AWCC

UEC Tokyo

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Propagation Channel Modeling for Wideband Radio Systems

- How to create realistic MIMO propagation environment for OTA measurements -

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Outline

1. Introduction: MIMO and MIMO-OTA
2. Channel Model for MIMO OTA Systems
   - Simplified Configuration
   - Channel Model
3. Two-Stage Scheme for MIMO Fading Emulator
4. Development of MIMO Fading Emulator using FPGA
5. Application Examples
6. Conclusion

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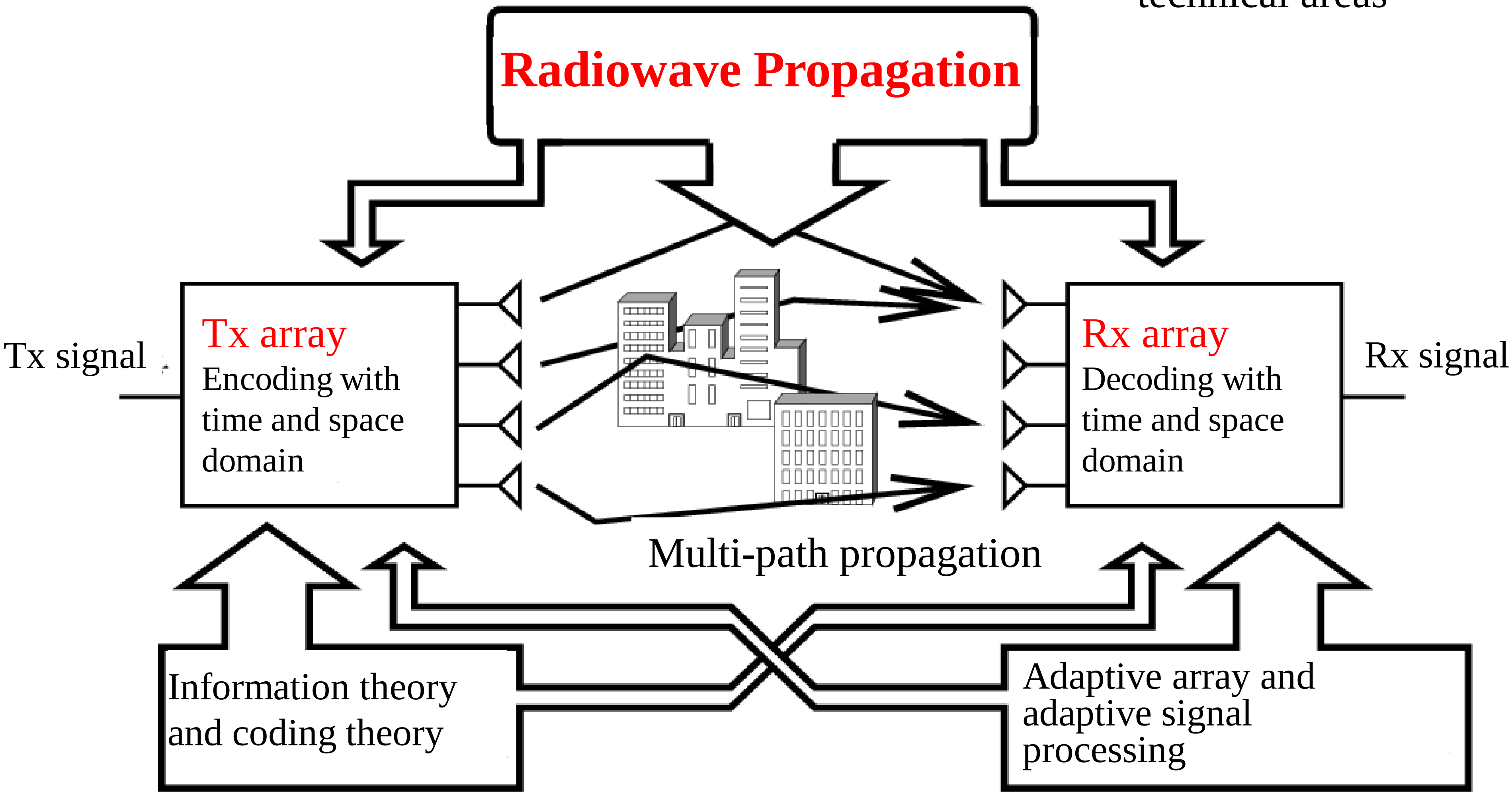
MIMO Technologies

MIMO covers wide technical areas



Applications are from W-LAN to next-generation mobile wireless systems.

