Dynamic UWB Channel Modeling of Walking Motion

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Background

- Body Area Network (BAN)
  - Wide applications, especially for medical/healthcare

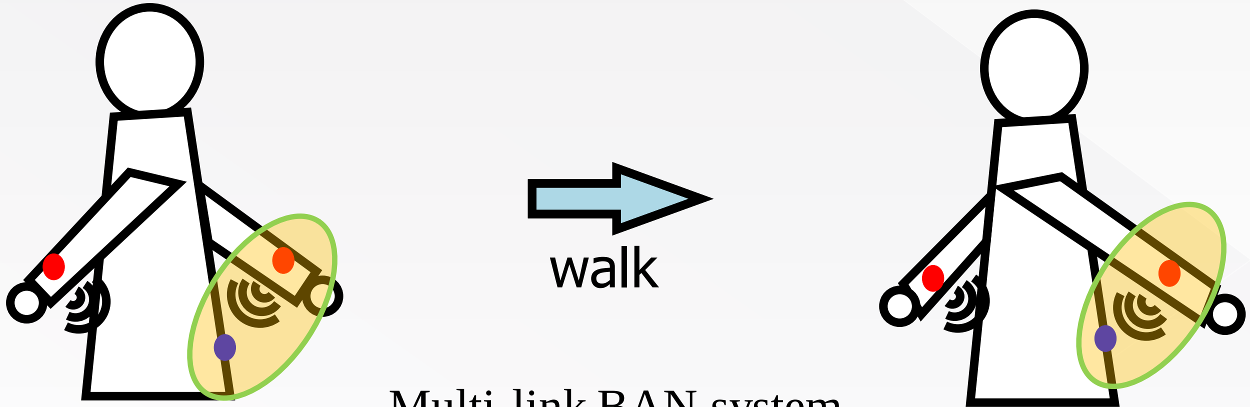
    ⇒Successful device and network design is important

- Requirement for BAN system
  - The channel response is influenced by the body status and movement

    ⇒ Dynamic property of the propagation channel

  - Improvement of reliability for BAN system
    - Construction of a multi-link system by multiple sensors

    ⇒Interlink correlation between each sensor



Multi-link BAN system

Purpose of Research

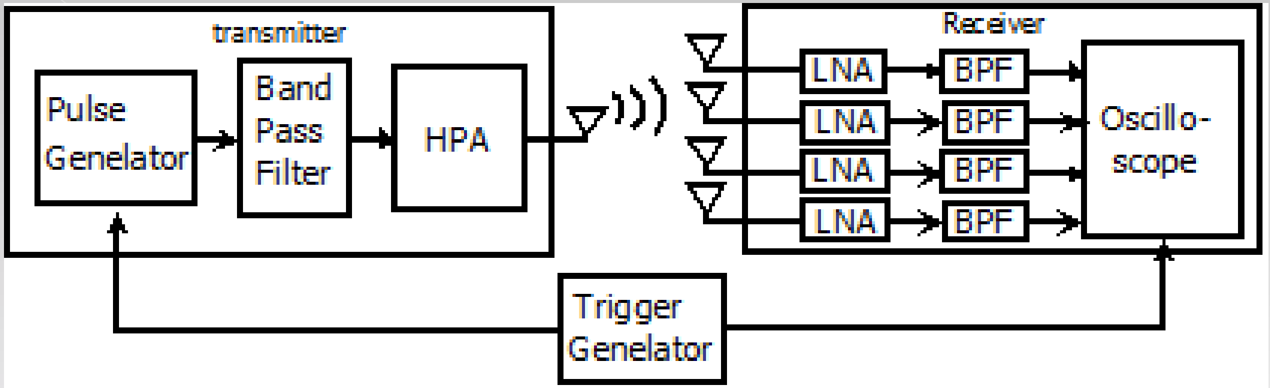
- Development of measurement system
  - VNA is a popular tool
    - Difficult to use VNA for dynamic channel measurement
    - Multi-port VNA measurement is very expensive

  ⇒ We developed multi-port time-domain channel measurement system for dynamic UWB channel by Digital Sampling Oscilloscope (DSO)

- Experiment of dynamic channels
  - Simultaneous measurement of multiple channel
    - Select walking motion due to fundamental human action
    - Measurement in experiment room like office environment
  - Investigation about relation between each channel
    - Obtain the mean path gain
    - Calculate the correlation

Measurement System

➤ The configuration of the measurement system



➤ Transmitter

- Pulse generator (PG)
- Band Pass Filter (BPF)
  - Frequency band:3.0-4.8 GHz
- High Power Amplifier (HPA)
  - Gain: 30 dB

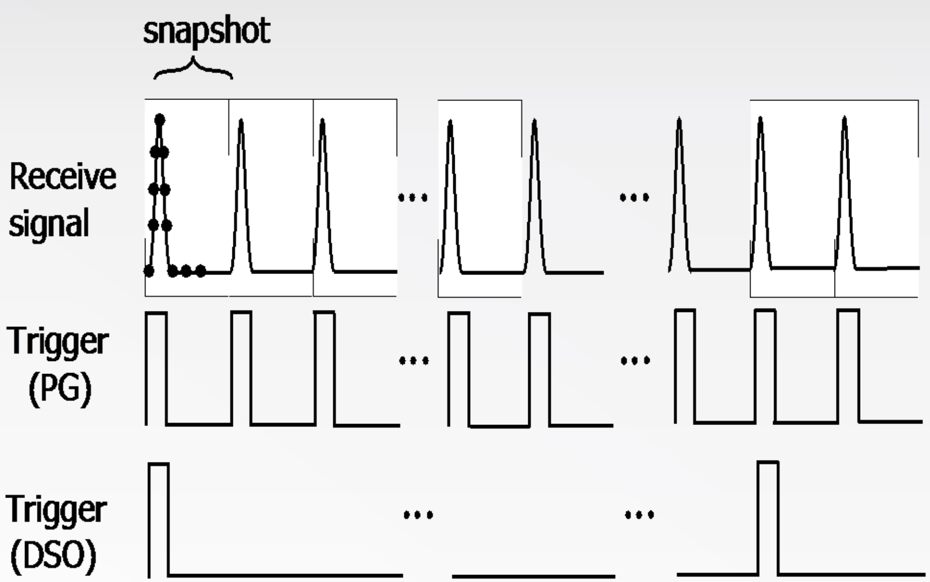
➤ Receiver

- Low Noise Amplifier (LNA)
  - Gain : 40 dB
- Band Pass Filter (BPF)
  - Frequency band:3.0-4.8 GHz
- Digital Sampling Oscilloscope (DSO)
  - Sampling rate : 25 G samples/sec
  - 4 Ports

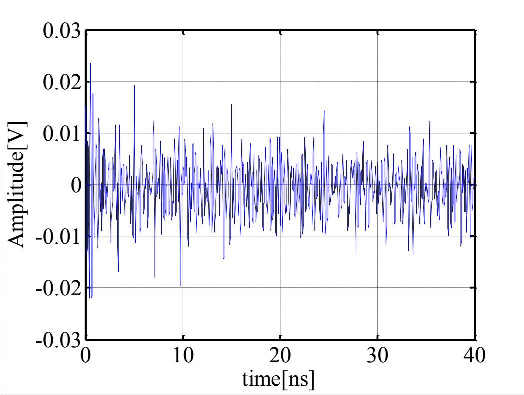
⇒ These are synchronized by Trigger Generator (TG) to observe the pulse within the limited time window of the measurement

Data Acquisition

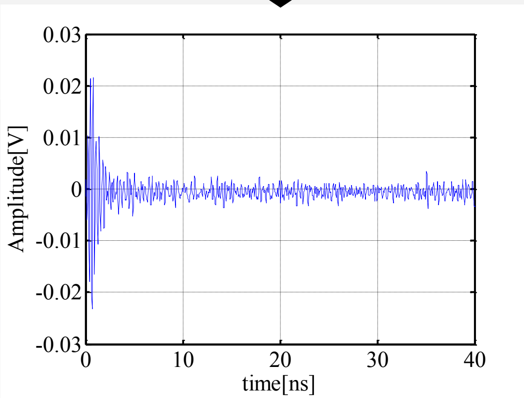
- Intermittent measurement
  - Obtain consecutive snapshots (block) at variable interval using two types of trigger
    - Trigger for PG
    - Trigger for DSO acquisition
  - Averaging several snapshots to improve SNR
    - 20 times averaging : gain 13dB



Timing Chart

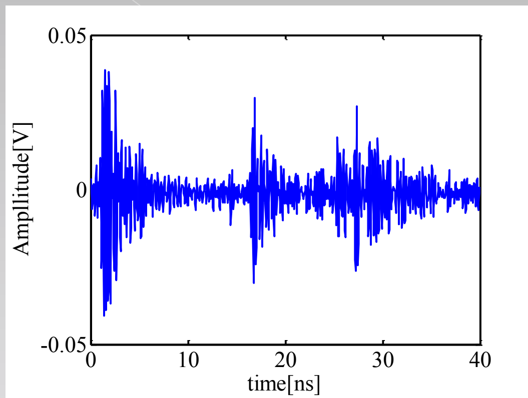


20times



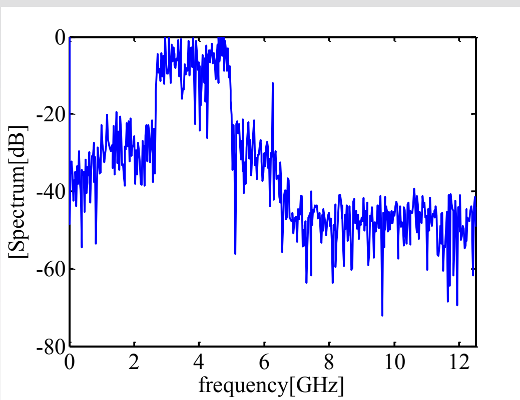
Averaging

Data Processing



Time domain

FFT



Frequency domain

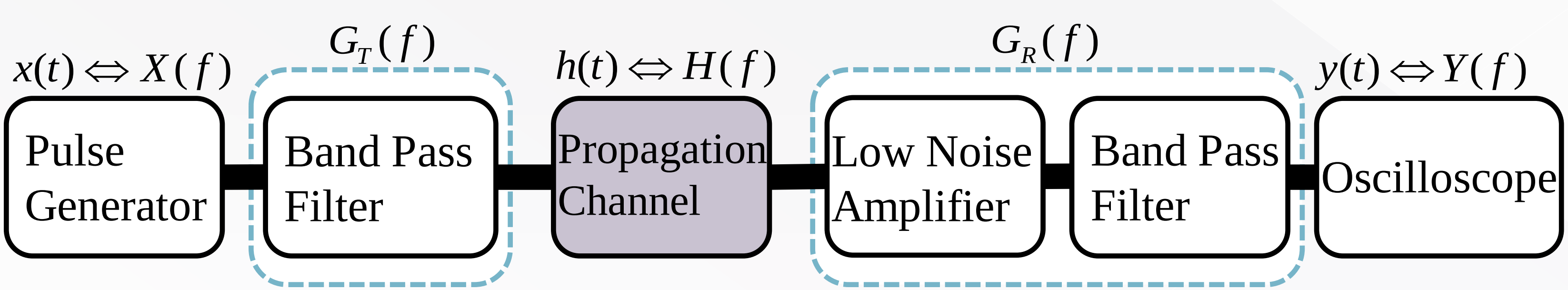
- Receive signal includes the characteristics of each instrument

  ⇒Carry out the simple calibration method

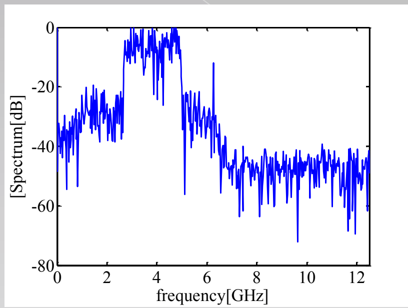
- Received signal is shown by convolution in time domain ⇒ complex

