Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Characterization of Indoor Sub-THz Channels at 154 and 300 GHz

Date Submitted: November 2024

Source: Minghe Mao, Minseok Kim, Shigenobu Sasaki
Graduate School of Science and Technology, Niigata University, 8050 Ikarashi 2-no-cho, Nishi-ku, Niigata, Niigata, Japan
Voice:+81-25-262-7478, E-Mail: meika@eng.niigata-u.ac.jp, mskim@eng.niigata-u.ac.jp

Re: N/A

Abstract: In this document, an indoor dual-band channel measurement in two typical scenarios of a large conference room at 154 and 300 GHz is conducted and presented. Compared with the previous measurement with insufficient azimuth scanning range, this document provides 360 degrees azimuth scanning in both transmitter and receiver sides. In the measurement, the wide-beam probe antennas were used at the transmitter side and the narrow-beam horn antennas were used at the receiver side to investigate the double directional full azimuth scattering processes. The measured and modelled transmission losses are investigated with model parameters fitting, highlighting the potential of utilizing multipaths in THz indoor applications, even in the absence of the line-of-sight path. Then, the large-scale parameters in terms of route mean square delay spread, angle spread and K-factor are evaluated.

Purpose: Information document for IEEE 802.15 SC THz

Characterization of Indoor Sub-THz Channels at 154 and 300 GHz

Minghe Mao, Minseok Kim, and Shigenobu Sasaki
Niigata University, Japan

Abstract

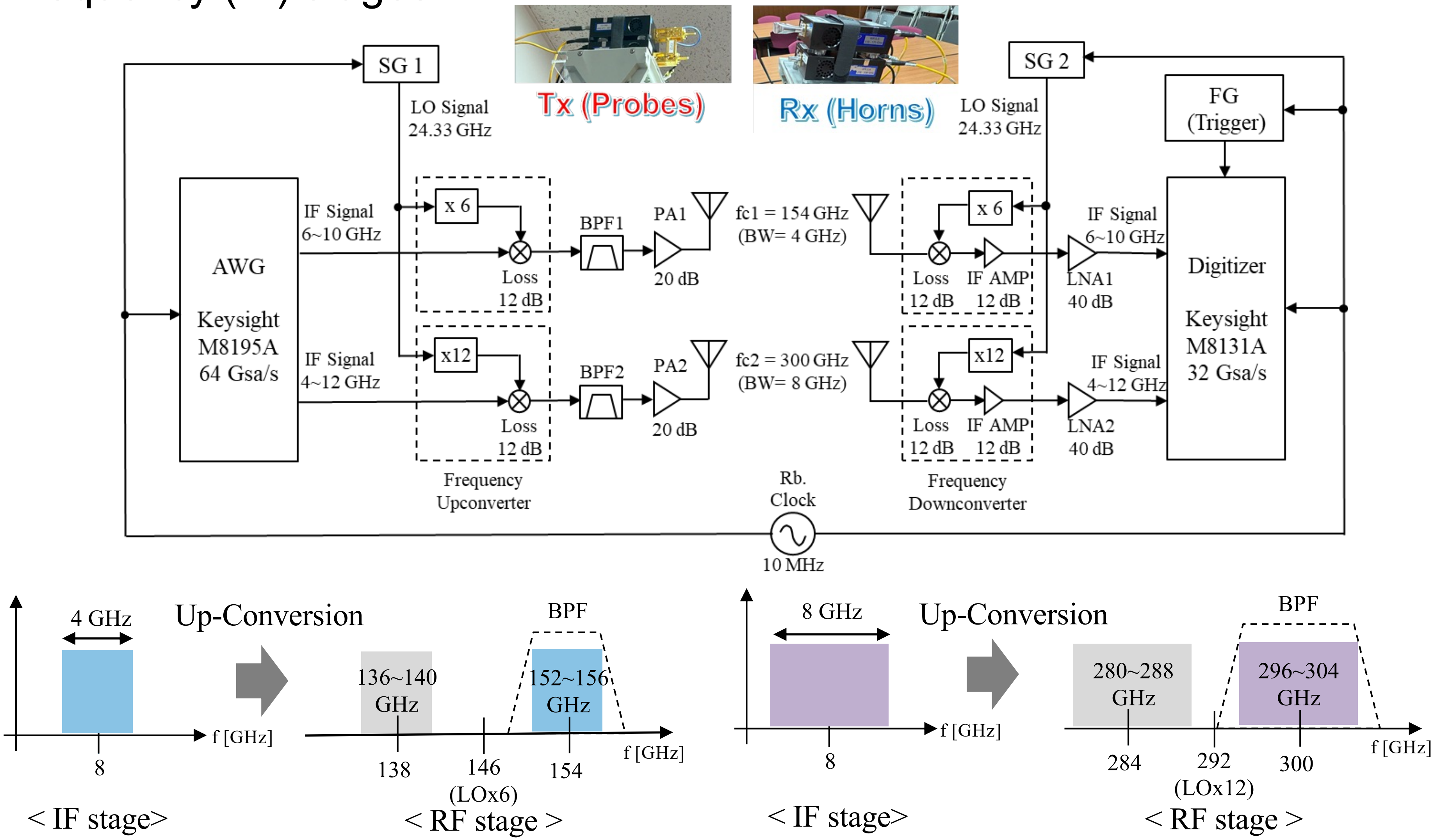
- The quick results of the large conference room measurement were reported (15-24-0240-01-0thz) [1].
- This document presents the updated results in terms of the path loss and large-scale parameters.
  - Adding scenarios (LoS and NLoS)
  - Increasing number of Rx points
  - Expanding azimuth scanning range (360 deg. at both Tx and Rx)