Trend of MIMO R&D

- ○ Transmission scheme
- ○ System application (from WLAN to LTE-advanced)
- ○ System development (MU-MIMO, large-scale MIMO)

⇩

○ Establishment of performance evaluation system for MIMO user terminal (MIMO-OTA)

- Handset-related problem such as antenna coupling effect
- High needs to the measurement system development
- Insufficient research for MIMO-OTA
- Establishment of standard scheme

We want to evaluate MIMO user terminal performance.

Necessity of evaluation environment

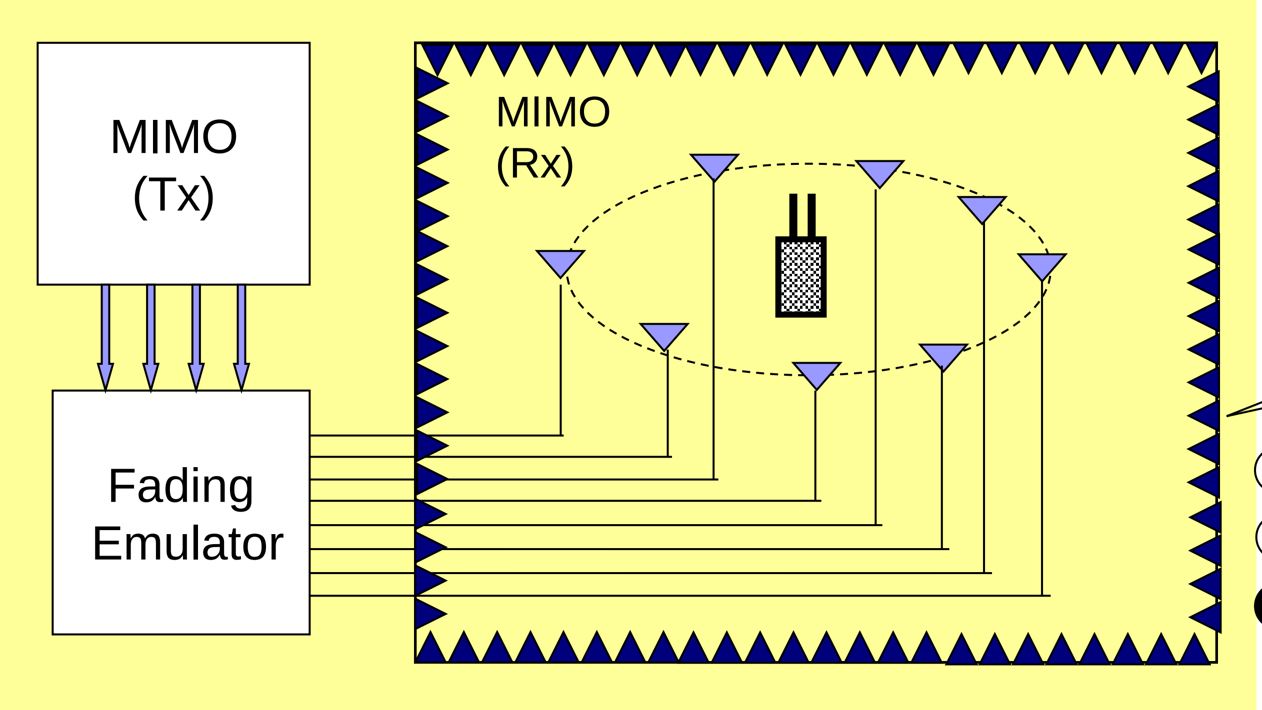
Construction of MIMO-OTA Measuring System