  ⇒ Processing in the frequency domain by Fourier transformation

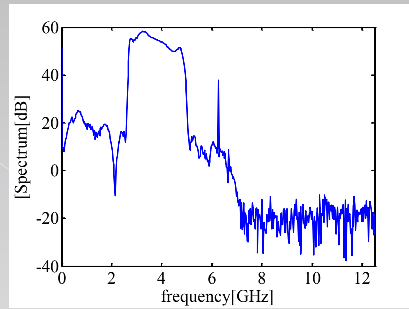
$$Y(f) = \sum_{m=1}^{M} y(t) e^{-j\frac{2\pi f t m}{M}}$$



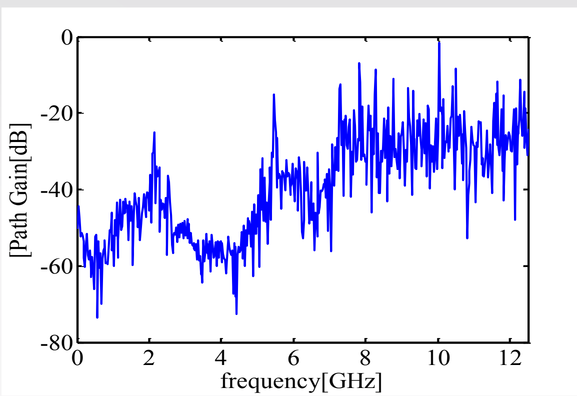
Data Processing



Received signal



Calibration function



- In frequency domain
  - Received signal : Multiplication of each frequency characteristic

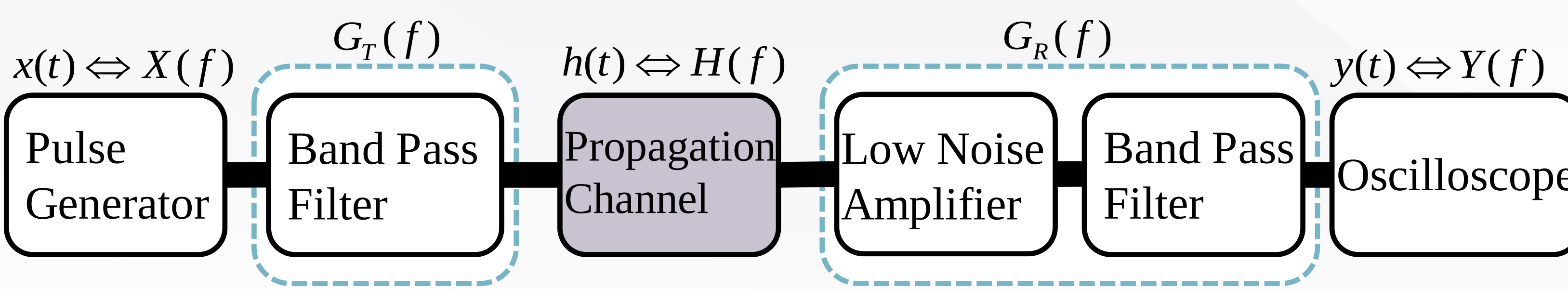
$$Y(f) = X(f)G_T(f)H(f)G_R(f)$$

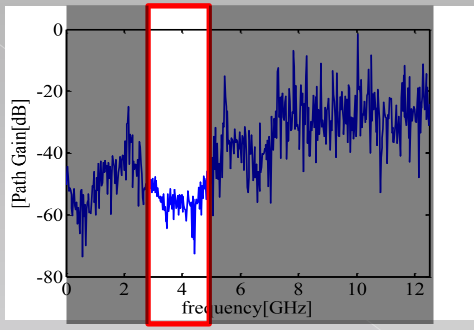
  - Connect the transmitter and receiver through an attenuator directly (calibration function)

$$Y'(f) = X'(f)G_T(f)H_{ATT}(f)G_R(f)$$

  - Obtain channel transfer function

$$H(f) = \frac{Y(f)}{X(f)G_T(f)G_R(f)} = \frac{Y(f)H_{ATT}}{Y'(f)}$$

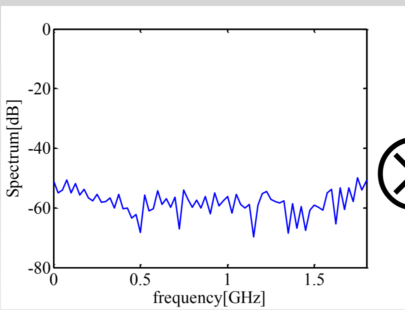




Cut off

Data Processing

- Cut off and Utilize only the data of in-band (3-4.8 GHz ,73 points)



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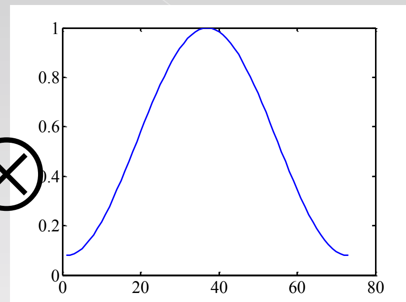
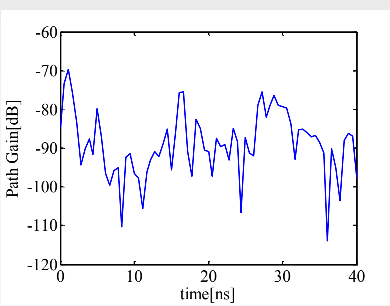


hamming window

IFFT



Impulse response

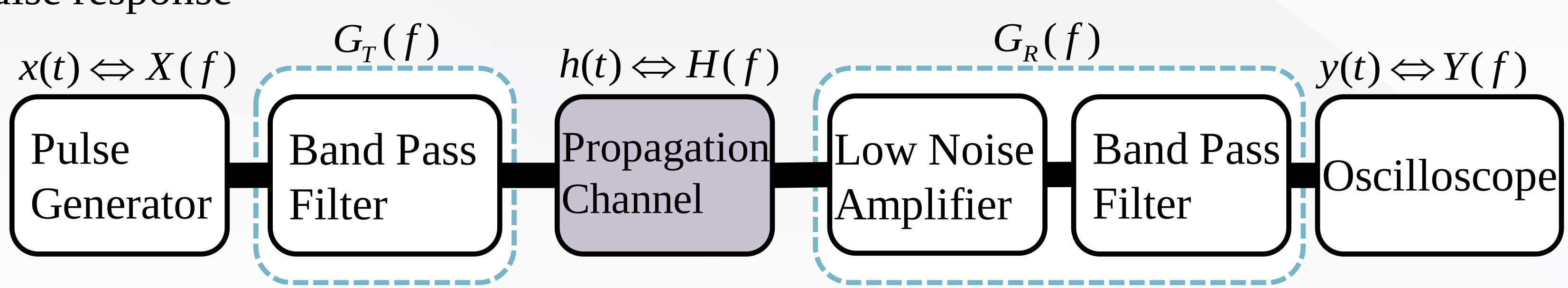
- This data is not continuous
  - Multiply the hamming window

$$\omega(n) = 0.54 - 0.46\cos\left(2\pi \frac{n}{N}\right) \qquad 0 \le n \le N$$

- Obtain Impulse response
  - Inverse Fourier Transform

$$h(t) = \frac{1}{M}\sum_{m=1}^{M} H(f)e^{j\frac{2\pi ftm}{M}}$$

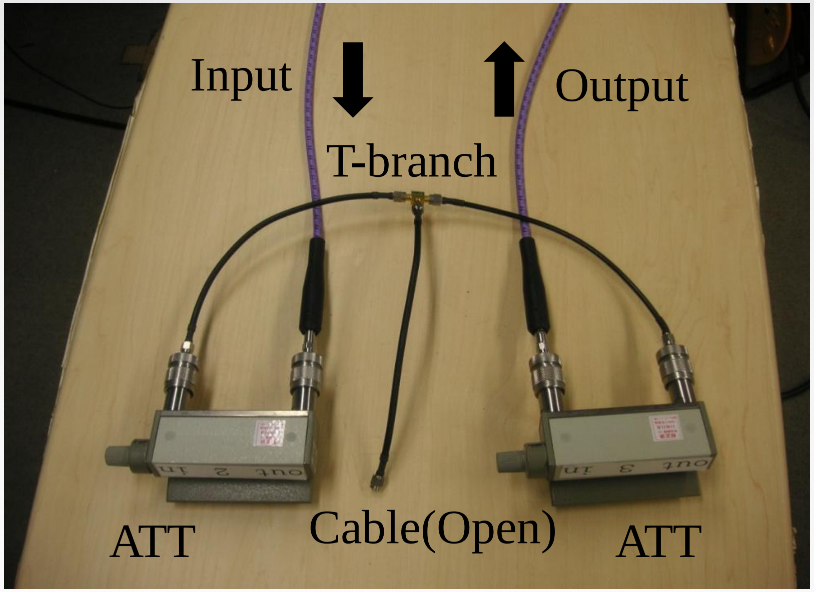
- Delay axis : 40ns $\Rightarrow$ 73tap (1tap 550 ps)



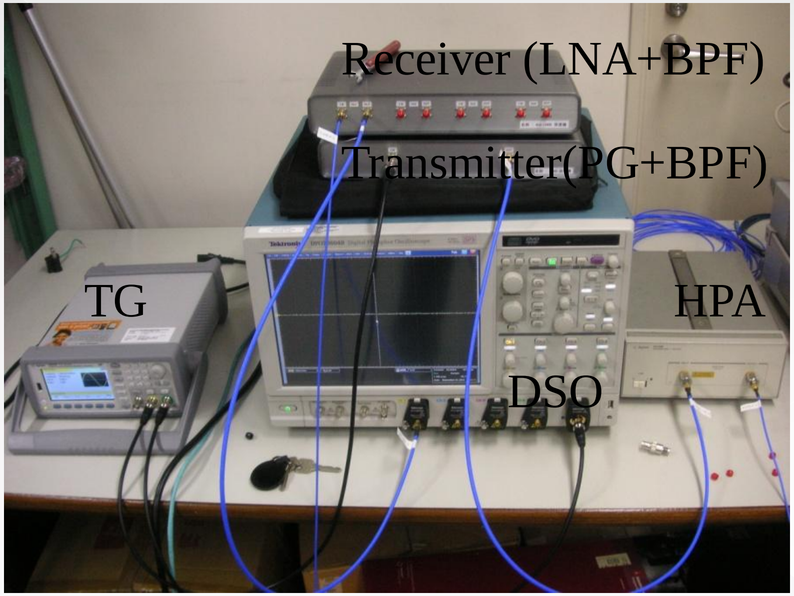
Verification

- Confirm the accuracy of measurement result from this system
  - Measure the transfer function of DUT
  - Obtain the transfer function by calibration
  - Compare the transfer function measured by VNA

