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

Submission Title: radio propagation performance of close proximity P2P on 60 GHz band

Date Submitted: 14 July, 2014

Source: Ichiro Seto, Kiyoshi Toshimitsu, Kazuaki Kawabata, Koji Akita and Hideo Kasami

Company: Toshiba Corporation
Address: 580-1 Horikawa-cho, Saiwai-ku, Kawasaki, Kanagawa, Japan
Voice:+81-44-548-2342, FAX: +81-44-548-2342, E-Mail: ichiro.seto@toshiba.co.jp

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Abstract: This document describes measured radio propagation performance of close proximity P2P communication on 60 GHz band for applications of file transfer between CEs, kiosk downloading etc.

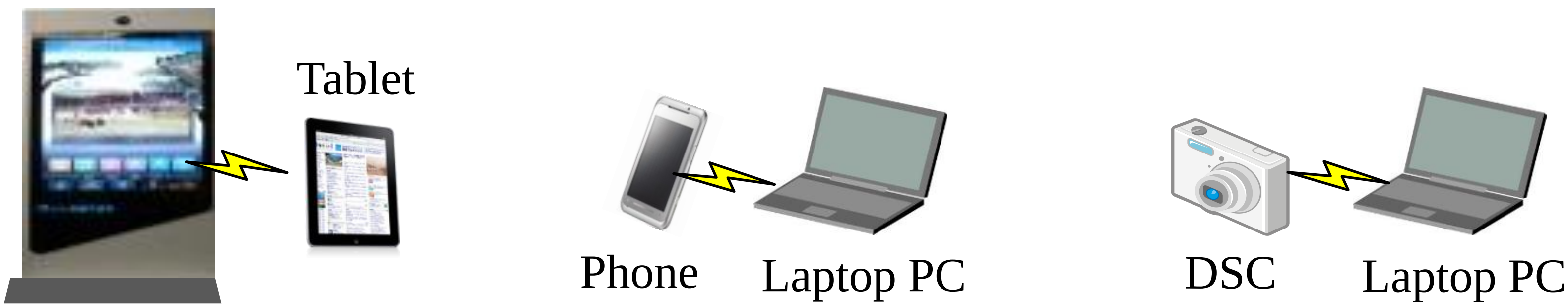
Purpose: To discuss radio propagation performance of close proximity P2P on 60 GHz band

Contents

- **Background for studying channel model in 802.15.3d which focuses close proximity point-to-point, P2P, communication on 60 GHz band**
- **Measurement results of radio propagation performance**
  - **Small form factor antennas**
  - **Antennas are placed inside consumer electronic, CE**

Application Usages and Technical Features on 60 GHz band in 15.3d

- Close Proximity P2P Communication System



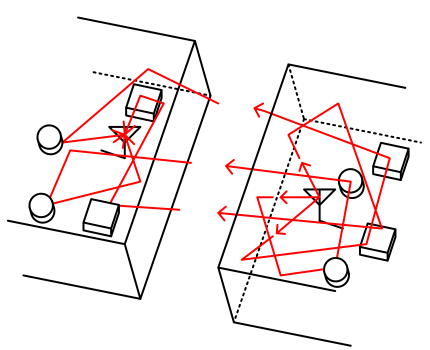
Kiosk Download   File Exchange

- Technical features
  - **Distance: a few to 5 centimeters** [TBD]
  - Wide unlicensed band: 57 to 66 GHz [TBD]
  - Capability of data-rate: over Gbps to 100 Gbps [TBD]

Millimeter-wave, mmW, antenna difference

- Conventional channel measurements in 15.3c for Kiosk [1]
  - Reference Antenna : Horn type with FWHM of 30 deg , not small form factor type
  - Transmission distance : 1m range

- Close proximity channel [2] in 15.3d
  - Applying small form factor antennas to be placed inside CE devices,
    - Tendency of wide-angle radiation
  - Transmission distance : a few to 5 centimeters



mmW antenna of small form factor

- Antenna Type for Single-Input-Single-Output
  - **Wire like monopole, dipole, loop**
  - **Planer like patch**
  - Directional like Horn
  - Slot
- Antenna Radiation Performance we should consider
  - Polarization
    - Horizontal, Vertical, Circle
  - Directivity
    - Full width of half maximum, FWHM
    - Forward / Backward
  - Obstacles between TX and RX
    - Without metal or with metal which belongs to CE chassis