Fading Emulator Type

Reverberation Chamber Type

Hybrid Structure Type

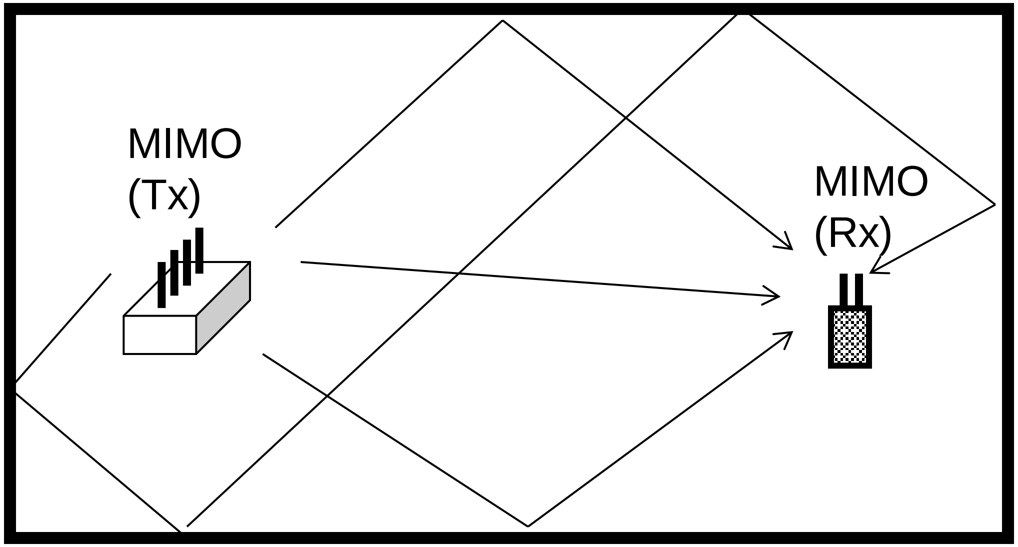
Two Types of MIMO-OTA Systems



Fading Emulator Type (FE)

- ○ Full functions
- ○ Higher Flexibility
- ● Higher Construction Cost

Reverberation Chamber Type (RC)



- ○ Multipath-rich Environment with large delay
- ○ Lower Construction Cost
- ● Lower Flexiblility