Cable	22cm
ATT	20dB×2

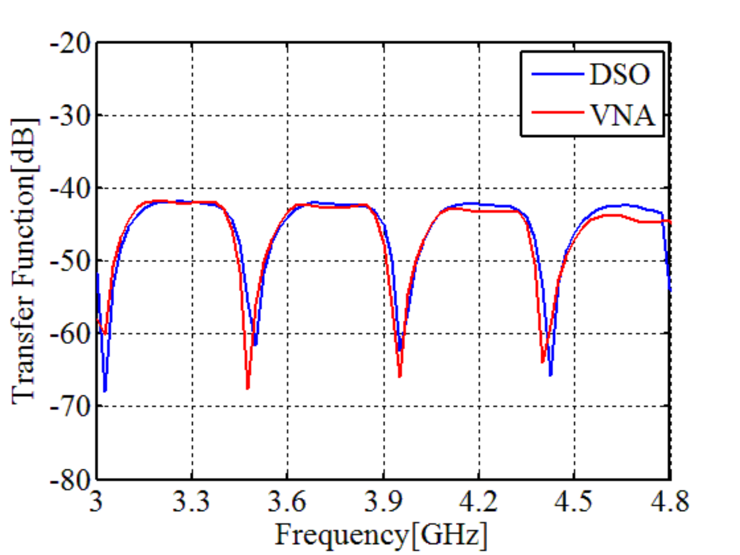


DUT

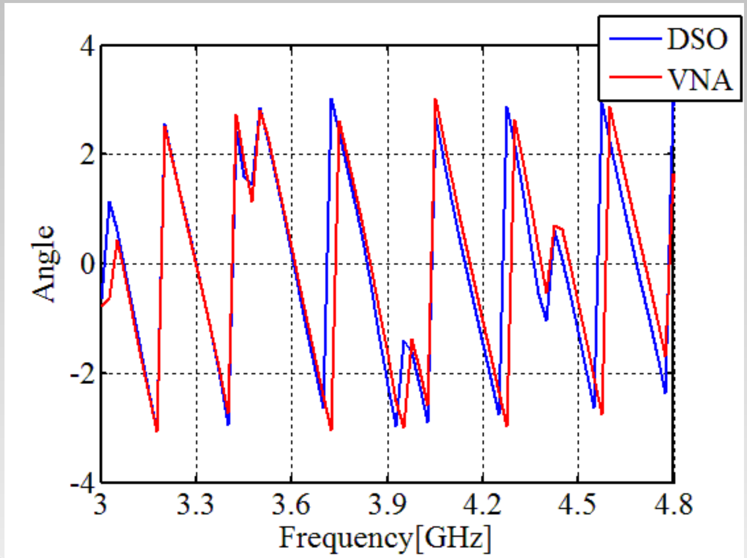


Measurement system

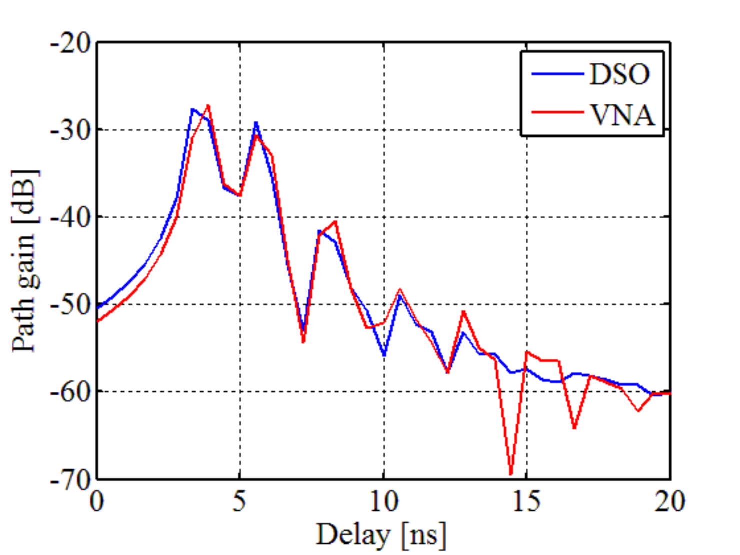
Results



Transfer Function (Amplitude)



Transfer Function (Amplitude)



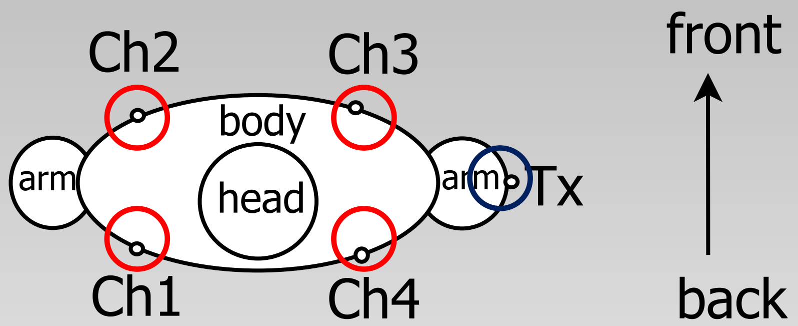
Impulse response

- The result of transfer function and impulse response
- Almost same value between DSO and VNA

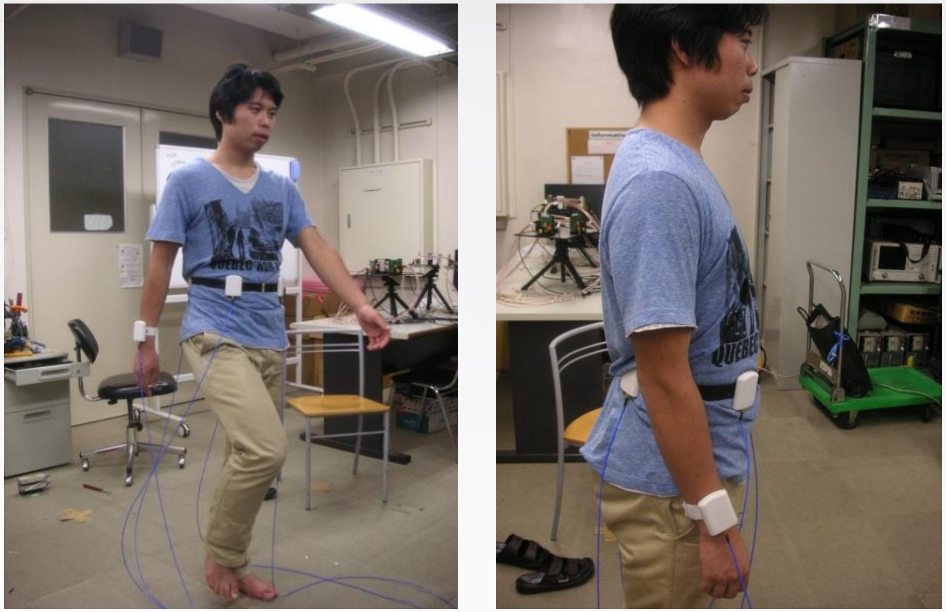
⇒ There is the reliability of the measured value

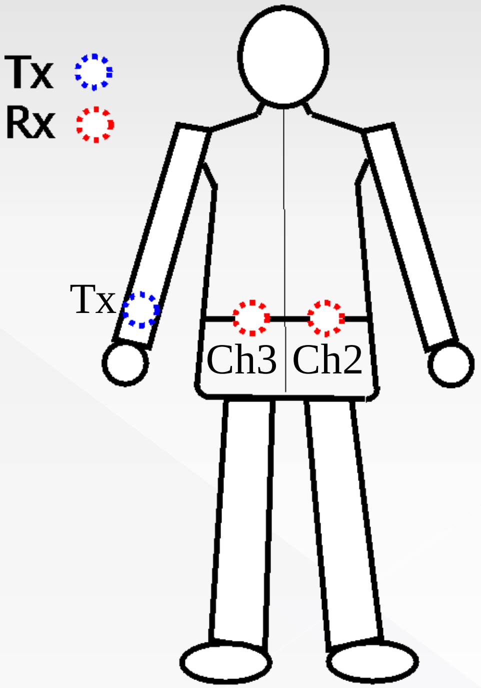
UWB Multi-link Channel Measurement

- Antenna position
  - Transmit antenna：wrist
  - Receive antenna：around body
- Movement
  - Walk
- Antenna type
  - Skycross (for UWB, Omni antenna)