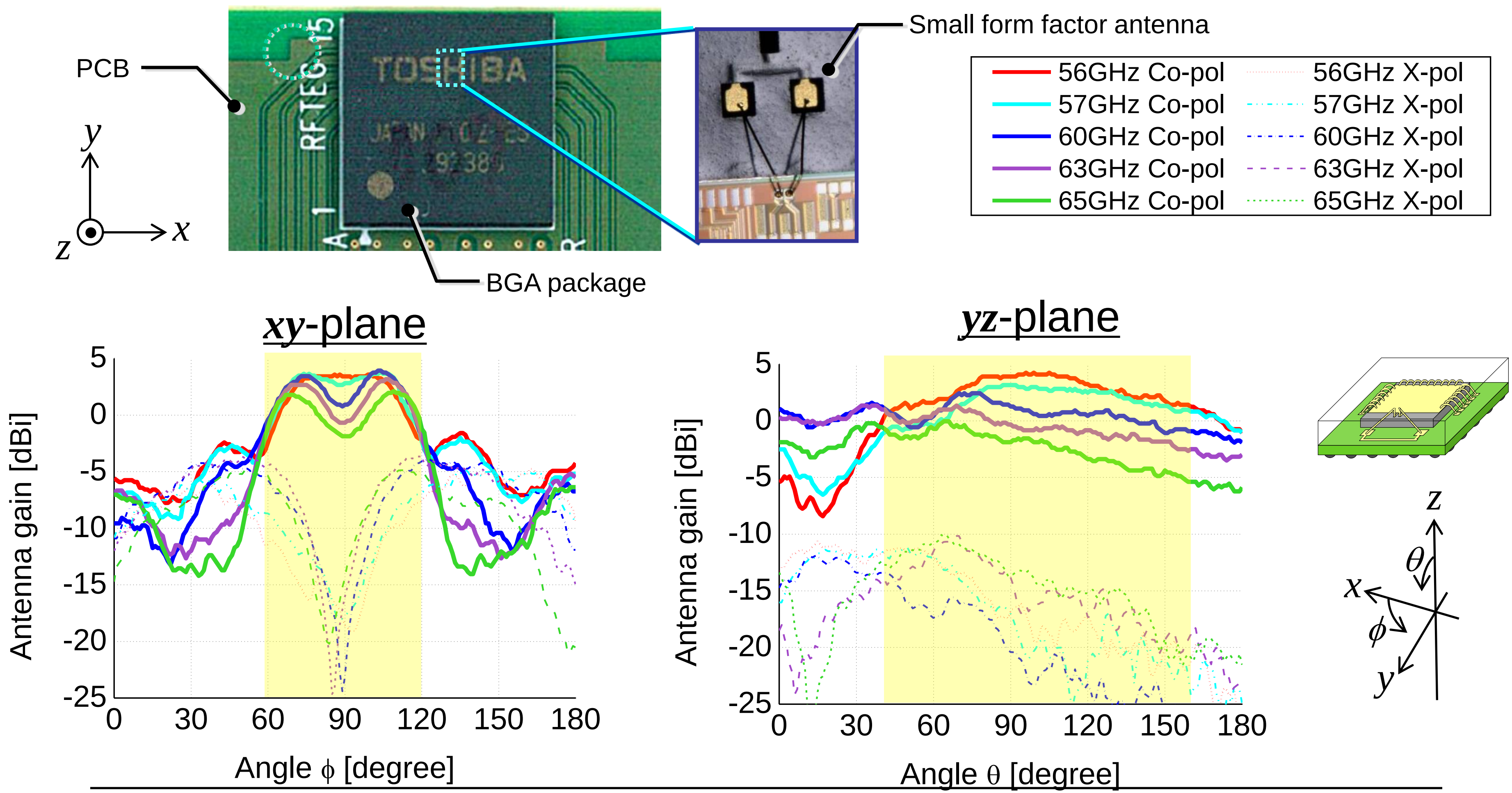
Study on Channel Model in 15.3d on 60 GHz band

- We need to confirm radio propagation performance in close proximity P2P communication concerning
  - Antenna of small form factor like wire or planer type
  - The effects of CE chassis or reflections in CE
  - Transmission distance of a few centimeters

- We show our measurement results in close proximity P2P communication using
  - Loop antenna of wire type
    - FWHM : 60 deg. of forward and backward radiation
  - Antennas are placed inside CE with/without metal chassis
  - Transmission distance of a few centimeters