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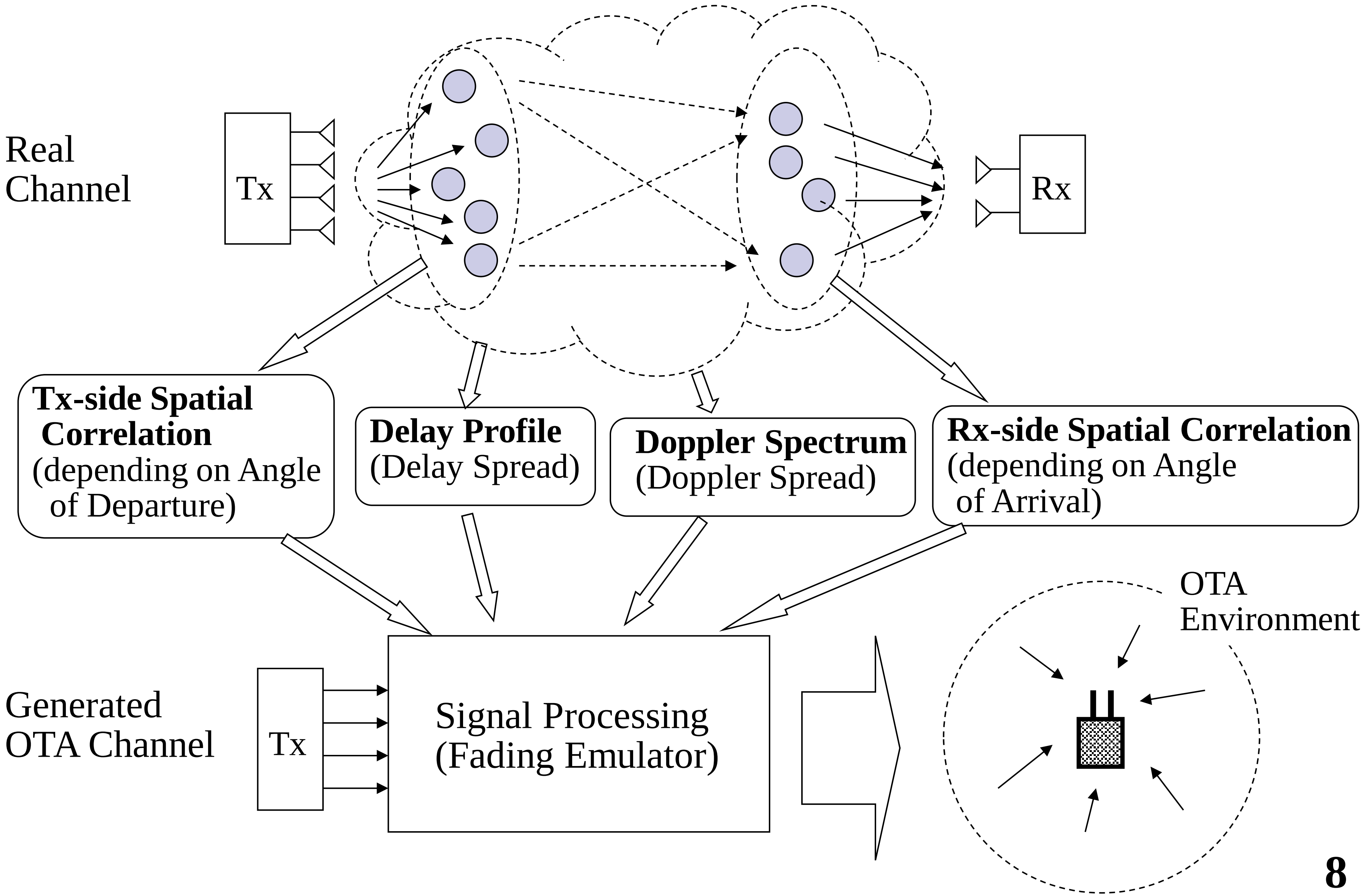
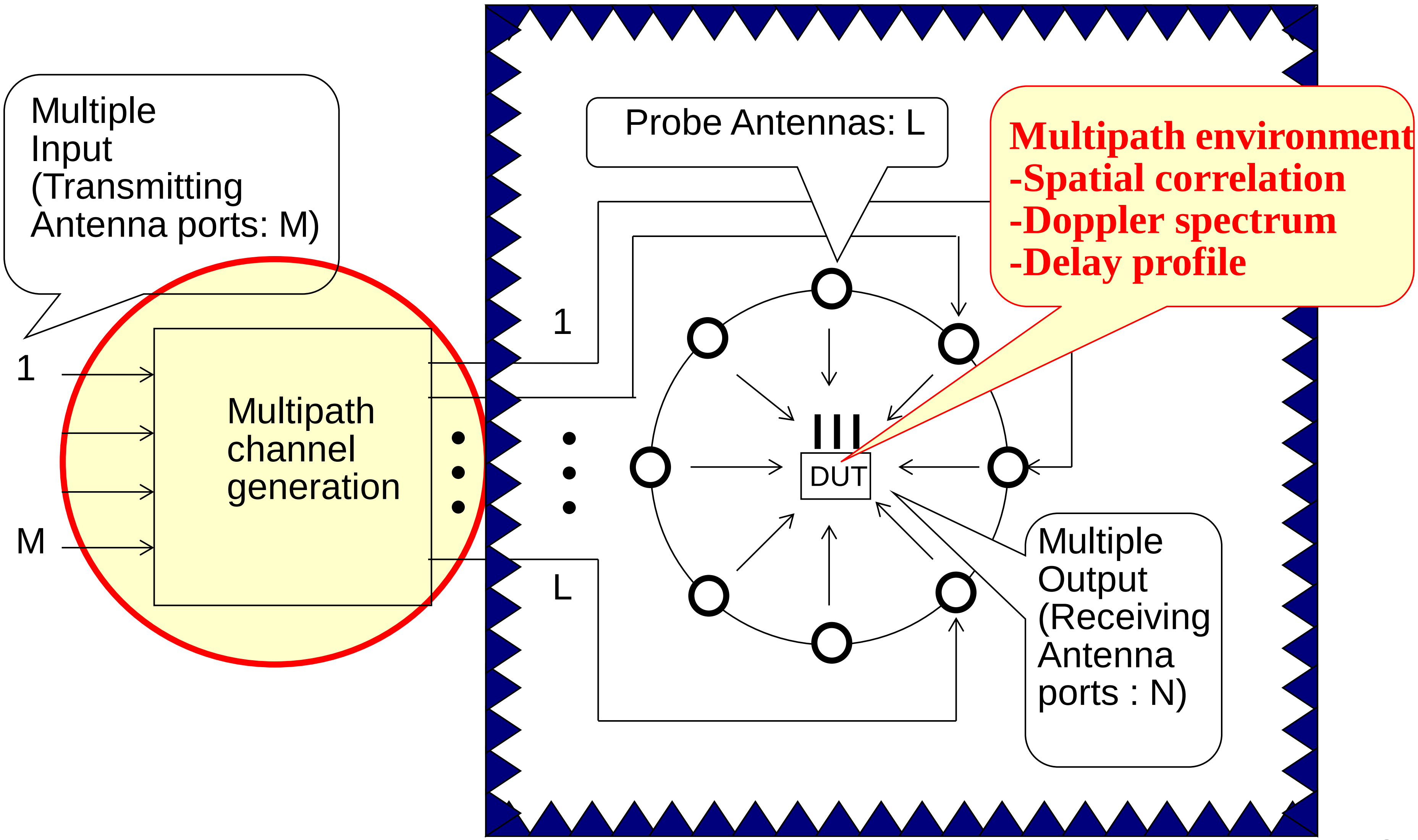
Required Function for MIMO-OTA Measurement System