Outline

- 154/300-GHz Dual-Band Channel Sounder[1]
- High resolution
    - Bandwidth: 4 and 8 GHz
    - Beamwidth: 9° at Rx, 55° at Tx
- Full azimuth and sufficient elevation angle sweeping range
- Channel Measurement and Results
    - LoS/NLoS scenarios in a Large Conference Room
        - Measurement and post processing
        - Omni and best-beam PL with models fitting
        - Large scale parameters (LSPs)
- Summary and Future Works

Channel Sounder Architecture: Dual-Band [1]

- Instruments-based super-heterodyne architecture and intermediate frequency (IF) stages



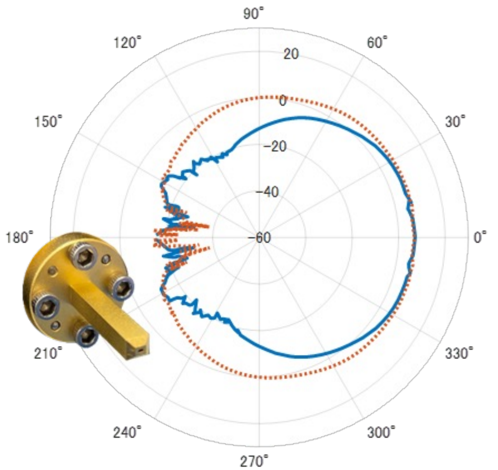
Channel Sounder Setup and Parameters

Channel sounder setup

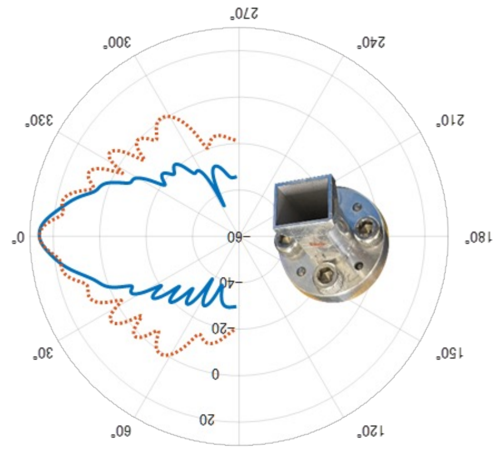
Parameters	Description or Value	Parameters	Description or Value
Freq.	154/300 GHz	Delay span	160 ns
Signal BW	4/8 GHz	Dynamic range	60~80 dB
Sounding signal	NPM (N=640/1, 280)	Polarization	Vertical
Sampling rates	64 GSa/s (AWG), 32 GSa/s (Digitizer)	EIRP (dBm)	2.1/-2.9
Delay resolution	250/125 ps	Tx/Rx height	2.0/1.2 m