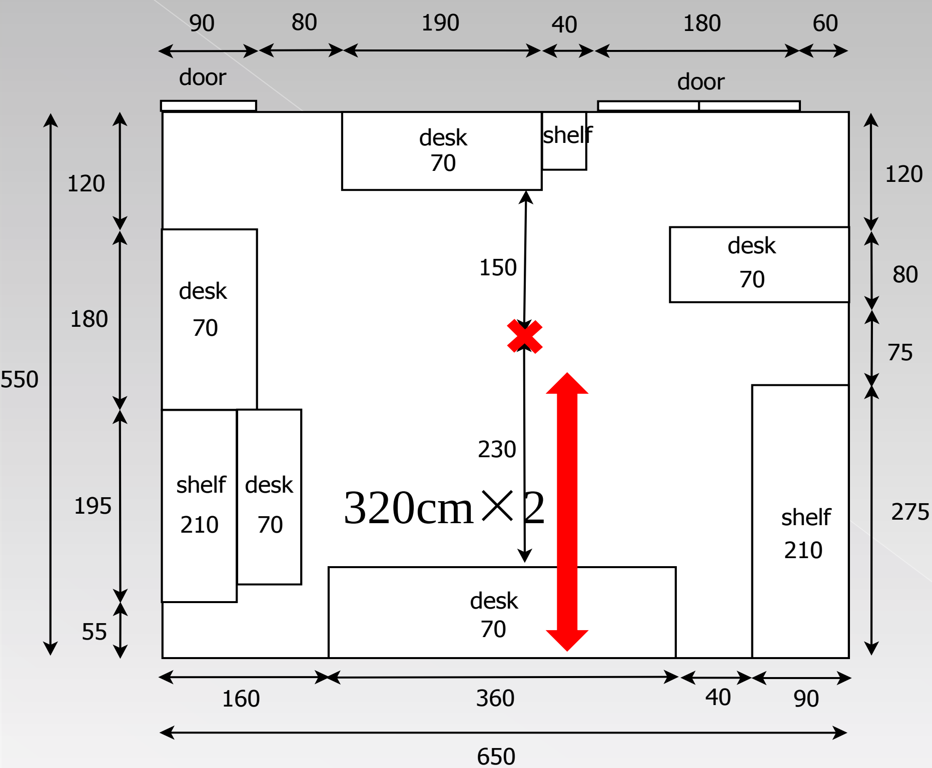
Antenna Position



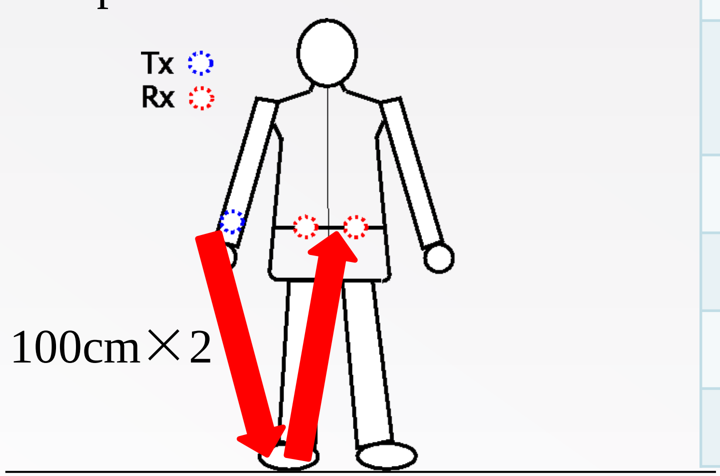


Antenna Position

Measurement Condition



Experiment room



Environment

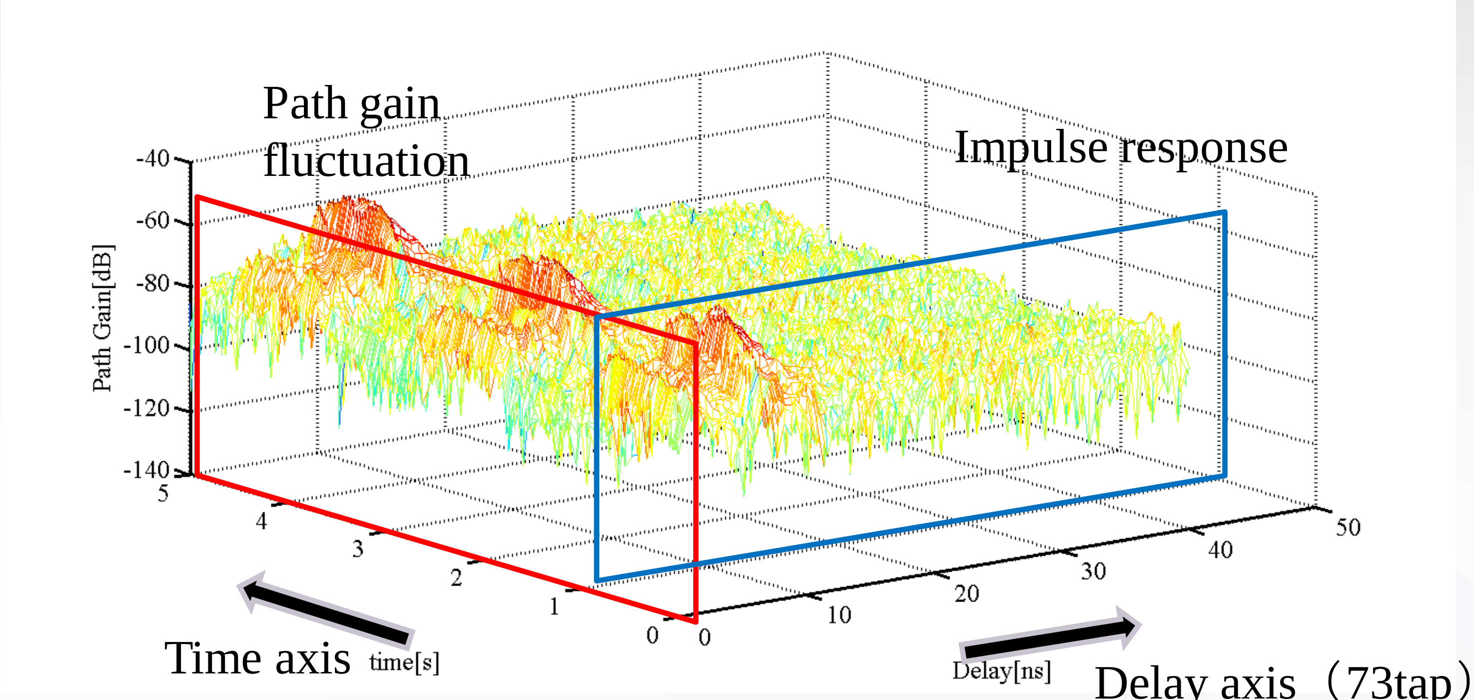
- Place : Experiment room
  - Size : 5.5m × 6.5m
  - Ceiling : 2.7m ～3.3m

- Expected arrival time
  - Ground
    - ✓200cm: 6.6 ns (tap #12)
  - Wall
    - ✓640cm : 9.8ns (tap #40)

Sampling ratio	25 G sample/s
Snapshot	1000 points 40 ns
Trigger for PG	25 MHz
Trigger for DSO	100 Hz
The number of frames	500 frames/1 port
Frequency	3.0-4.8GHz

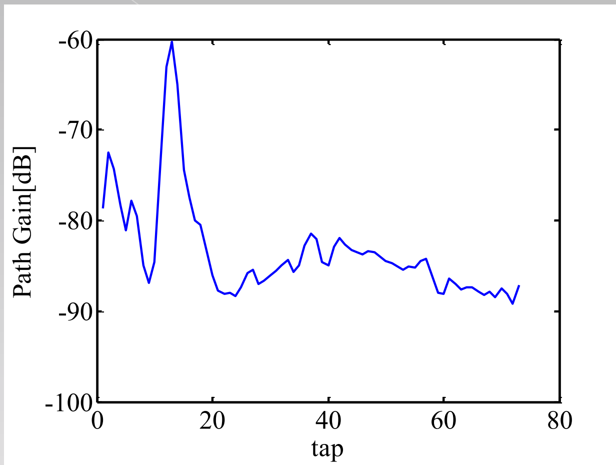
Impulse Response

- Path Gain
  - Consider the path gain fluctuation about each delay tap
    - Delay axis : 40ns ⇒ 73tap (1tap ≈550 ps)
  - Obtain the mean path gain about each channel

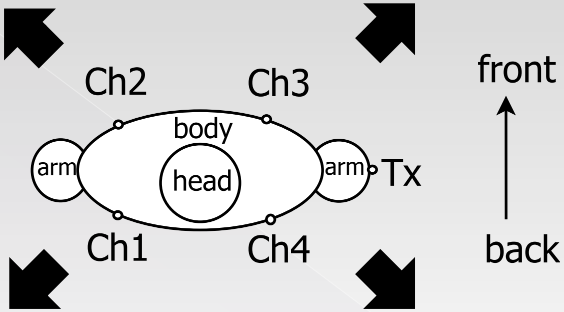


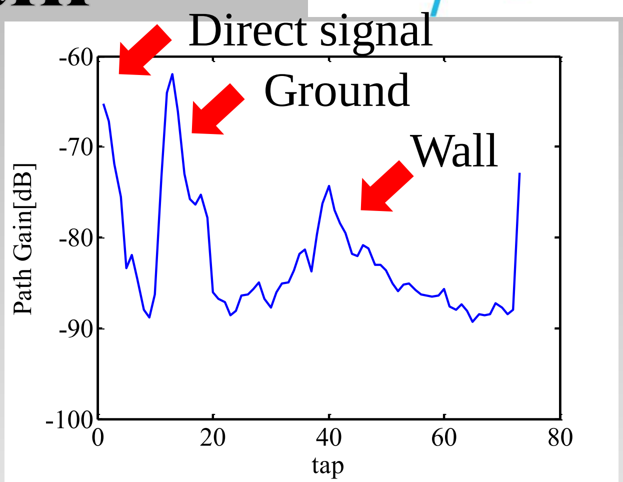
Experiment data

Mean Path Gain

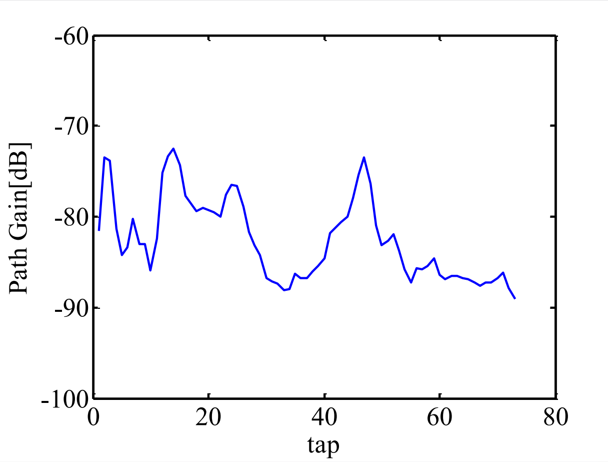


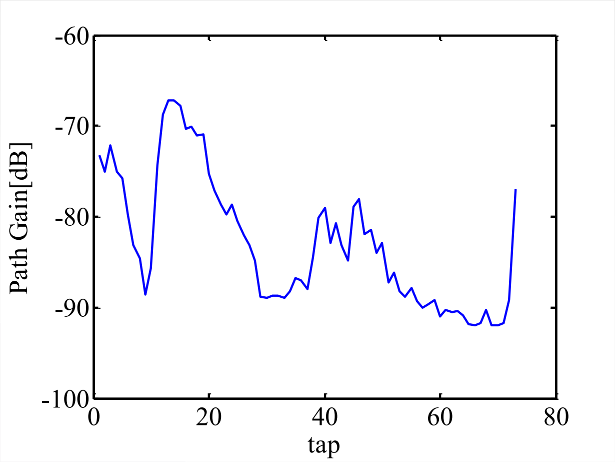
Mean value (ch2)





Mean value (ch3)





Mean value (ch1)

Mean value (ch4)

- 3 path are observed (tap #1, #12, #40)
  - Direct signal, signal from ground, and wall
- The signal from ground tends to be lager than direct signal
  - Reflected signal is less influenced by shadowing than direct signal

Correlation

- Correlation
  - Correlation can be obtained by the following equation [3]

$$\rho_{(ix,\,jy)} = \frac{E[(|h_{ix}|_{\mathrm{dB}} - E[|h_{ix}|_{\mathrm{dB}}])(|h_{jy}|_{\mathrm{dB}} - E[|h_{jy}|_{\mathrm{dB}}])]}{\sqrt{E[(|h_{ix}|_{\mathrm{dB}} - E[|h_{ix}|_{\mathrm{dB}}])^2]E[(|h_{jy}|_{\mathrm{dB}} - E[|h_{jy}|_{\mathrm{dB}}])^2]}}$$

    - Delay Correlation
      - Correlation between each tap in same element(antenna)
    - Delay-Domain Spatial Correlation
      - Correlation between each element

$\Rightarrow$relation between correlation and each antenna distance

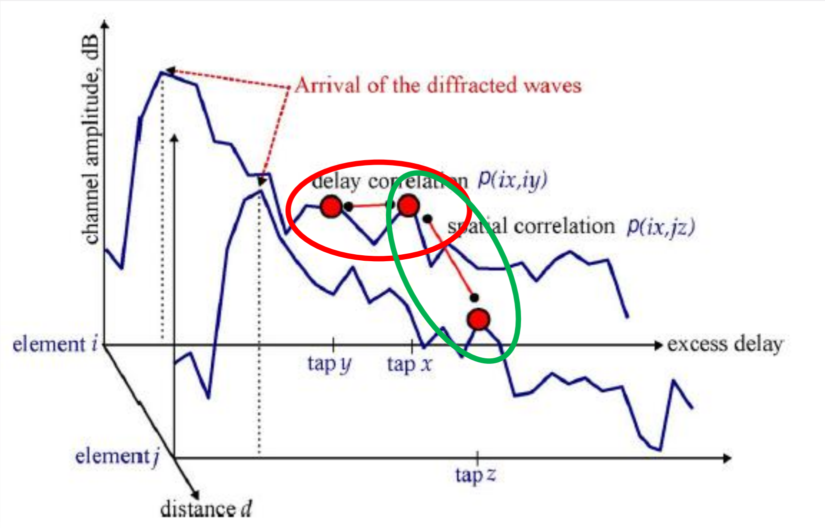
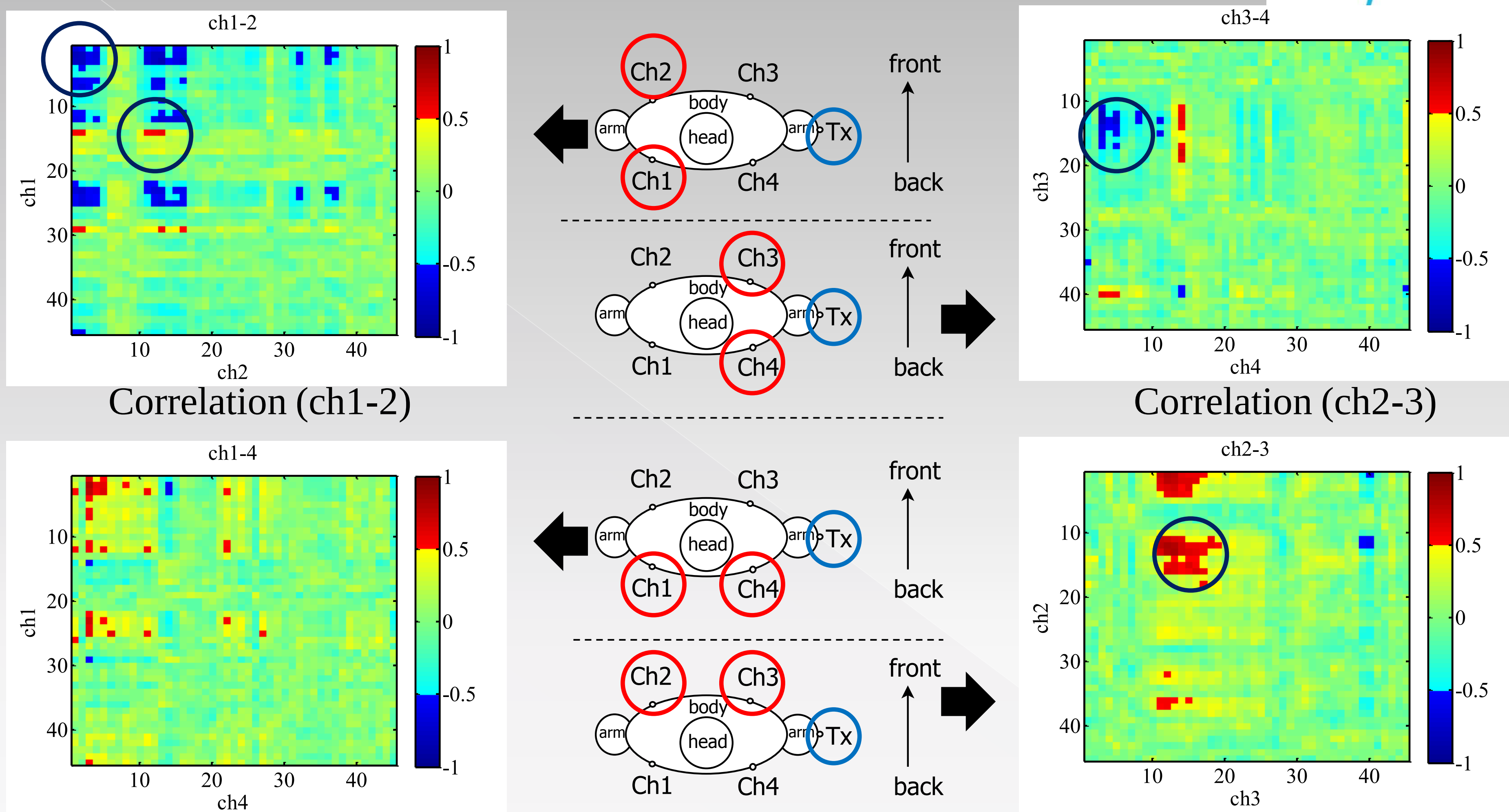