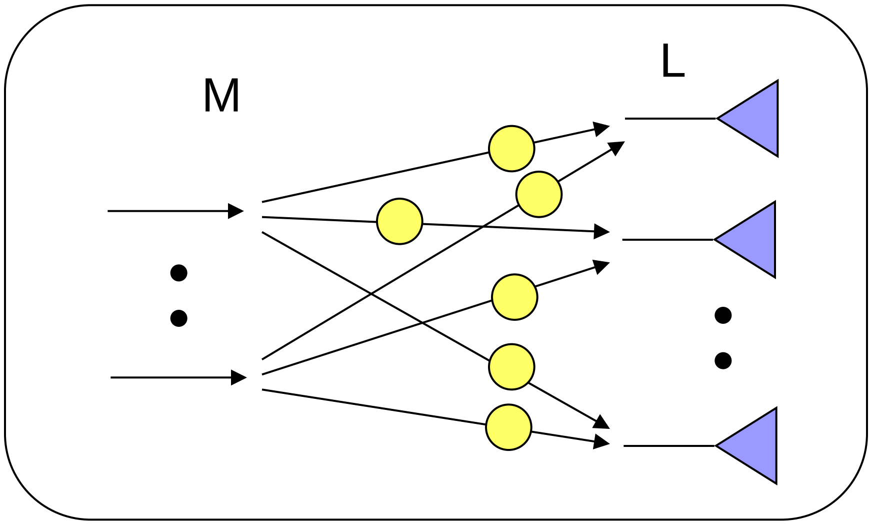


Fading Emulator-type MIMO OTA System



Basic Configuration of Multipath Fading Generation Part

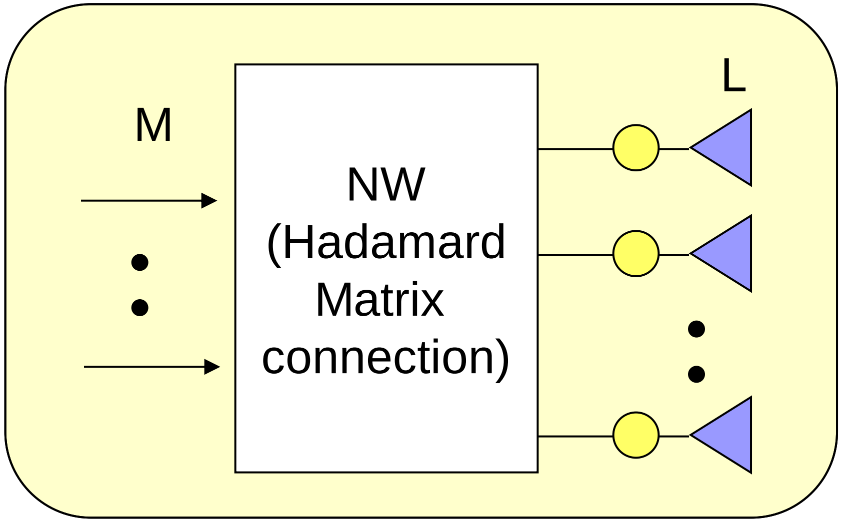
Path-Controlled Scheme



Number of delay units: *MLK*
Number of Rayleigh faders: *MLK*
(*K*: Number of multipath delays)