Angle sweep setup

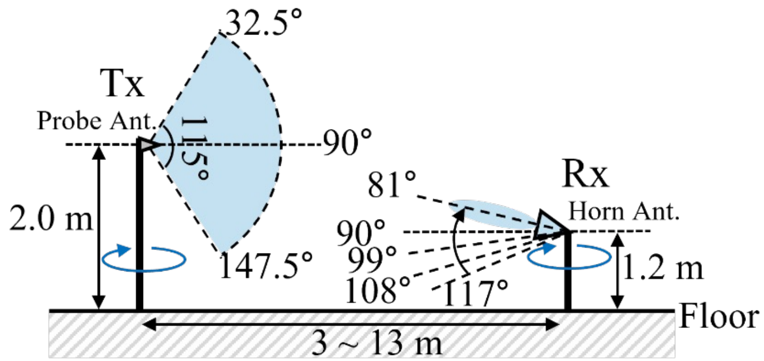
Tx full azimuth [deg]	0:45:315 (8)
Fixed Tx elevation [deg]	90
Rx full azimuth [deg]	0:9:351 (40)
Rx elevation [deg]	81:9:117 (5)



Gain: 6.5 dBi
HPBW: 55°@Az, 115°@El

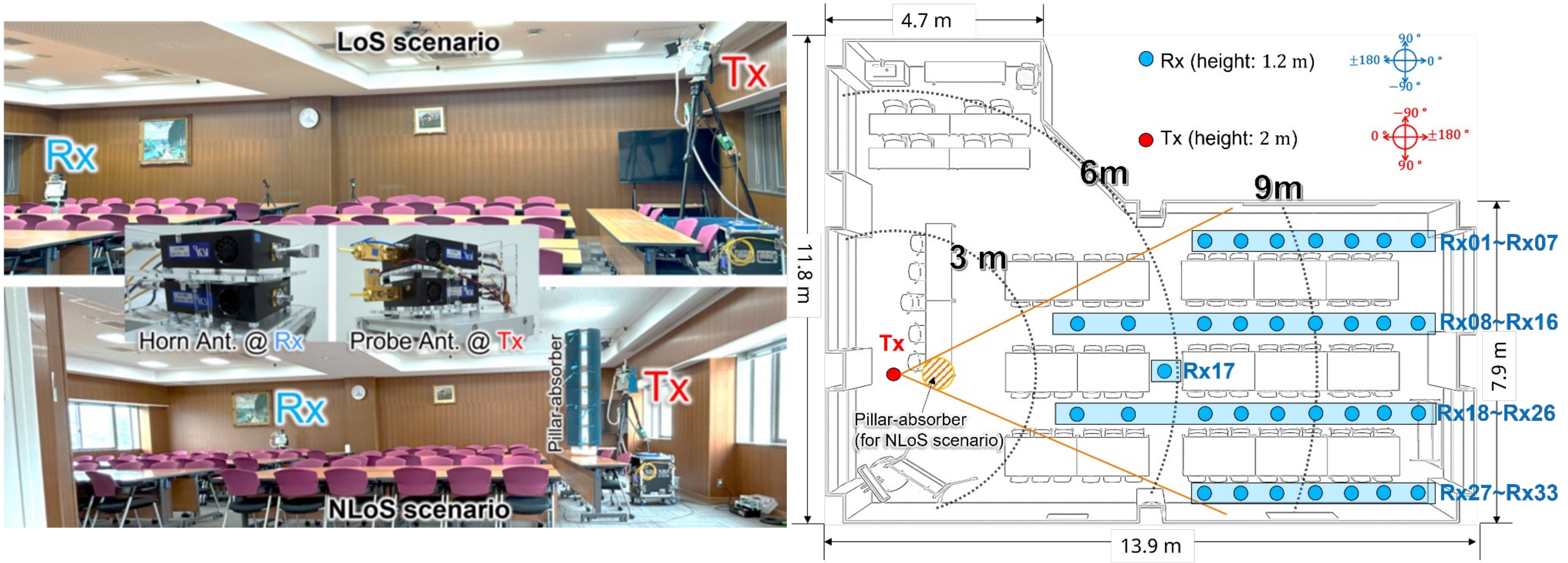


Gain: 26 dBi
HPBW: 9°@Az, 8°@El



Measurement Setup

- LoS scenario
- NLoS scenario: A pillar-absorber blocks the LoS path (2 m-long foam pillar wrapped in the radio-wave-absorbing material with a diameter of 0.5 m)
- Tx: fixed near the wall
- Rx: 33 positions (Rx-Tx separation is from 3 m to 13 m)