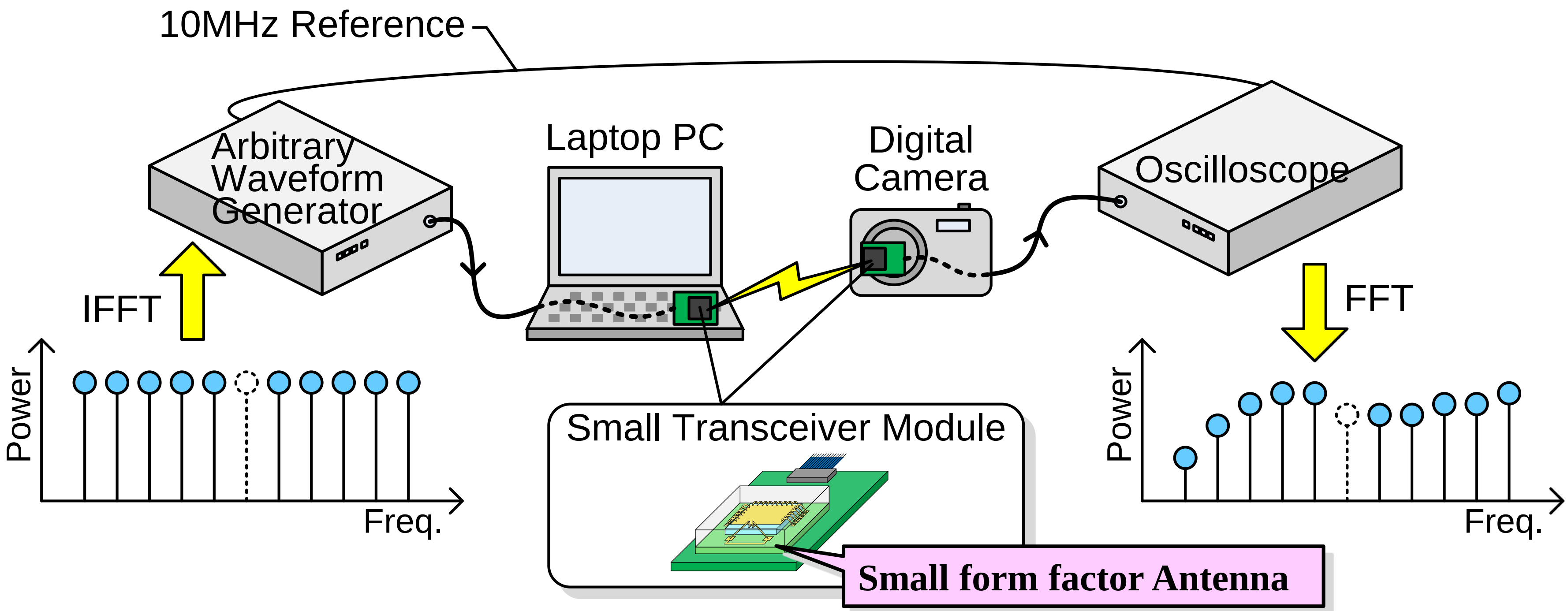
Antenna Type and Radiation Pattern

- Loop antenna of wire type having wide-angle radiation



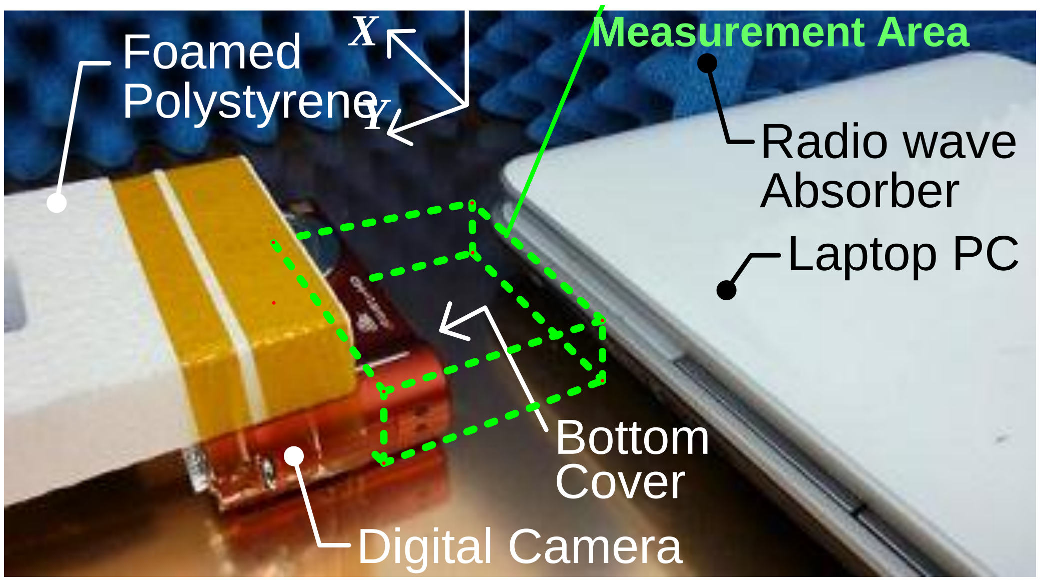
Measurement Setup

- The LSIs having small form factor antennas are placed inside CEs.
- OFDM signals generated by AWG are transmitted via this 60 GHz close proximity channel, and sampled by an oscilloscope.
- By using IFFT to measure 10GHz band frequency spectra, Power Delay Profiles (PDP) with about 0.1nsec resolution are obtained.



Measurement Conditions

- Laptop-PC (for Tx) is fixed on metal desk.
- Digital Camera (for Rx) is moved in the measurement area.
  - Distance(Y) : 10 ~ 40 mm
  - Horizontal (X) and Vertical offset : -15 ~ +15 mm and 0 ~ 6 mm
- Under conditions with or without metal on the cover of CE chassis
- Under condition with antenna polarization align



(a) A Digital Camera and a Laptop PC


(b) with metal on the cover

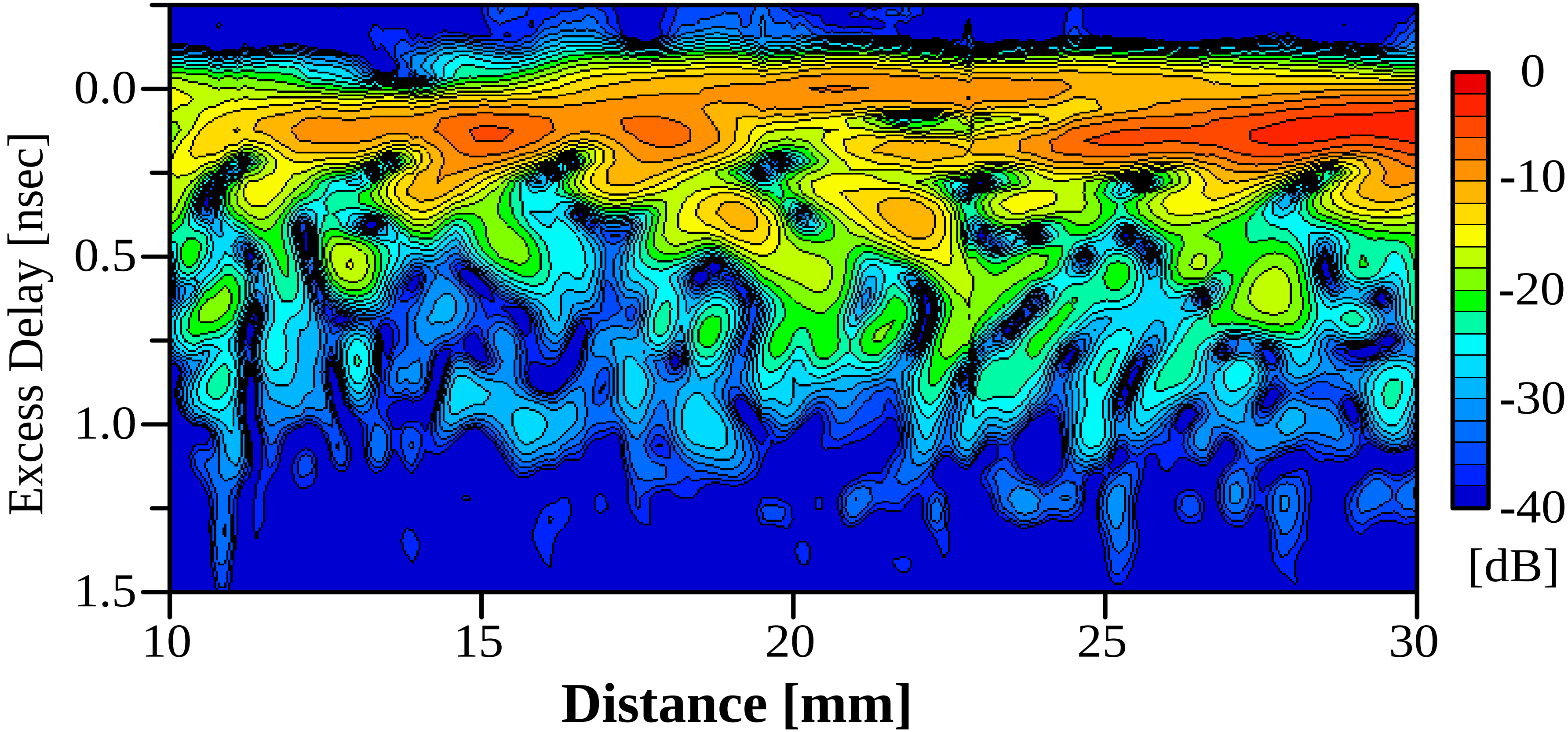

(c) without metal on the cover

Parameters of Measurements

Frequency range	56-66 GHz
Frequency step	15.625 MHz
Tx power	0 dBm
Tx electronic device	Laptop PC
Rx electronic device	Digital camera with and without metal on cover
Measurement range	X: -15~15 mm, Y: 10~40 mm, Z:0~6 mm
Measurement step	0.1 mm, 1.5 mm
Antenna polarization	Horizontal polarization

Example of measured PDP

- Fading in a cycle of about a half wavelength is observed. There are a lot of reflections at devices and a desk.