Illustration of two correlated impulse response [3]

[3] S. V. Roy, C. Oestges, F. Horlin, and P. D. Doncker, ”A Comprehensive Channel Model for UWB Multisensor Multiantenna Body Area Networks,” IEEE Transactions on Antennas and Propagation, Vol. 58, No.1, pp. 163 - 170, Jan. 2010.

Correlation between Each Channel



Correlation (ch1-2)

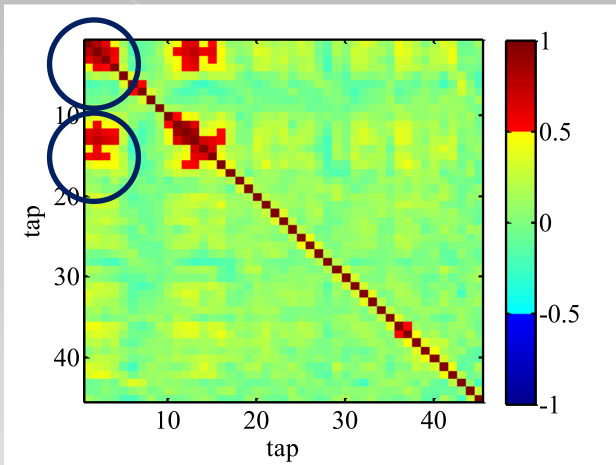
Correlation (ch2-3)

Correlation (ch1-4)

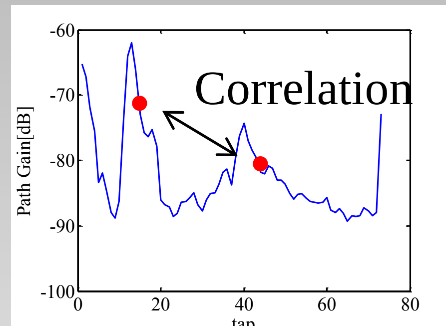
Correlation (ch2-3)

- Calculate the correlation between each taps
  - Inverse correlation between front and back side channel
  - High correlation between same side channel

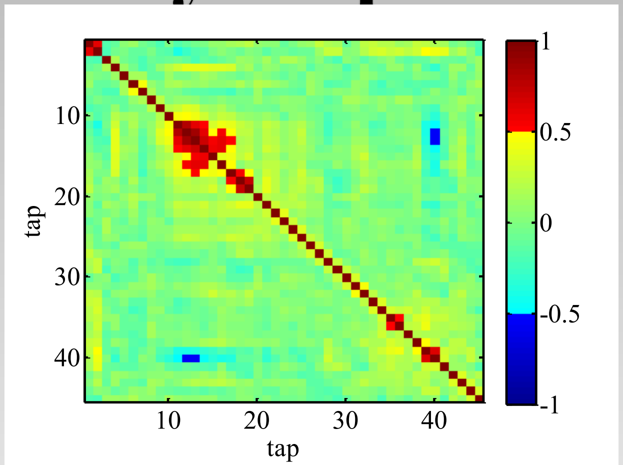
Correlation between Delay Tap



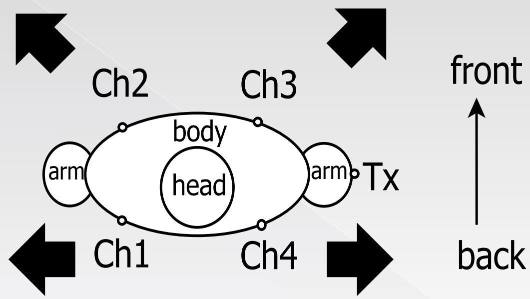
Correlation (ch2)

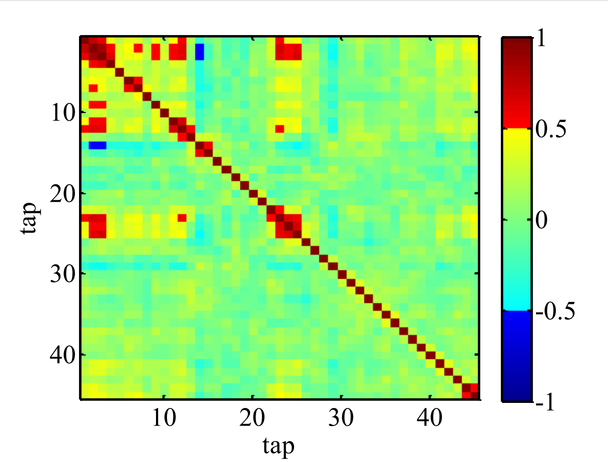


Impulse response

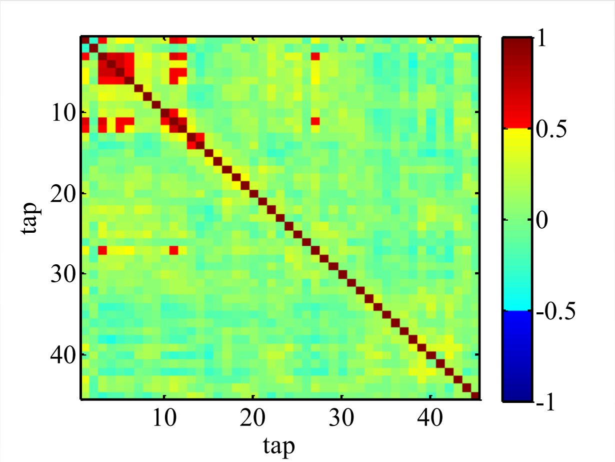


Correlation (ch3)





Correlation (ch1)



Correlation (ch4)

- Calculate the correlation between each taps
  - High correlation between several taps around the reception time of each path
  - High correlation between direct signal and ground reflection signal

Summary and Future Work

- Summary
  - Development of measurement system
    - Using Digital Sampling Oscilloscope (DSO)
  - Experiment of dynamic channel
    - Correlation between delay tap
- Future work
  - Modeling dynamic channel of UWB BAN
    - Summarize each data
  - Evaluation of the efficient for multiple antenna in receiver side
    - Improve the channel capacity

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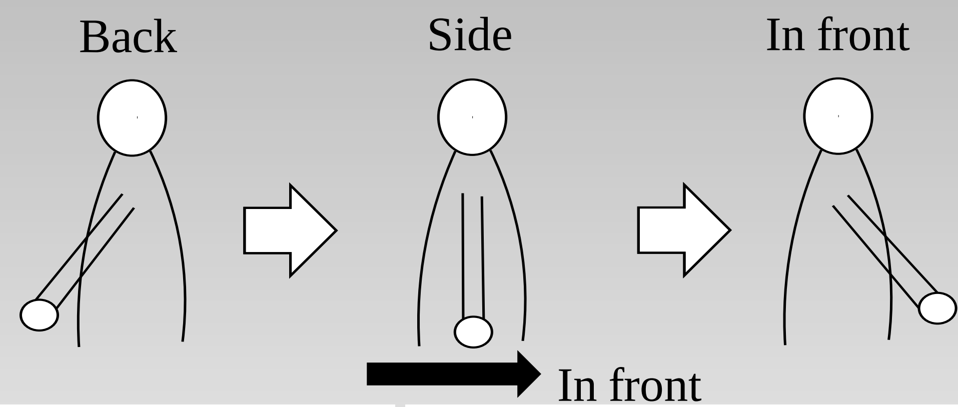
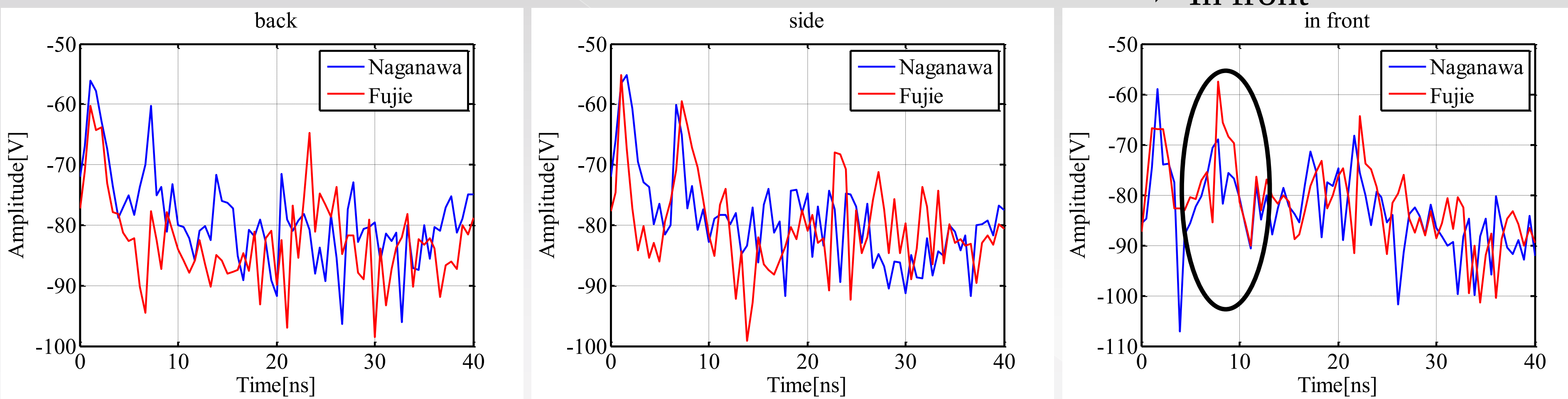
Thank you for listening!

Appendix

Impulse response in static case

- Firstly, we obtain the channel impulse response when subject is not moving (3 poses).