Power Spectra

- Double-Directional Angle Delay Power Spectrum

$$P(\check{\tau},\check{\theta}_{\mathrm{T}},\check{\phi}_{\mathrm{T}},\check{\theta}_{\mathrm{R}},\check{\phi}_{\mathrm{R}}) = \left|h(\check{\tau},\check{\theta}_{\mathrm{T}},\check{\phi}_{\mathrm{T}},\check{\theta}_{\mathrm{R}},\check{\phi}_{\mathrm{R}})\right|^2$$

- Noise-filtered DDADPS [*]: $P'(\check{\tau},\check{\theta}_{\mathrm{T}},\check{\phi}_{\mathrm{T}},\check{\theta}_{\mathrm{R}},\check{\phi}_{\mathrm{R}})$

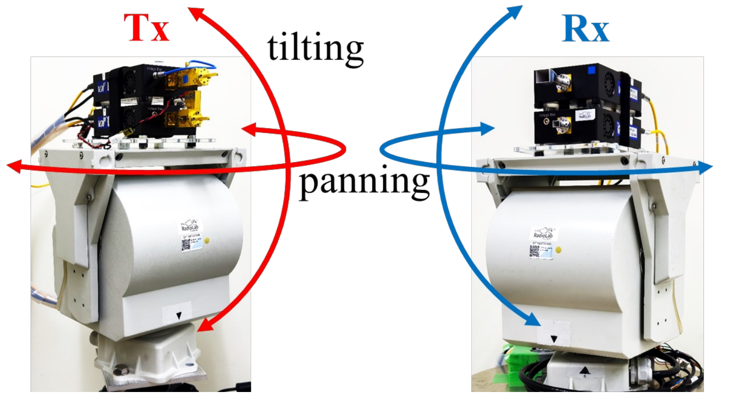
- Angular Power Spectra (APS)

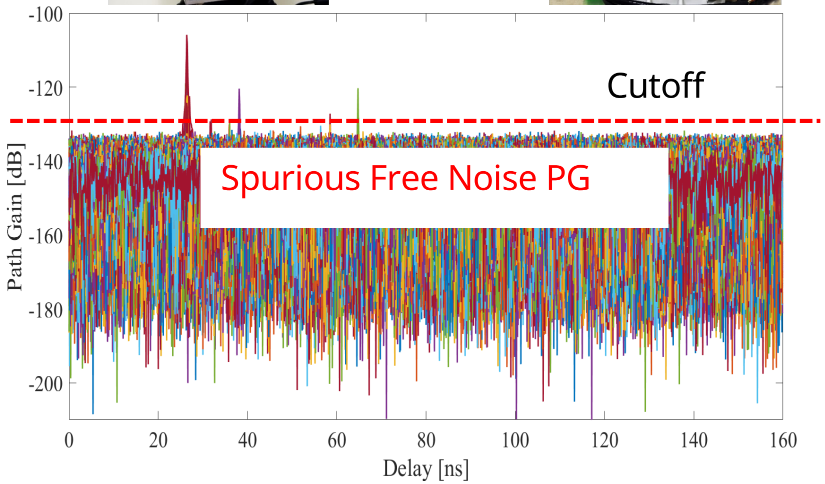
$$\mathrm{APS}_{\mathrm{T/R}}(\check{\theta}_{\mathrm{T/R}},\check{\phi}_{\mathrm{T/R}}) = \sum_{n_{\check{\tau}},n_{\check{\theta}_{\mathrm{R/T}}},n_{\check{\phi}_{\mathrm{R/T}}}} P'$$

- Synthesized Power Delay Profile

$$\mathrm{PDP}(\check{\tau}) = \sum_{n_{\check{\theta}_{\mathrm{T}}},n_{\check{\phi}_{\mathrm{T}}},n_{\check{\theta}_{\mathrm{R}}},n_{\check{\phi}_{\mathrm{R}}}} P'$$

$\check{\tau}$	Delay bin
$\check{\theta}_{\mathrm{T}},\check{\phi}_{\mathrm{T}}$	Pointing angle of Tx
$\check{\theta}_{\mathrm{R}},\check{\phi}_{\mathrm{R}}$	Pointing angle of Rx