Averaged Power Delay Profiles (PDP)

- Averaging measured N PDPs with

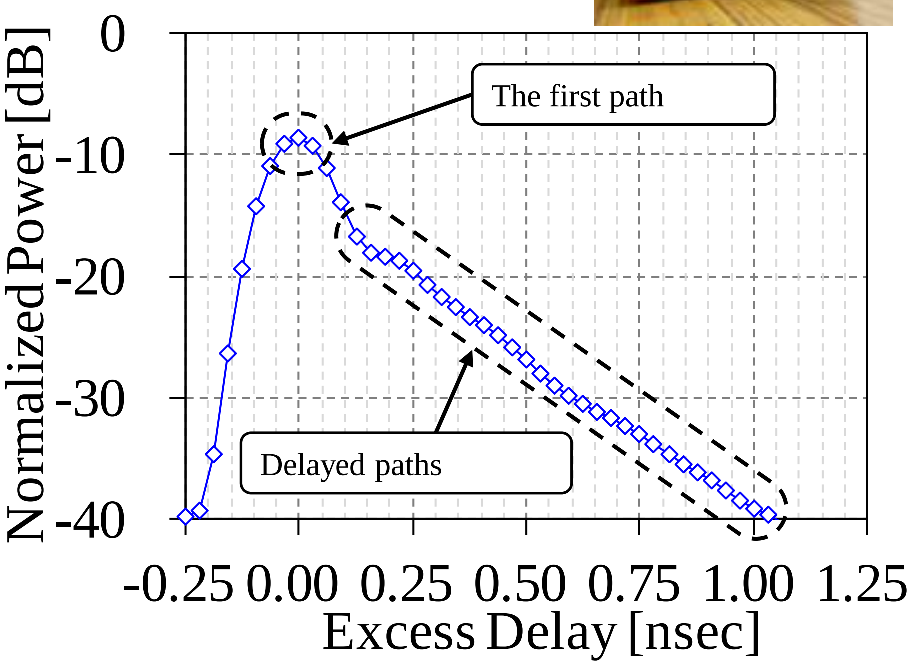
$$\frac{1}{N}\sum_{n=1}^{N}\frac{1}{L_i}P_i\left(t-T_i\right)$$

$P_i(t)$ PDP at i-th meas. point.

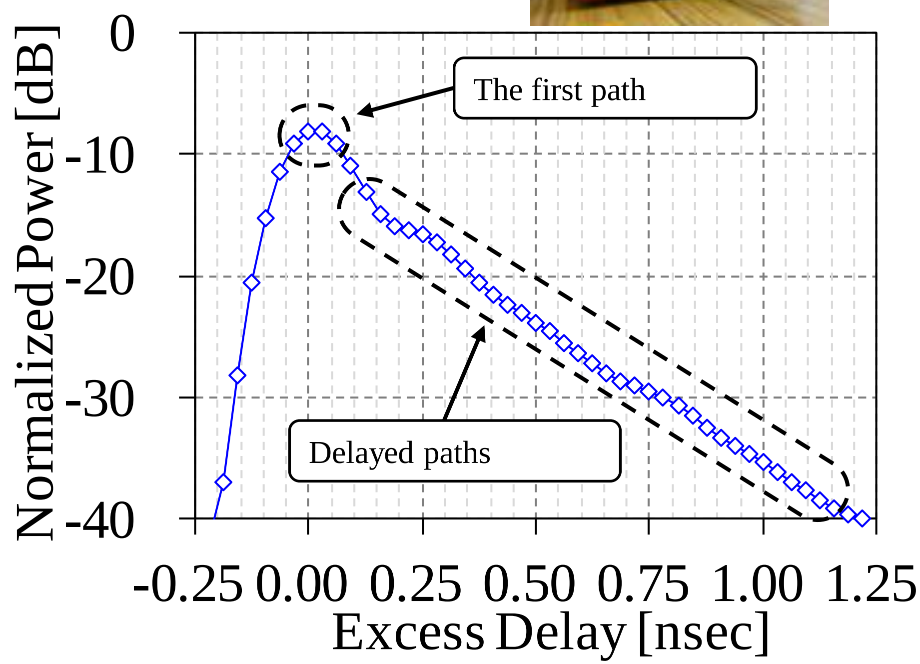
T_i Theoretical delay at i-th meas. point.

L_i Theoretical propagation loss at i-th meas. point.