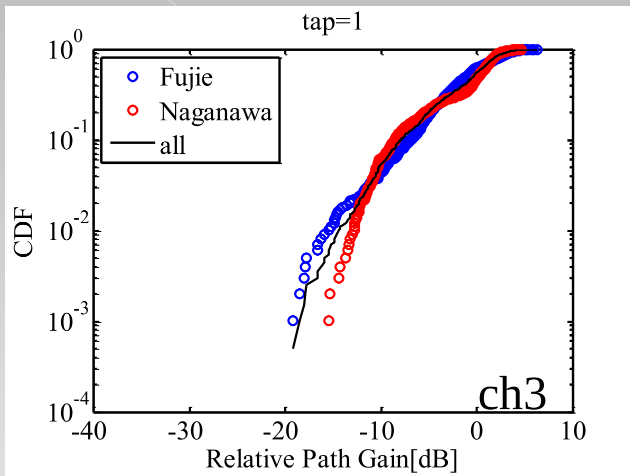


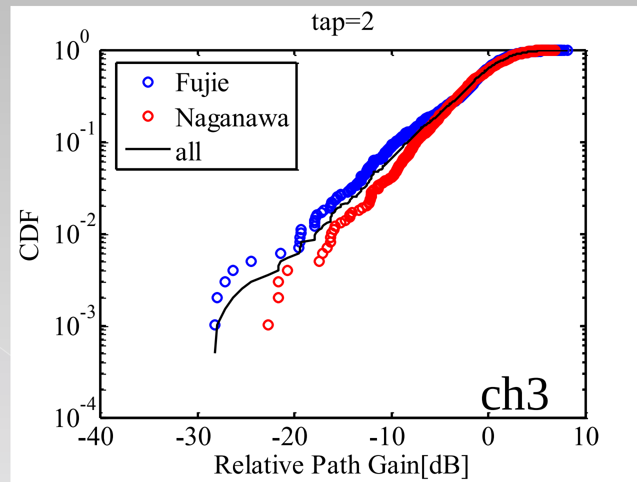


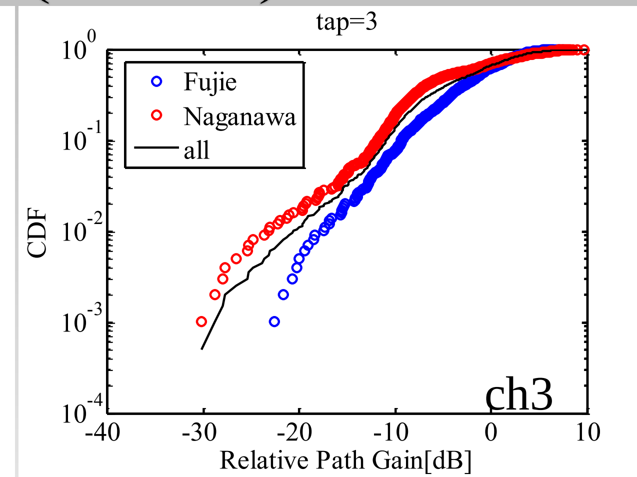
Back Side In front

- The first signal show the same value in each case(Naganawa san) ⇒difficult to be characterized by distance
- The data of Fujie kun when transmit antenna is located in front of the body we receive a second signal lager than first signal.

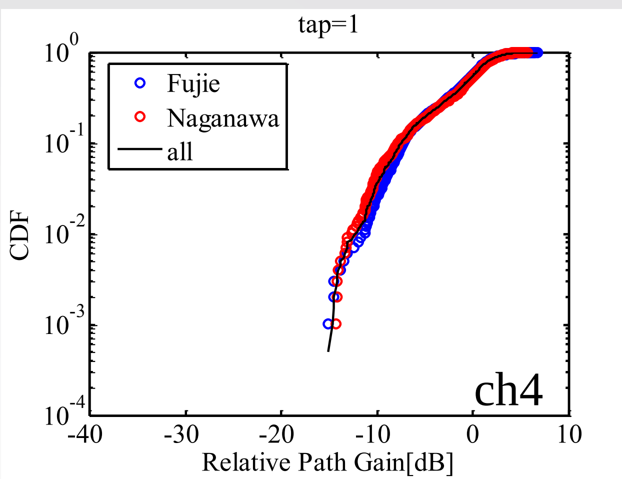
Relative Path Gain(CDF)

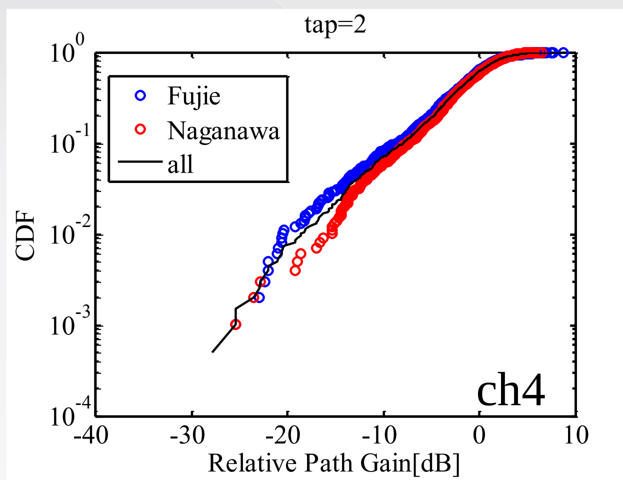


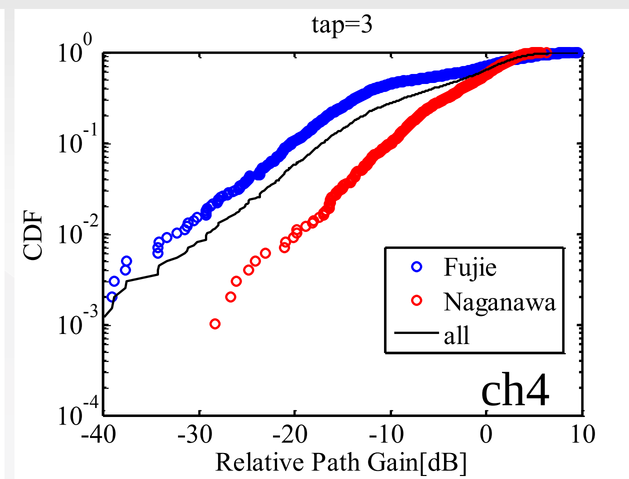




Tap 1 Tap 2 Tap 3



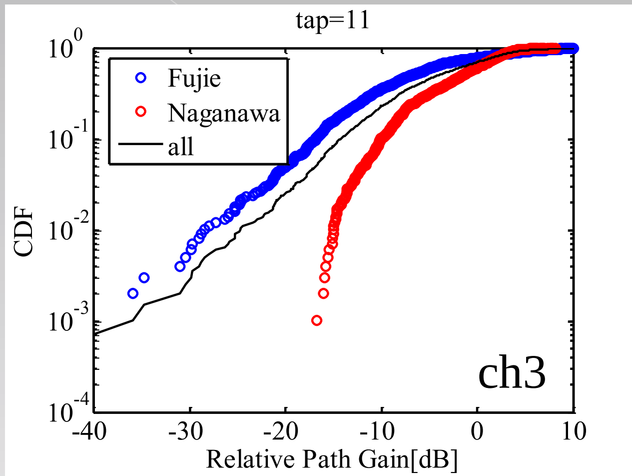


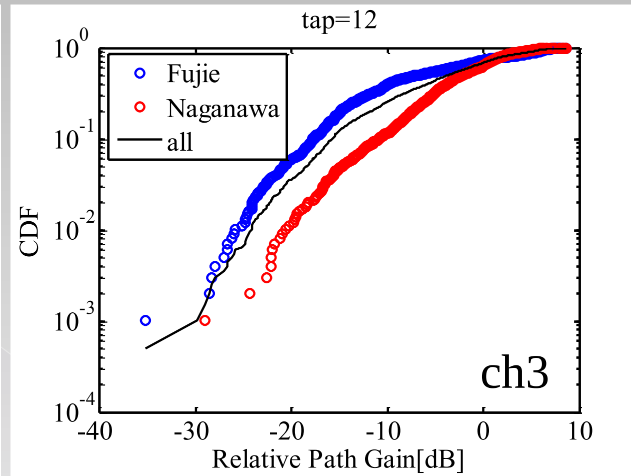


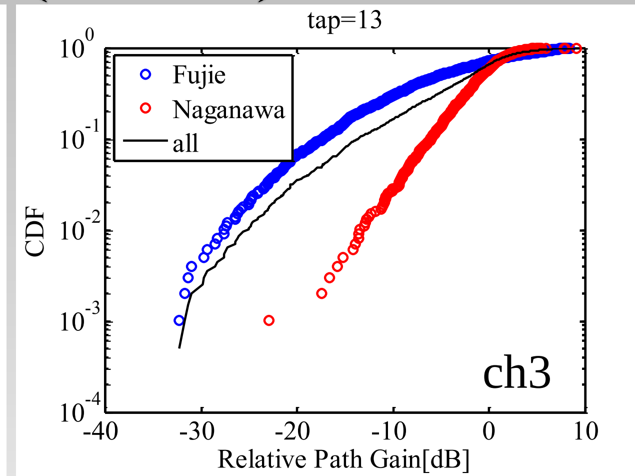
Tap 1 Tap 2 Tap 3

- Tap 1 has lower fluctuation than others due to first arrival signal
- Tap2 and 3 seem no t to receive the signal

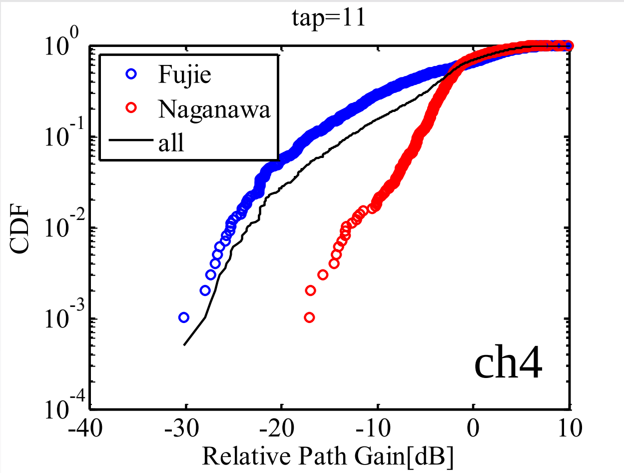
Relative Path Gain(CDF)

