmWave frequencies [15], [16], [17], [18]. Xing et al. provide guidelines for measuring penetration loss [19] and present penetration and reflection loss measurements using a 140 GHz channel sounder with a 4 GHz bandwidth for common materials such as drywall and glass [20]. Reflection, transmission, and scattering measurements are studied for the same set of materials [21]. Penetration through a plasterboard wall and a door is investigated by Pometcu [12]. Penetration and reflection losses for an incident angle of 45° are provided by Olsson et al. using a VNA based channel sounder with a bandwidth of 7 GHz and a center frequency of 140 GHz [22]. Kim et al. reported that the measured PL for the reflected NLOS case is close to the free space PL when the reflector is an aluminum plate and the incident angle equals the reflection angle [13]. Dupleich et al. created spatio-temporal channel models for a conference room at 190 GHz, using a channel sounder with a bandwidth of 7.5 GHz [23]. Diffraction is well-studied at mmWave frequencies [15], [24], [25] but not yet at sub-THz frequencies.

CONCLUSIONS

CONCLUSIONS

- D-band measurements, characterizing the full band in an office environment
- Line-of-Sight path loss model ~ free space path loss
- Data kiosk use case
    - High throughput, small distance
    - Assess attenuation due to desk objects (partly) obstructing Line-of-Sight path
    - Attenuation up to 25-30 dB compared to free space
    - Reflected NLOS path provides an alternative
- Access point use case
    - Diffraction around screen monitor
    - Reflection on nearby objects or walls

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