Without metal cover

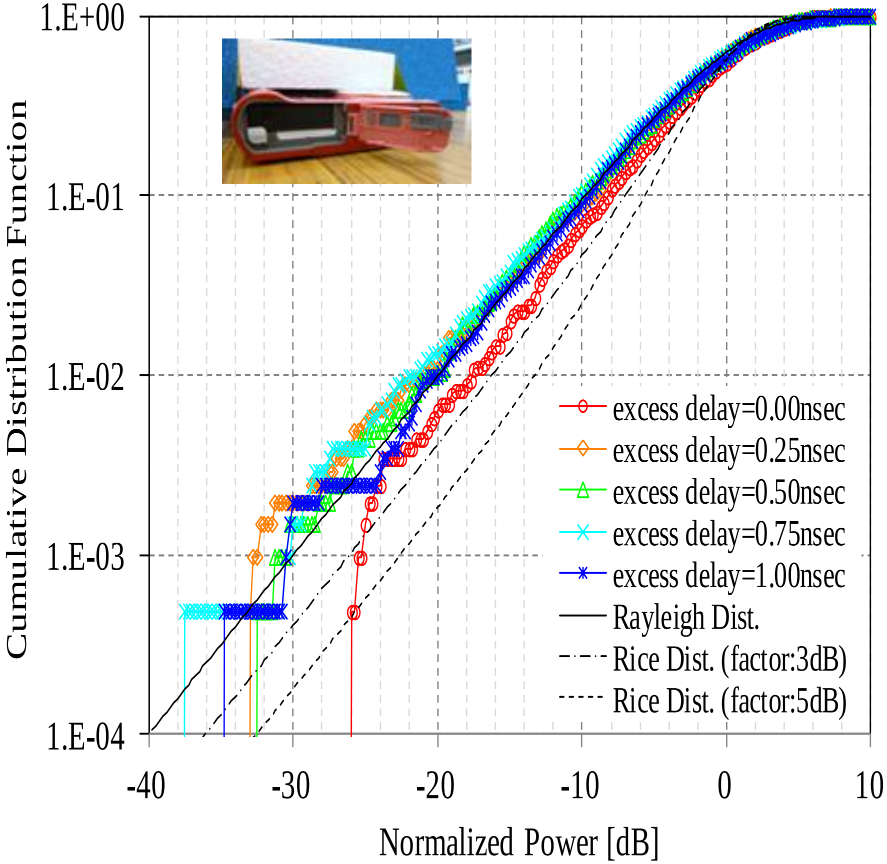


With metal cover

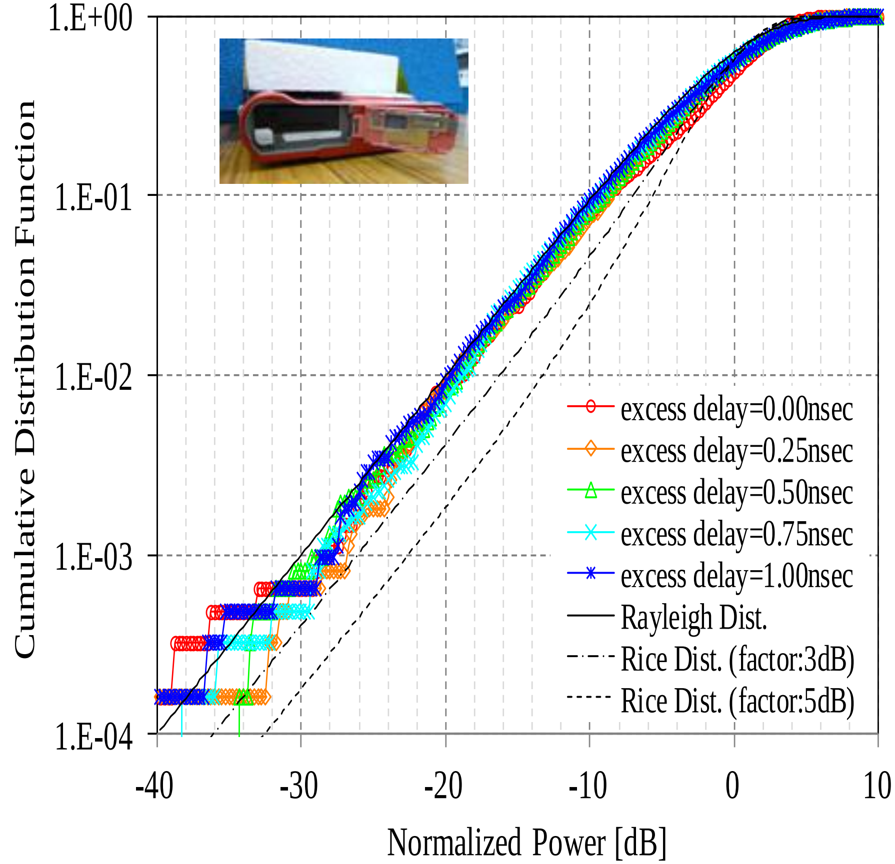


Cumulative Distribution Functions of Each Path Power

Without metal cover

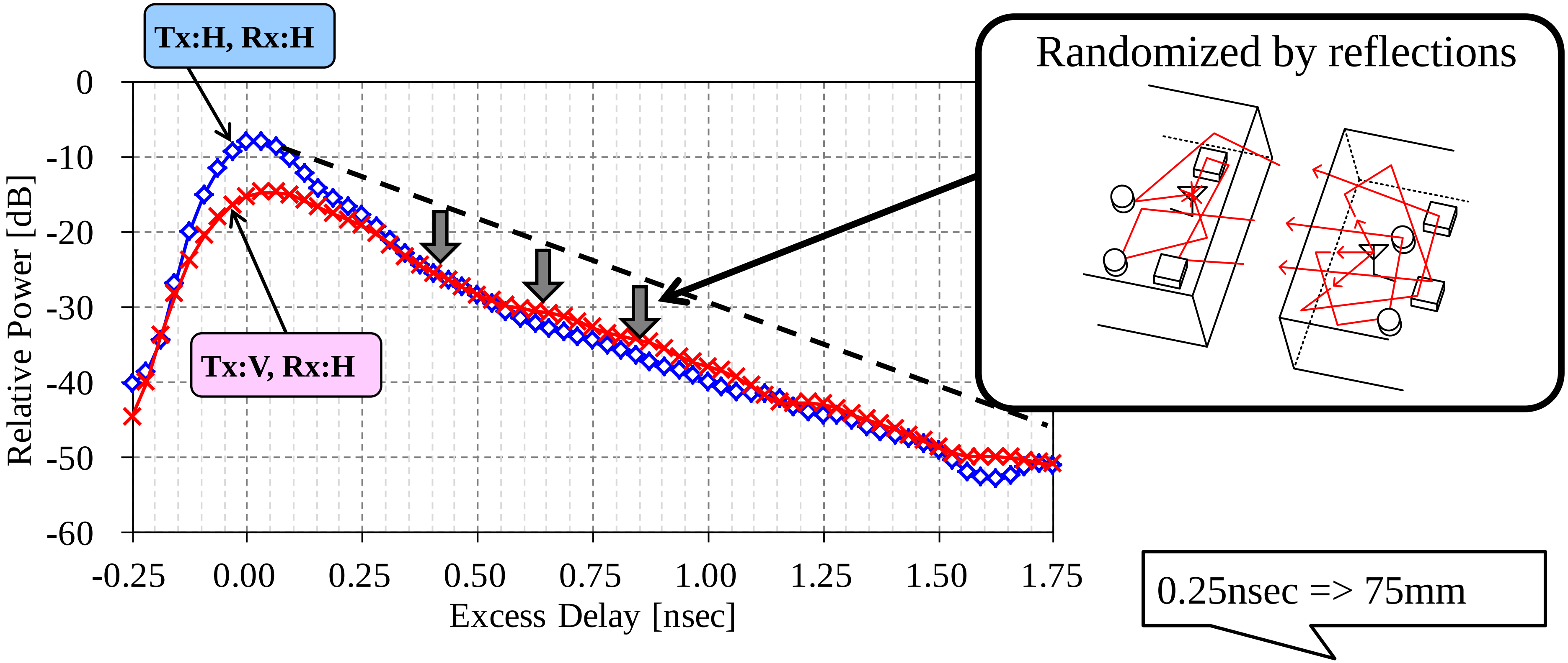


With metal cover



- Delayed Paths : Rayleigh Distribution.
- The first path : Rice or Rayleigh Distribution.