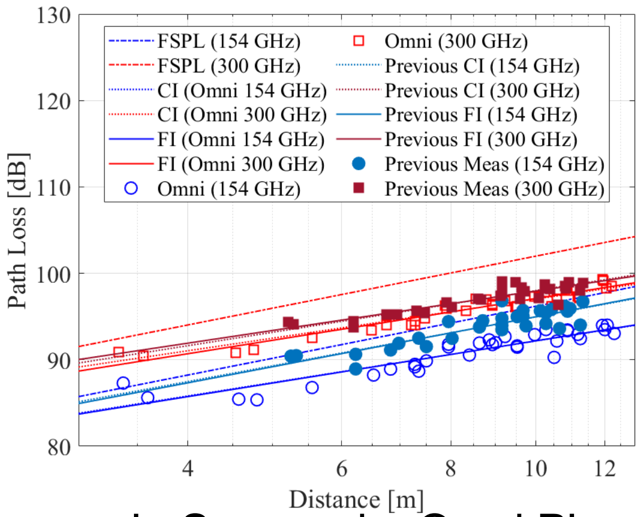


[2] A. Ghosh, et al., "Double-Directional Channel Characterization of an Indoor Corridor Scenario at 300 GHz," in IEEE GLOBECOM 2023-2023, Kuala Lumpur, Malaysia, 2023, pp.1465-1470.

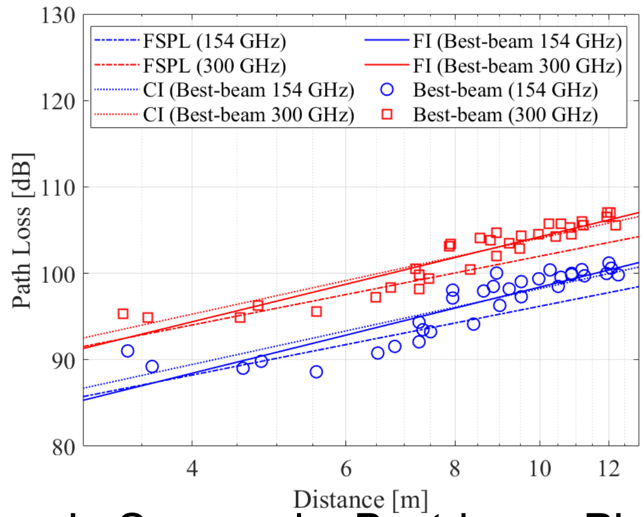
Path Loss and Models

- Omni path loss
  - $\mathrm{PL_{omni}}\ [\mathrm{dB}] = -10\log_{10}\left(\frac{\Delta_{\phi_\mathrm{T}}\Delta_{\phi_\mathrm{R}}}{\phi_{\mathrm{BW,T}}\phi_{\mathrm{BW,R}}}\sum_{\forall} P'(\check{\tau}, \check{\theta}_\mathrm{T}, \check{\phi}_\mathrm{T}, \check{\theta}_\mathrm{R}, \check{\phi}_\mathrm{R})\right)$
  - $\Delta_{\phi_\mathrm{T}}, \Delta_{\phi_\mathrm{R}}$ are the angular resolution, and $\phi_{\mathrm{BW,T}}, \phi_{\mathrm{BW,R}}$ represent the HPBW
- Best beam path loss
  - $\mathrm{PL_B}\ [\mathrm{dB}] = -10\log_{10}\left(\sum_{n_{\check{\tau}}} P'(\check{\tau}, \check{\theta}_{\mathrm{T_B}}, \check{\phi}_{\mathrm{T_B}}, \check{\theta}_{\mathrm{R_B}}, \check{\phi}_{\mathrm{R_B}})\right)$
  - Where $\left(\check{\theta}_{\mathrm{T_B}}, \check{\phi}_{\mathrm{T_B}}, \check{\theta}_{\mathrm{R_B}}, \check{\phi}_{\mathrm{R_B}}\right) = \underset{\check{\theta}_\mathrm{T}, \check{\phi}_\mathrm{T}, \check{\theta}_\mathrm{R}, \check{\phi}_\mathrm{R}}{\arg\max} \sum_{n_{\check{\tau}}} P'(\check{\tau}, \check{\theta}_\mathrm{T}, \check{\phi}_\mathrm{T}, \check{\theta}_\mathrm{R}, \check{\phi}_\mathrm{R})$
- Path Loss Models:
  - Close-in free space (CI)
    - $L_{\mathrm{CI}}(d)\ [\mathrm{dB}] = 10n\log_{10}(d) + 20\log_{10}\left(\frac{4\pi f_{\mathrm{GHz}}\times 10^9}{c}\right)$, where d is propagation distance, f_{GHz} denotes the frequency in GHz, n is path loss exponent, c is the light speed
  - Floating-intercept (FI)
    - $L_{\mathrm{FI}}(d)\ [\mathrm{dB}] = 10\alpha\log_{10}(d) + \beta$, where α and β are the slope and floating intercept