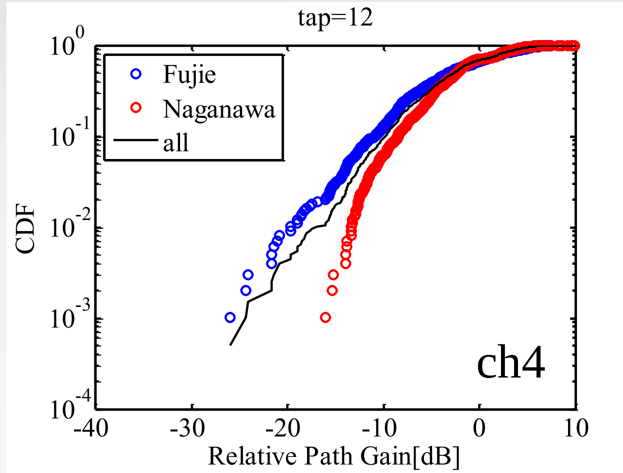


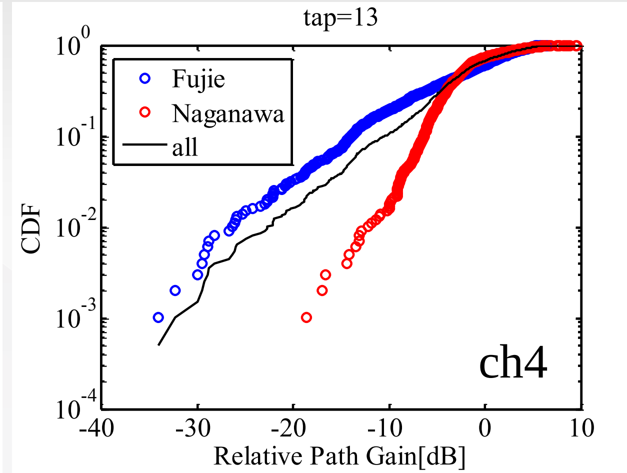




Tap 11 Tap12 Tap 13



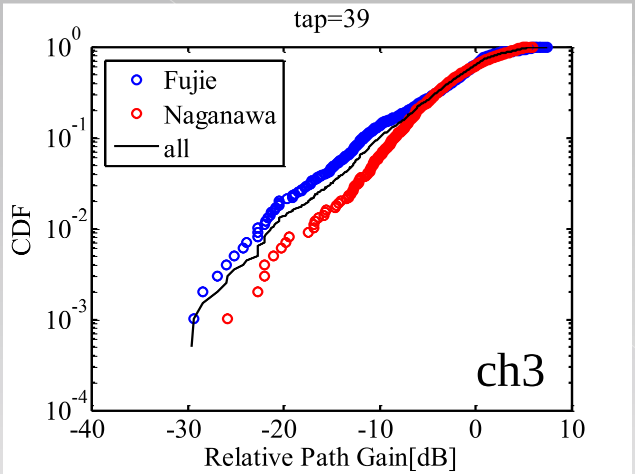


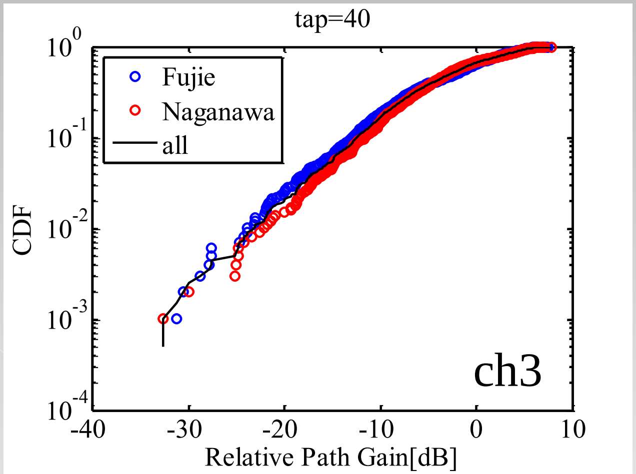


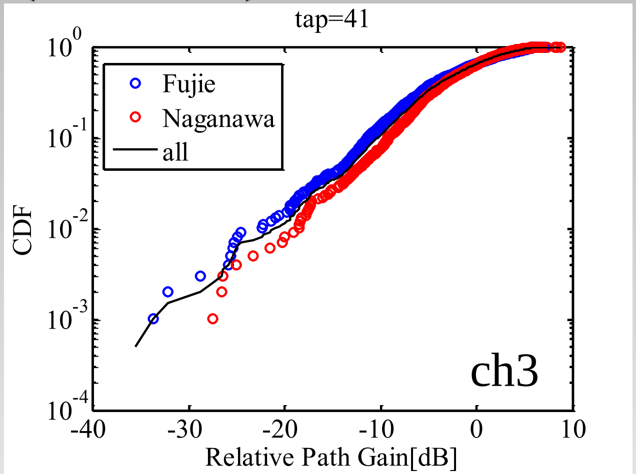
Tap 11 Tap12 Tap 13

- Fudjie-kun’s data is too fluctuating

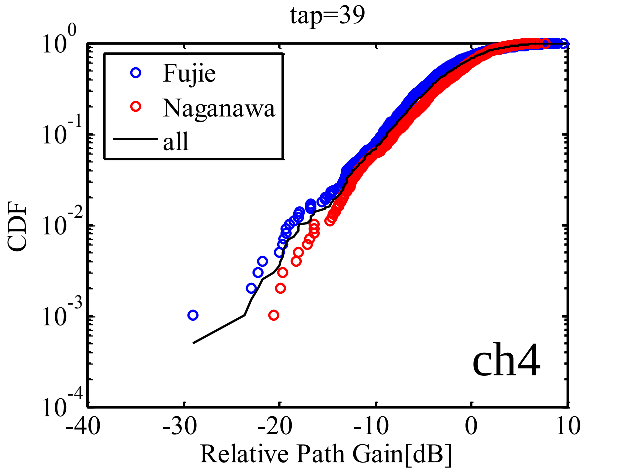
Relative Path Gain(CDF)

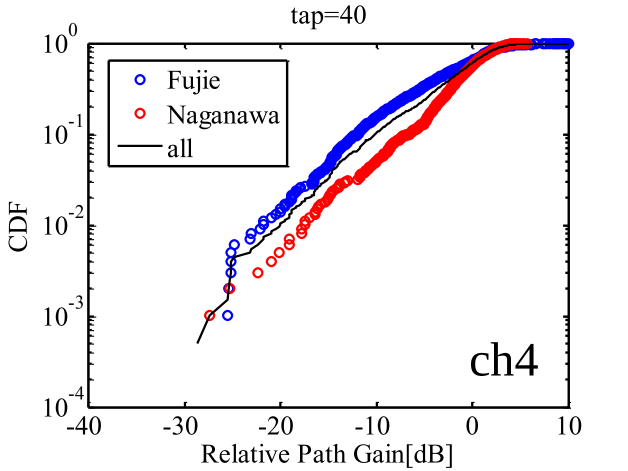


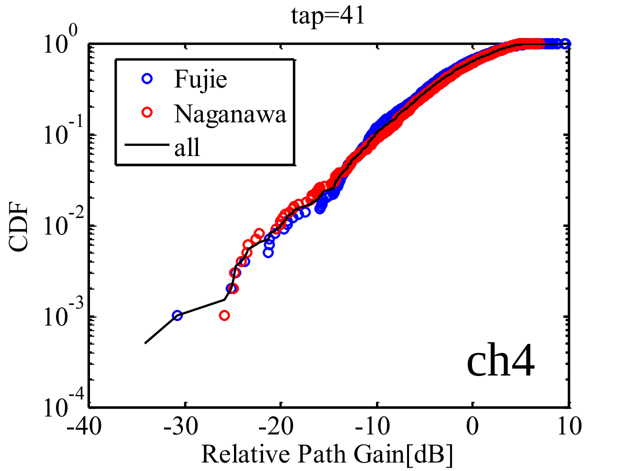




Tap 39 Tap40 Tap 41



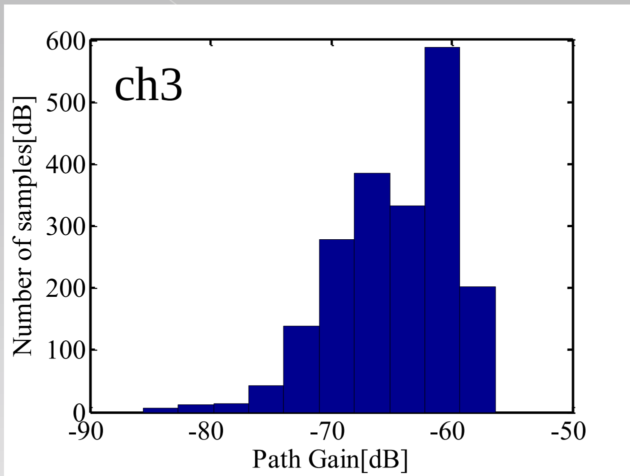




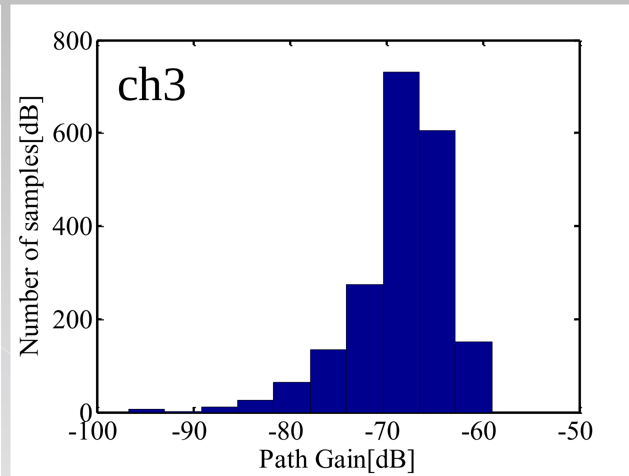
Tap 39 Tap40 Tap 41

- tap 39 - 41 don’t change about each fluctuation
  - Due to low power?