Almost perfectly controllable
Large scale configuration

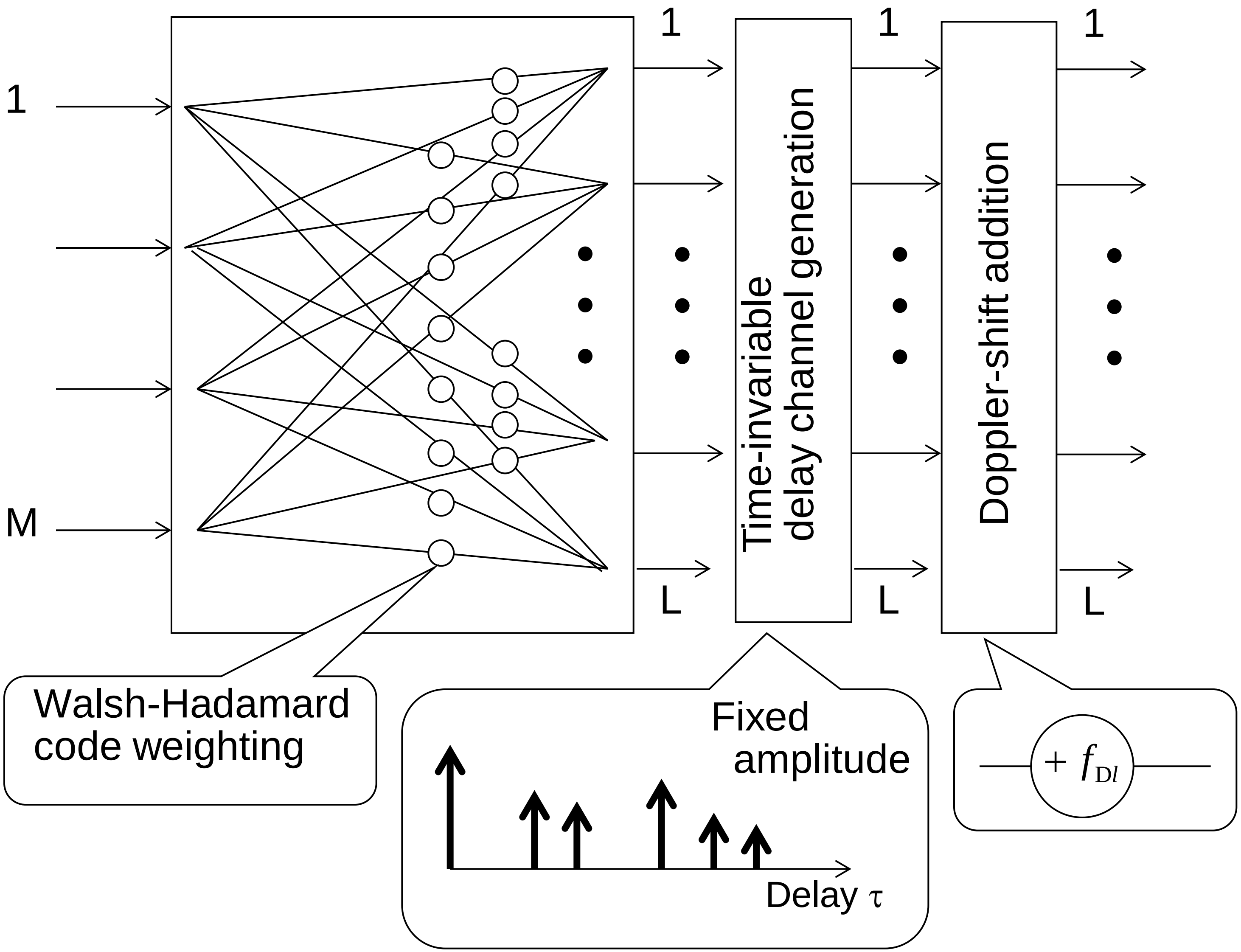
Antenna-Branch-Controlled Scheme



Number of delay units: *LK*
Number of Doppler shifters: *L*

Flexibly controllable
(realization of some functions is limited.)
Simplified configuration
(easy to FPGA implementation)

Functional Block Configuration of Antenna-Branch-Controlled Scheme



Channel Model

Received Signal $\boldsymbol{r}(t)=\boldsymbol{H}(t,\tau)\otimes\boldsymbol{s}(t)+\boldsymbol{n}(t)$

Channel Characteristics

$$\boldsymbol{H}(t,\tau)=\boldsymbol{A}_{\mathrm{RX}}\boldsymbol{A}_{\mathrm{Doppler}}(t)\boldsymbol{H}_{\mathrm{delay}}(\tau)\boldsymbol{A}_{\mathrm{TX}}$$

Independent fluctuation for each input signal

$$\boldsymbol{A}_{\mathrm{TX}}=\begin{pmatrix}\boldsymbol{w}_1 & \boldsymbol{w}_2 & \cdots & \boldsymbol{w}_M\end{pmatrix}$$

$$\boldsymbol{w}_m=\begin{pmatrix}w_{m1} & w_{m2} & \cdots & w_{mL}\end{pmatrix}^{\mathrm{T}}$$

WH code

Multipath Delay

$$\mathbf{H}_{delay}(\tau)=\sum_{k=1}^{K}\mathbf{A}_{dalay}^{(k)}\delta(\tau-\Delta\tau_k)$$

$$\boldsymbol{A}_{dalay}^{(k)}=\mathrm{diag}\begin{pmatrix}\alpha_1^{(k)}c_k & \alpha_2^{(k)}c_k & \cdots & \alpha_L^{(k)}c_k\end{pmatrix}$$