Polarization randomization



PDP Gap exists on the first path. Two PDPs converge over 0.25nsec.

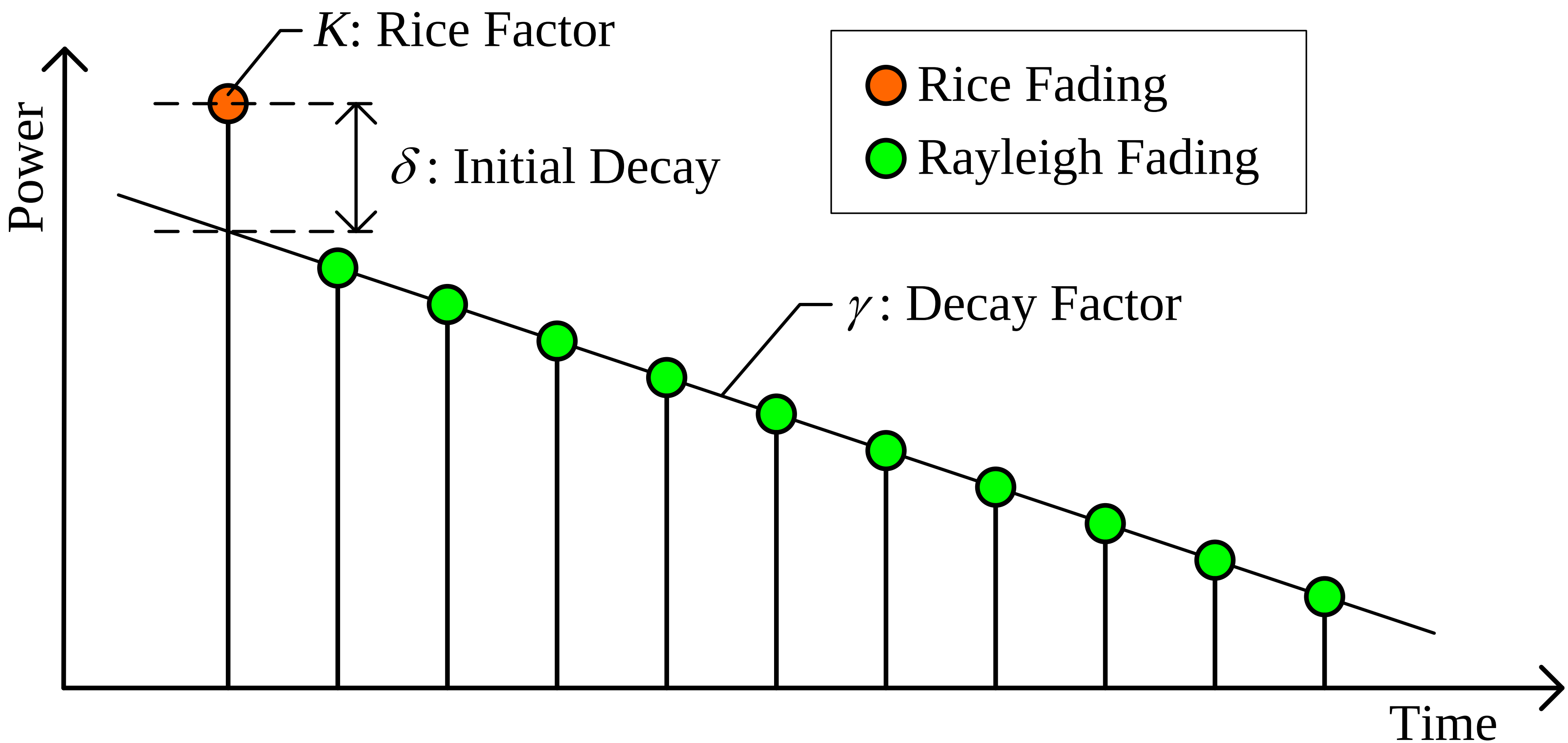
Radio wave polarization is sufficiently randomized on reflections over 0.25nsec inside devices,

Channel Model Idea

$$E\left[|\alpha_n|^2\right] = \begin{cases} 1, & n = 0 \\ 10^{-\delta/10} \cdot e^{-t_n/\gamma}, & 1 \le n \le N-1 \end{cases}$$