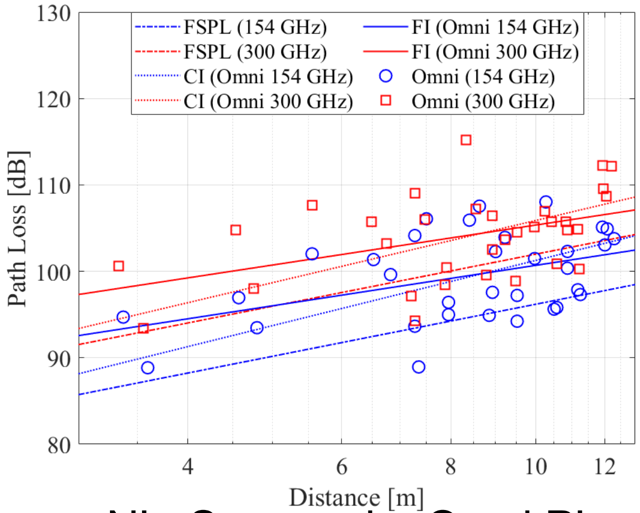
PL and Models Fitting Results



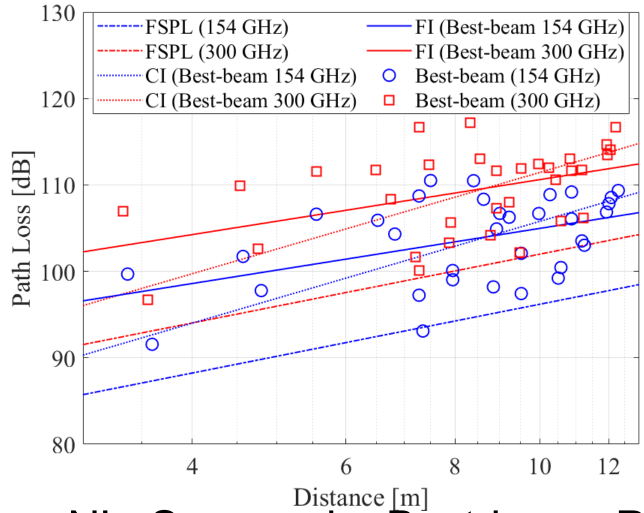
LoS scenario: Omni PL



LoS scenario: Best-beam PL



NLoS scenario: Omni PL



NLoS scenario: Best-beam PL

- Compared with the previous results, the omni PL values are further suppressed
  - More MPCs due to the full azimuth scanning on both side of Tx and Rx

PL Model Fitting Parameters

- Previous measurement:

Freq.	CI Model (n, σ)	FI Model (α, β, σ)
154 GHz	(1.88, 1.01)	(1.92, 75.77, 1.01)
300 GHz	(1.60, 0.71)	(1.52, 82.79, 0.71)

- Updated:

Scen.	PL	Freq.	CI Model (n, σ)	FI Model (α, β, σ)
LoS	Omni	154 GHz	(1.60, 1.01)	(1.62, 75.98, 1.01)
		300 GHz	(1.50, 0.69)	(1.61, 81.03, 0.68)
	Best-beam	154 GHz	(2.20, 1.83)	(2.50, 73.36, 1.78)
		300 GHz	(2.21, 1.41)	(2.47, 79.51, 1.35)
NLoS	Omni	154 GHz	(2.51, 4.78)	(1.55, 85.15, 4.57)
		300 GHz	(2.39, 4.66)	(1.54, 89.99, 4.49)
	Best-beam	154 GHz	(2.96, 4.90)	(1.60, 88.94, 4.48)
		300 GHz	(2.95, 4.95)	(1.60, 94.63, 4.53)

- Observations
  - PLE (n values) are further reduced due to full azimuth channel sounding
  - PLE of the Omni PL at both frequencies in two scenarios are smaller than 2, demonstrating the availability of using MPCs
  - CI and FI have the similar deviation
  - 300 GHz band experienced less shadowing (σ values)