Doppler shift Generation

$$\boldsymbol{A}_{\mathrm{Doppler}}(t)=\frac{1}{\sqrt{L}}\mathrm{diag}\begin{pmatrix}e^{j2\pi f_{\mathrm{D}1}t} & e^{j2\pi f_{\mathrm{D}2}t} & \cdots & e^{j2\pi f_{\mathrm{D}L}t}\end{pmatrix} \quad f_{\mathrm{D}l}=\frac{v}{\lambda}\cos(\theta_l+\Delta\theta_l)$$

$$\boldsymbol{A}_{\mathrm{RX}}=\begin{pmatrix}\boldsymbol{u}_1 & \boldsymbol{u}_2 & \cdots & \boldsymbol{u}_L\end{pmatrix}$$

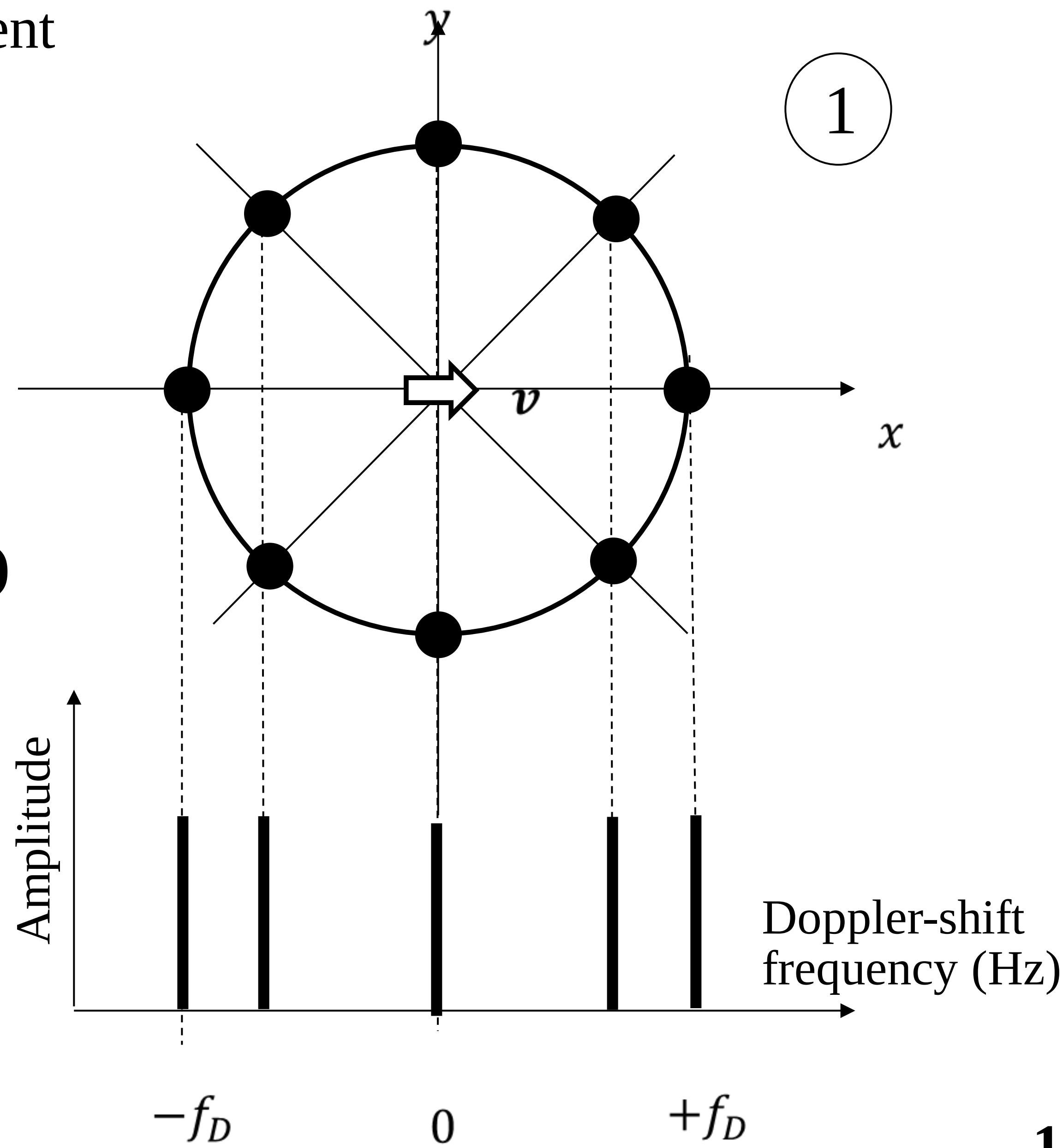
$$\boldsymbol{u}_l=\begin{pmatrix}u_{l1} & u_{l2} & \cdots & u_{lN}\end{pmatrix}^{\mathrm{T}}$$