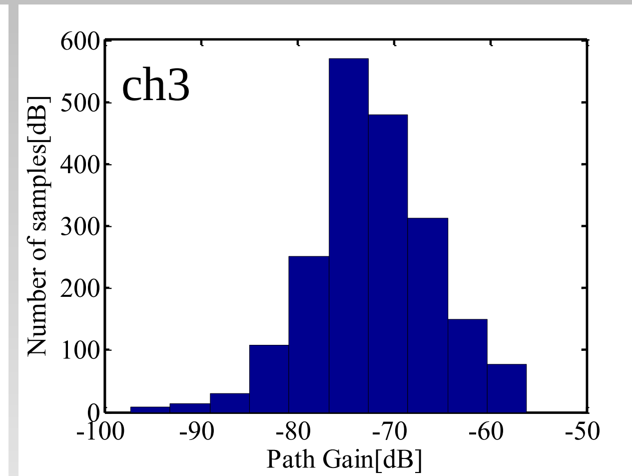
PDF



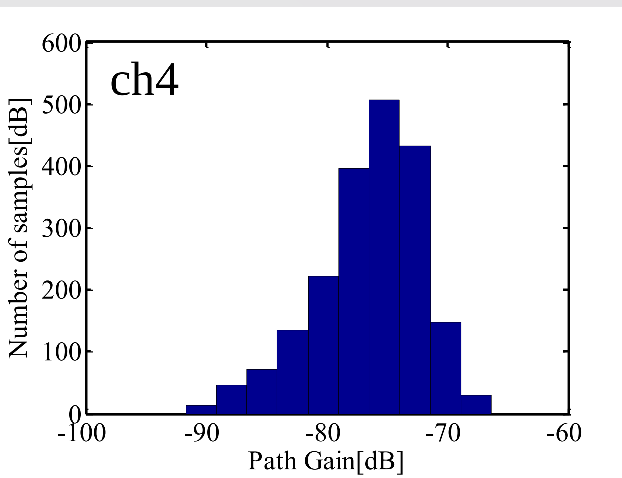
Tap 1



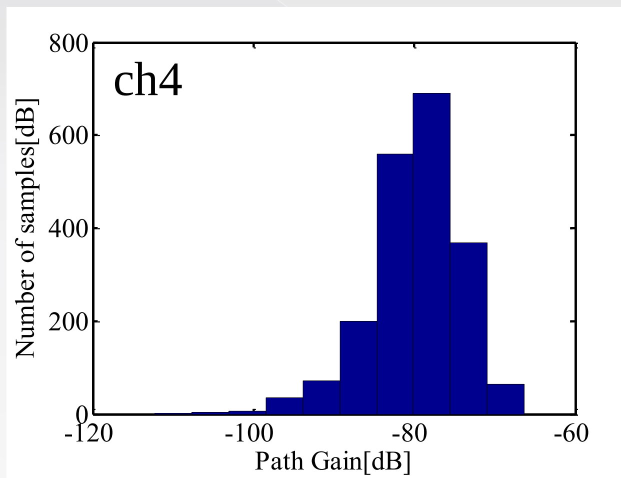
Tap 2



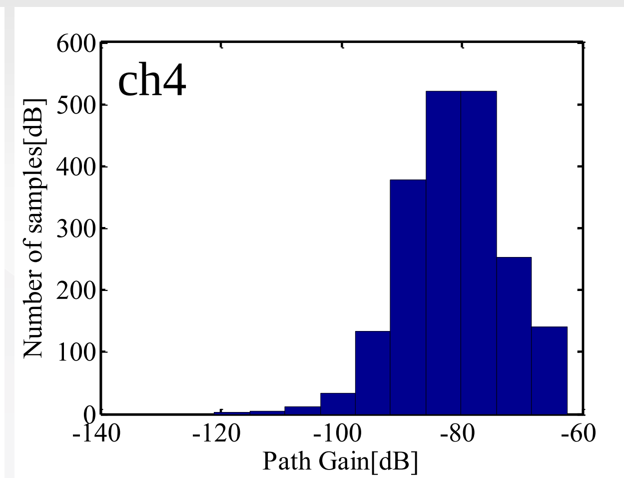
Tap 3



Tap 1



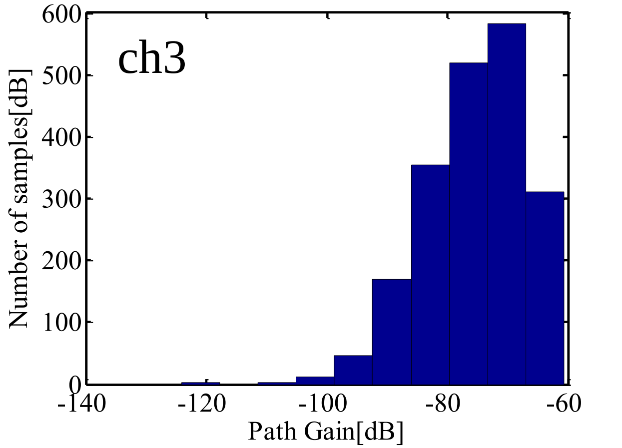
Tap 2



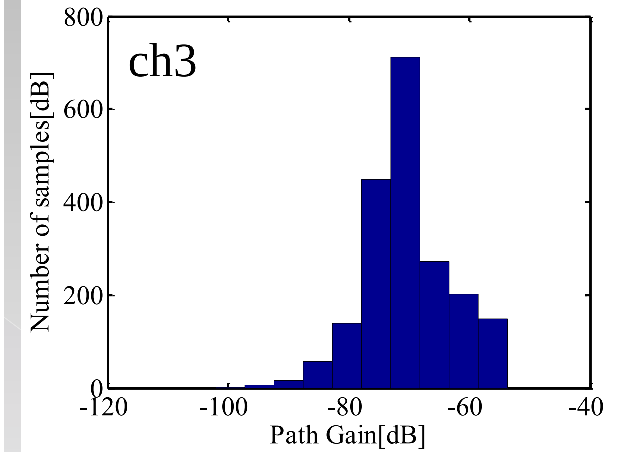
Tap 3

- All data seems to be conform log-normal distribution.

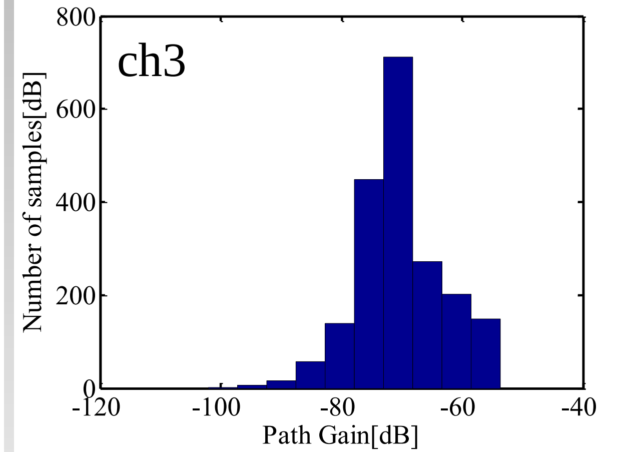
PDF



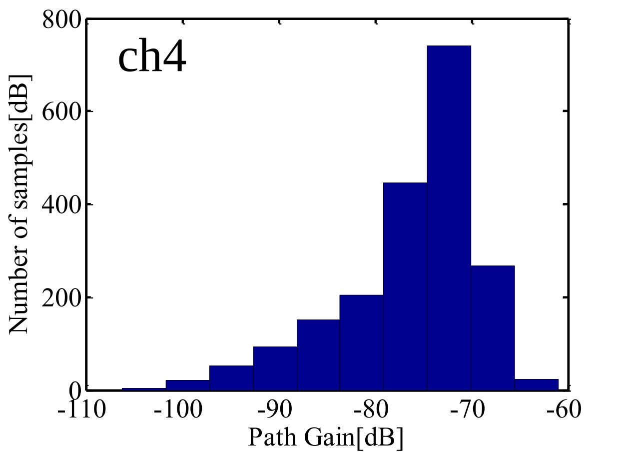
Tap 11



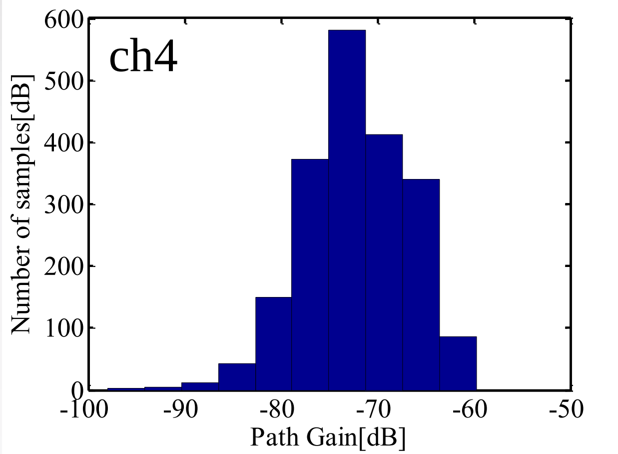
Tap12



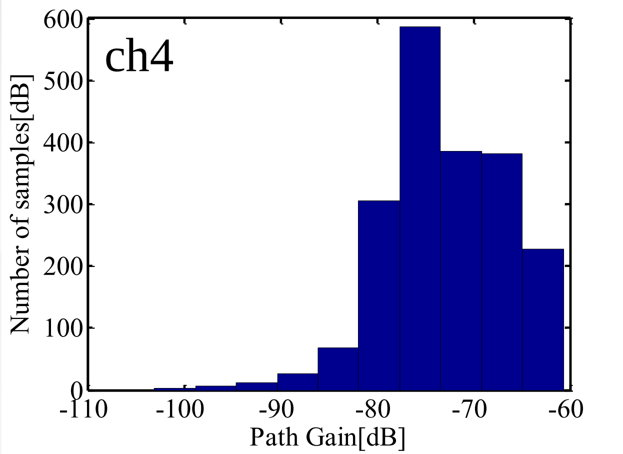
Tap 13



Tap 11

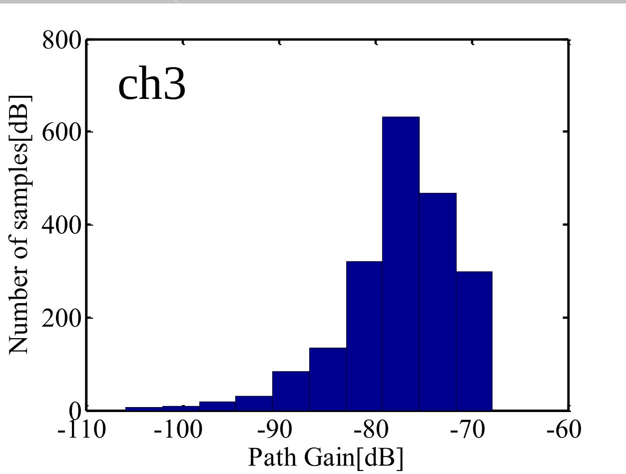


Tap12

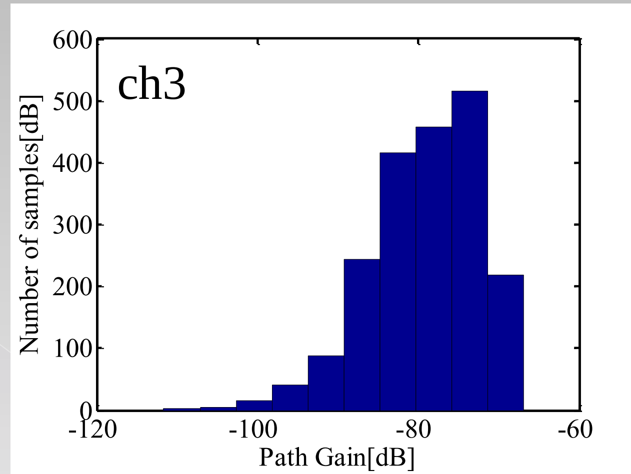


Tap 13

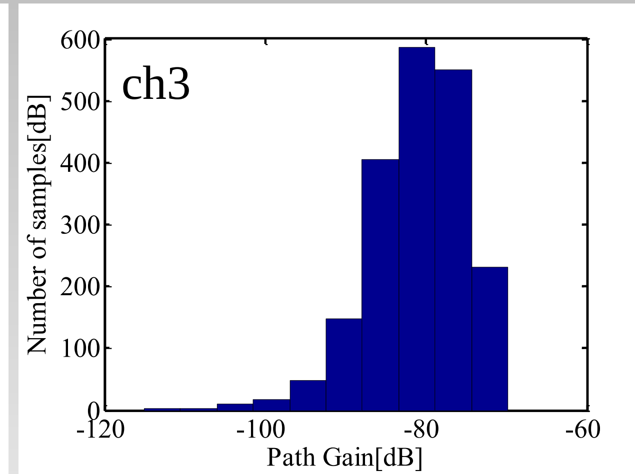
PDF



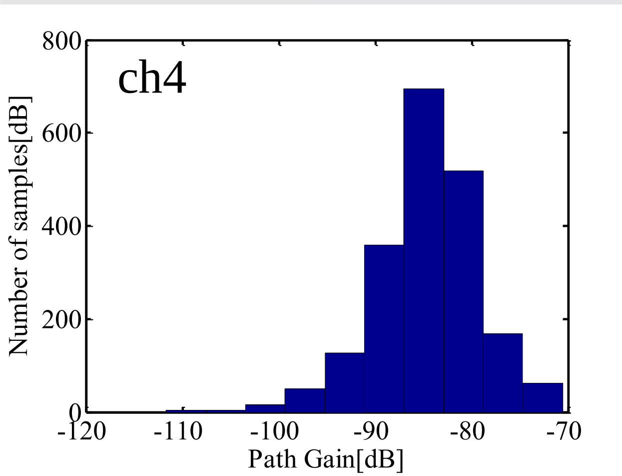
Tap 39



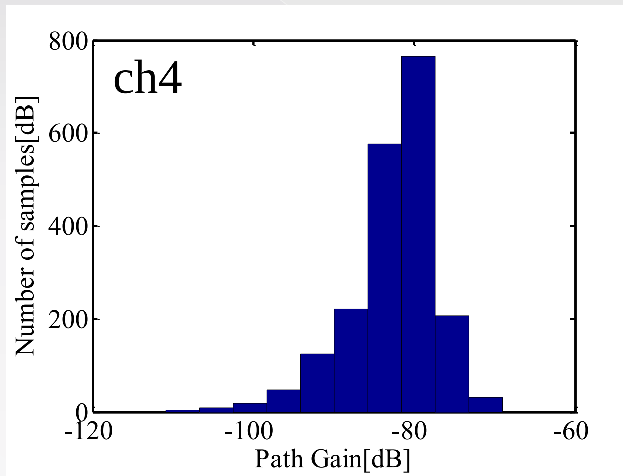
Tap40



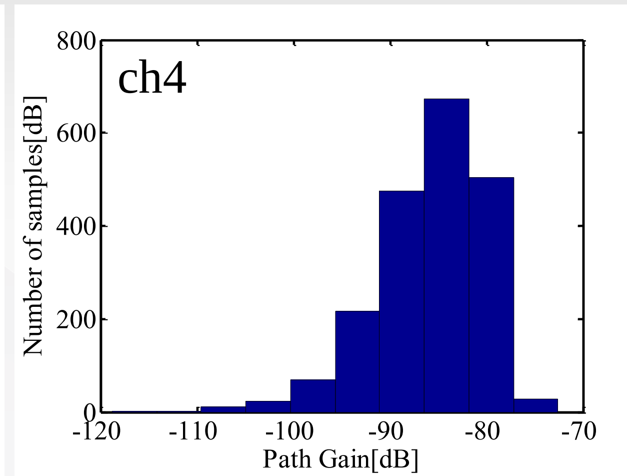
Tap 41



Tap 39



Tap40



Tap 41