LSP

- Root Mean Square Delay Spread (RMS DS)

$$\mathrm{DS_{RMS}} = \sqrt{\frac{\sum_{n_\tau} \check{\tau}^2 \mathrm{PDP}(\check{\tau})}{\sum_{n_\tau} \mathrm{PDP}(\check{\tau})} - \left(\frac{\sum_{n_\tau} \check{\tau} \mathrm{PDP}(\check{\tau})}{\sum_{n_\tau} \mathrm{PDP}(\check{\tau})}\right)^2}$$

- Angle Spread of Arrival (ASA)
  - Directional angular power (DAP): $\mathrm{DAP}(\breve{\Omega}) = \sum_{\{n_{\check{\tau}}, n_{\breve{\theta}_\mathrm{T}}, n_{\breve{\phi}_\mathrm{T}}, n_{\breve{\theta}_\mathrm{R}}, n_{\breve{\phi}_\mathrm{R}}\} | n_\Omega} P'$
  - ASA:

$$\mathrm{ASA} = \sqrt{-2\ln \left| \frac{\sum_{n_\Omega} \exp\left(j\breve{\Omega}\right) \mathrm{DAP}\left(\breve{\Omega}\right)}{\sum_{n_\Omega} \mathrm{DAP}\left(\breve{\Omega}\right)} \right|}$$

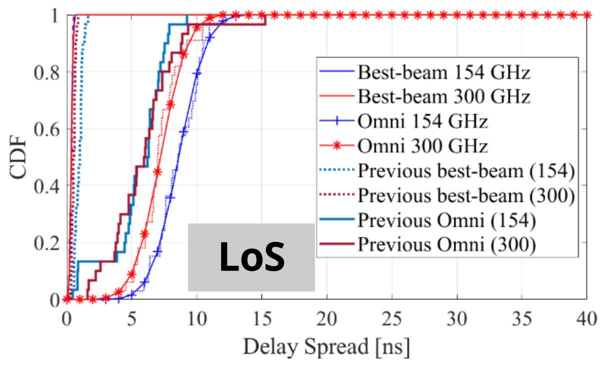
- K-Factor: the distribution of the MPC over the delay domain

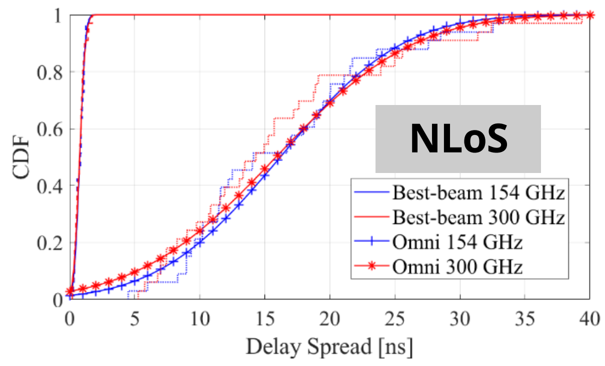
$$\mathrm{K} = \frac{\sum_{n_\tau \in \mathcal{R}} \mathrm{PDP}(\check{\tau})}{\sum_{n_\tau} \mathrm{PDP}(\check{\tau}) - \sum_{n_\tau \in \mathcal{R}} \mathrm{PDP}(\check{\tau})}$$

where $\mathcal{R}$ represents the set of delays of MPCs belongs to the LoS cluster.

LSP results: RMS DS and ASA

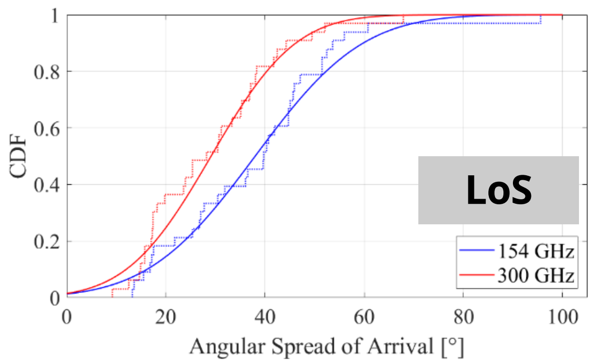
- RMS DS results
  - Nearly identical DS for both frequencies;
  - Best-beam has very small DS values