α_n : amplitude of ***n***-th path

t_n : delay of ***n***-th path



Calculation of initial decay δ

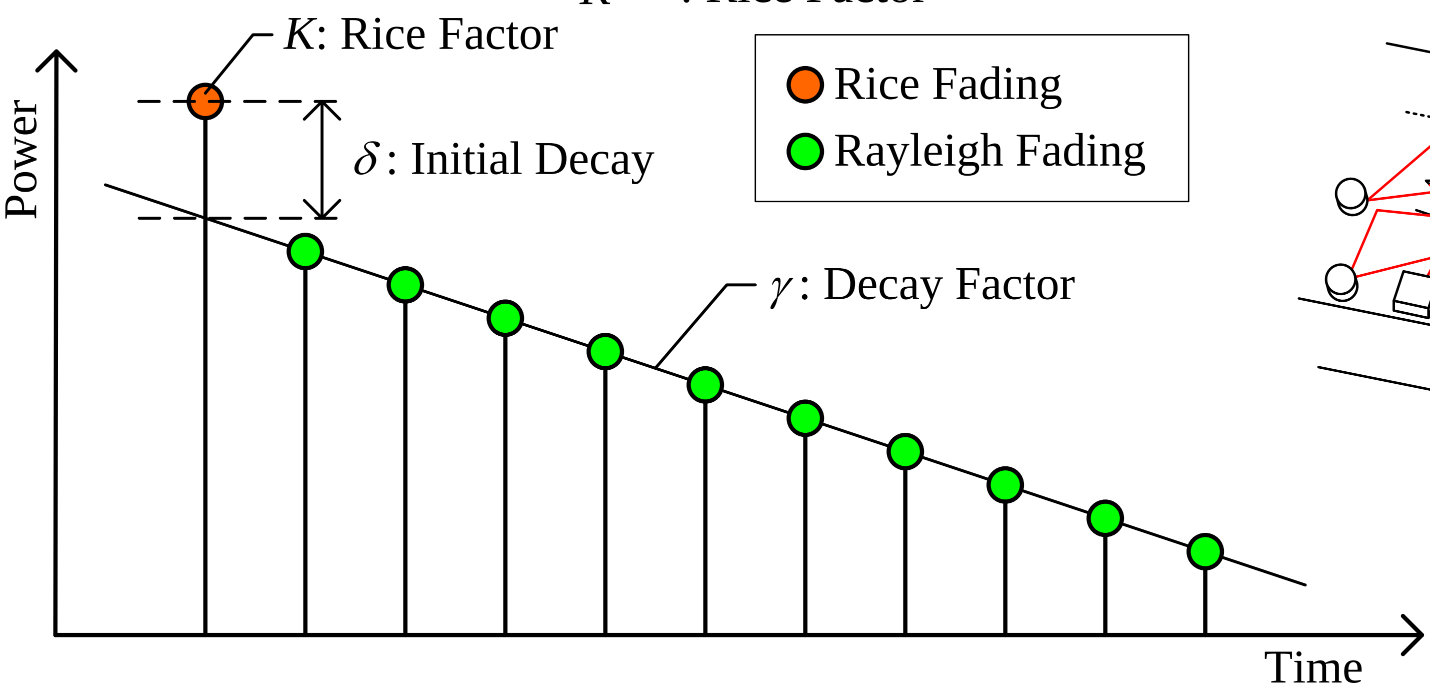
$$\delta = 10 \cdot \log_{10} \frac{\left(G_{Rx,V}G_{Tx,V} + G_{Rx,H}G_{Tx,H}\right)\left(1+10^{K/10}\right)}{G_{Rx,V}\left(\dfrac{G_{Tx,V}+G_{Tx,H}}{2}\right) + G_{Rx,H}\left(\dfrac{G_{Tx,V}+G_{Tx,H}}{2}\right)}$$

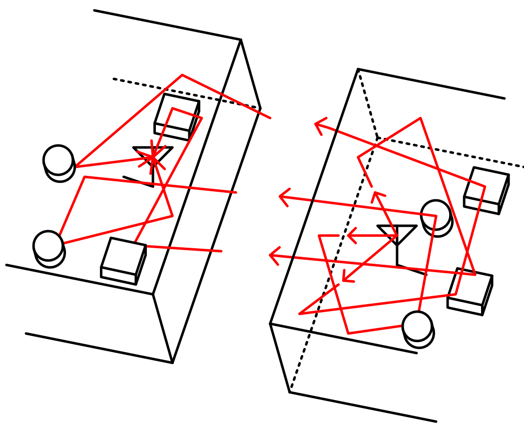
Numerator: Not de-polarized

Denominator: Sufficiently de-polarized

$G_{Tx,H}, G_{Rx,H}, G_{Tx,V}, G_{Rx,V}$: Antenna gain in linear scale for H/V and Tx/Rx.