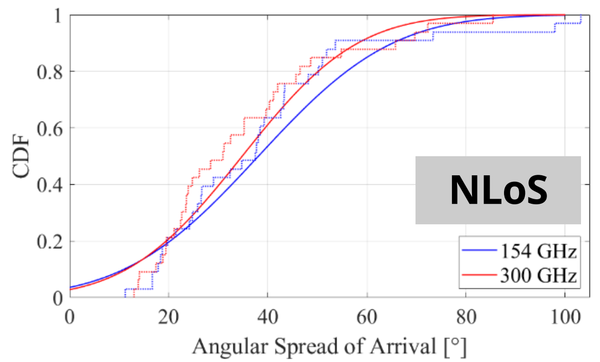




  - Comparing with the previous results
    - The larger omni DS mainly due to the full azimuth scanning with longer distance multipaths
    - Smaller best-beam DS mainly due to the different number and locations of the Rx positions

- ASA
  - 300 GHz band has smaller ASA
    - Due to more sparsity of MPC

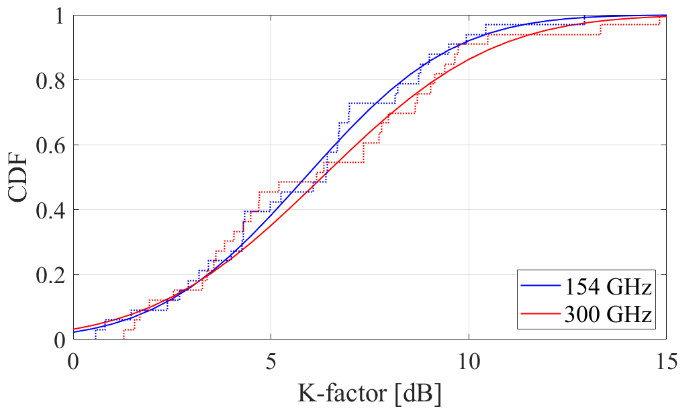




  - NLoS scenario exhibits larger ASA
    - Due to the absence of LoS components

LSP results: K-factor

■ K-factor



- 154 GHz band has a slightly lower K-factor, indicating that LoS propagation is more dominant at 300 GHz
  - ➢ Due to the sparser MPCs and higher interaction losses of reflected paths at 300 GHz

■ Parameters

LSP	Param.	LoS 154 GHz	LoS 300 GHz	NLoS 154 GHz	NLoS 300 GHz
DS [ns] Best beam	μ_{DS}	0.37	0.35	0.78	0.77
	σ_{DS}	0.12	0.11	0.33	0.37
DS [ns] Omni	μ_{DS}	8.62	7.21	16.19	15.86
	σ_{DS}	1.69	1.64	7.37	8.34
ASA [°]	μ_{ASA}	38.01	29.12	38.11	34.84
	σ_{ASA}	17.01	13.34	21.17	18.22
K [dB]	μ_K	5.87	6.29	-	-
	σ_K	2.93	3.39	-	-

Summary

- Channel characterization in typical indoor LoS and NLoS scenarios at 154 GHz and 300 GHz are presented.
- The characteristics of both omni PL and best-beam PL are derived by fitting the measurement data with standard models.
- Comparing with 154 GHz, the 300 GHz band has smaller PLE and less shadowing, reflecting the sparser MPCs at higher frequencies.
- LSPs were extracted, showing nearly identical RMS DS for both frequencies. However, the smaller azimuth angle spread of arrival (ASA) and slightly higher K-factor at 300 GHz, further indicating sparser MPCs and higher interaction losses for reflected paths at the higher frequency.

Thank You

http://radio.eng.niigata-u.ac.jp/

mskim@eng.niigata-u.ac.jp

+81 – 025 – 262 – 7478

This work includes the research results conducted under the National Institute of Information and Communications Technology (NICT) Beyond 5G R&D Promotion Program (#JPJ012368C02701) and the Ministry of Internal Affairs and Communications(MIC)/FORWARD (#JPMI240410003).

References

[1] M. Mao, M. Kim, S. Sasaki, “154/300 GHz Dual-band Double-Directional Channel Measurements in a Large Conference Room Environment”, doc.: IEEE802.15-24-0240-01-0thz, May 2024.

[2] A. Ghosh, et al., ”Double-Directional Channel Characterization of an Indoor Corridor Scenario at 300 GHz,” in IEEE GLOBECOM 2023, Kuala Lumpur, Malaysia, 2023, pp.1465-1470.