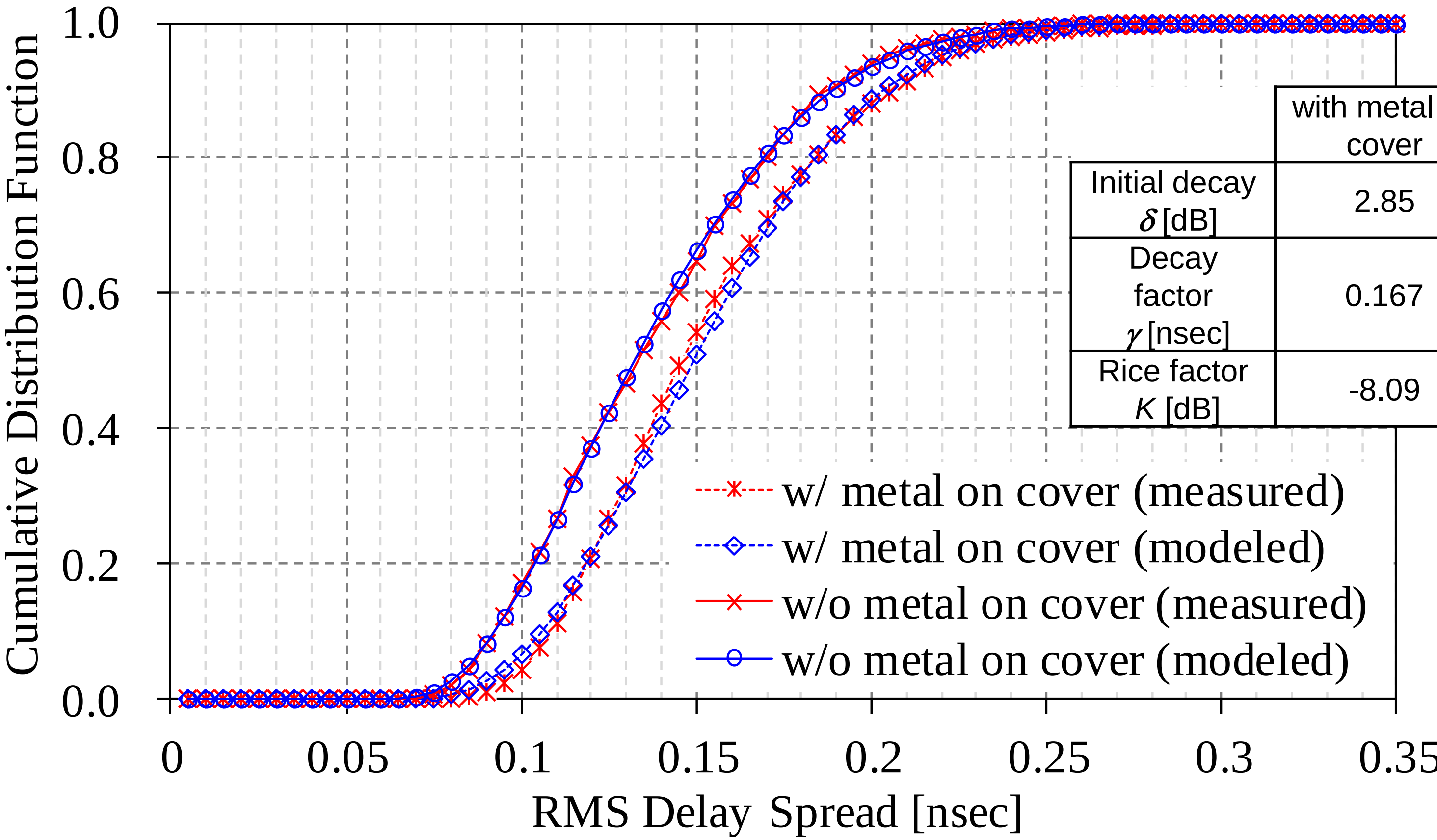
K : Rice Factor





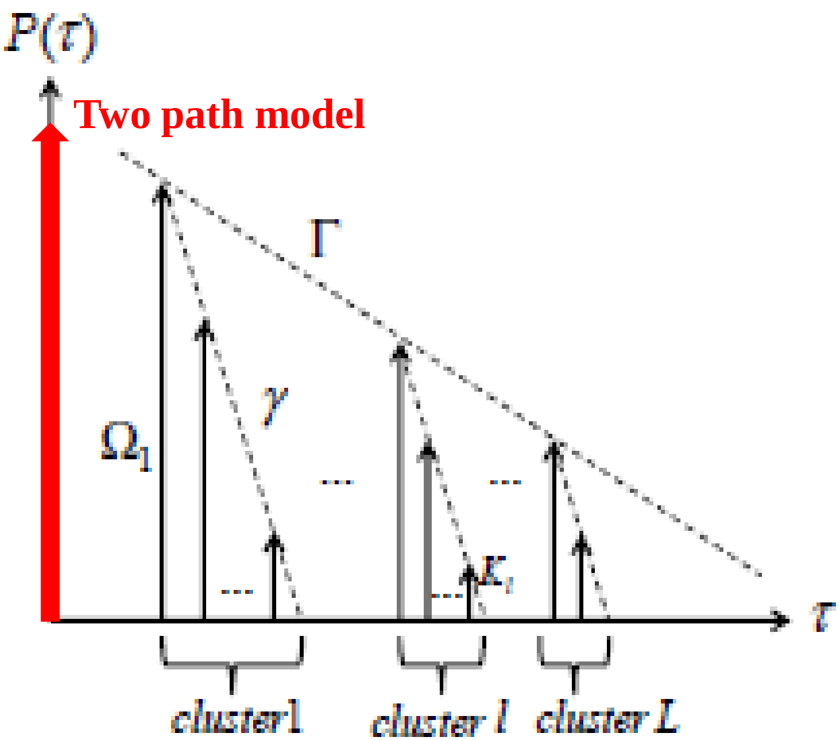
Evaluation of channel model idea

- RMS delay spread were compared with computer simulations.
- We confirmed the proposed model excellently fit the measured data.

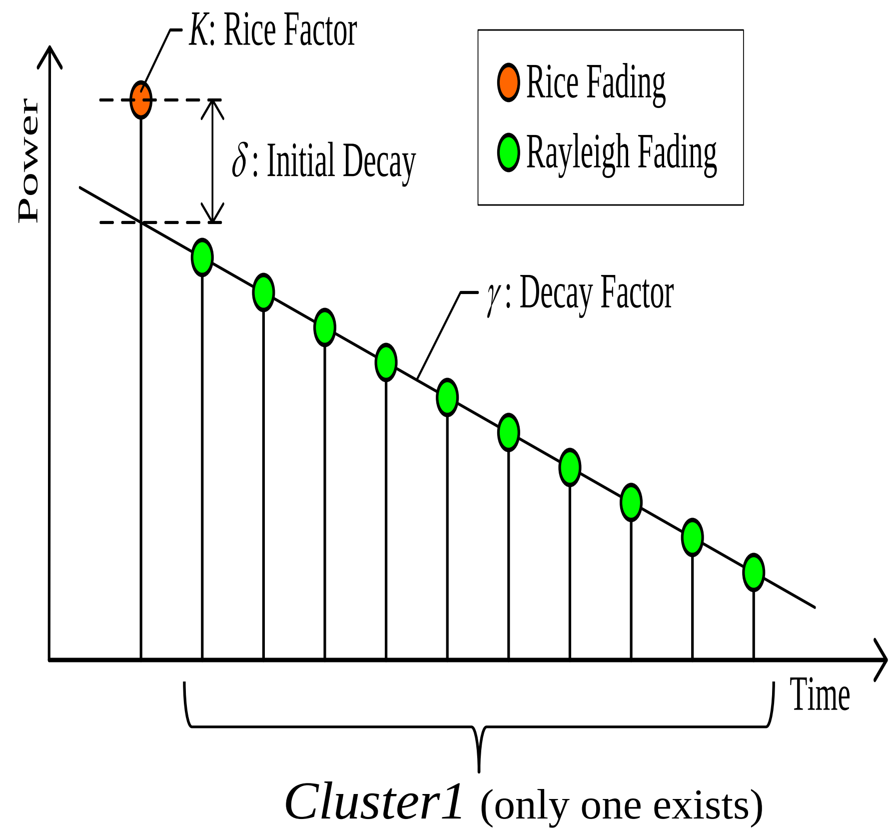


	with metal on cover	without metal on cover
Initial decay δ [dB]	2.85	5.04
Decay factor γ [nsec]	0.167	0.165
Rice factor K [dB]	-8.09	-0.41

Channel model difference



TSV Channel model in 15.3c



Channel model idea in 15.3d
for close proximity P2P communications

Conclusion

- We showed measured radio propagation performance of close proximity P2P communication
  - with small form factor antenna of wide-angle radiation characteristics
  - with the effects of CE chassis and desktop
- We presented channel model idea
  - Its channel model idea fits the measured data

- New channel model shall be defined for close proximity P2P communication on 60 GHz band in 15.3d
- Further works in 15.3d
  - Define radio propagation environment
  - Study other antenna cases as reference

Reference

[1] IEEE 15-07-0584-01-003c "IEEE 802.15.3c channel modeling sub-committee Report" in March 2007

[2] Koji Akita et al., "Design of a 60 GHz Proximity Communication System: Antenna in Package and Desktop Channel Measurements," 6th GSMM (global symposium on millimeter wave) 2013 in Sendai, Japan, April 22-23 2013