$$u_{ln}=e^{jkd_n\cos(\theta_l-\theta_0)}$$

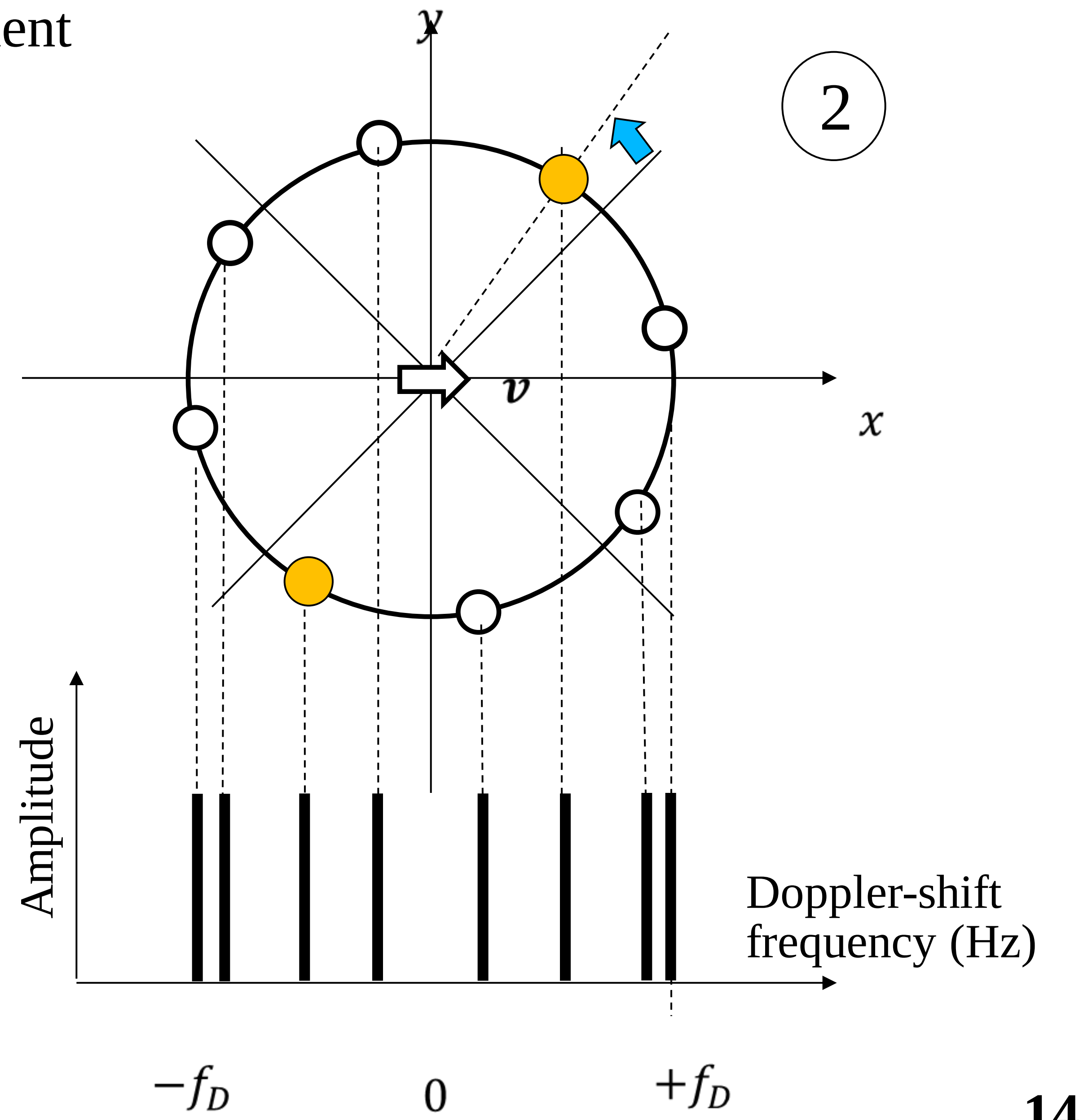
Array antenna reception
in the case of a linear array without antenna coupling

Probe antenna arrangement
having all different
Doppler-shift values

Regular arrangement
(Synmetric arrangement)



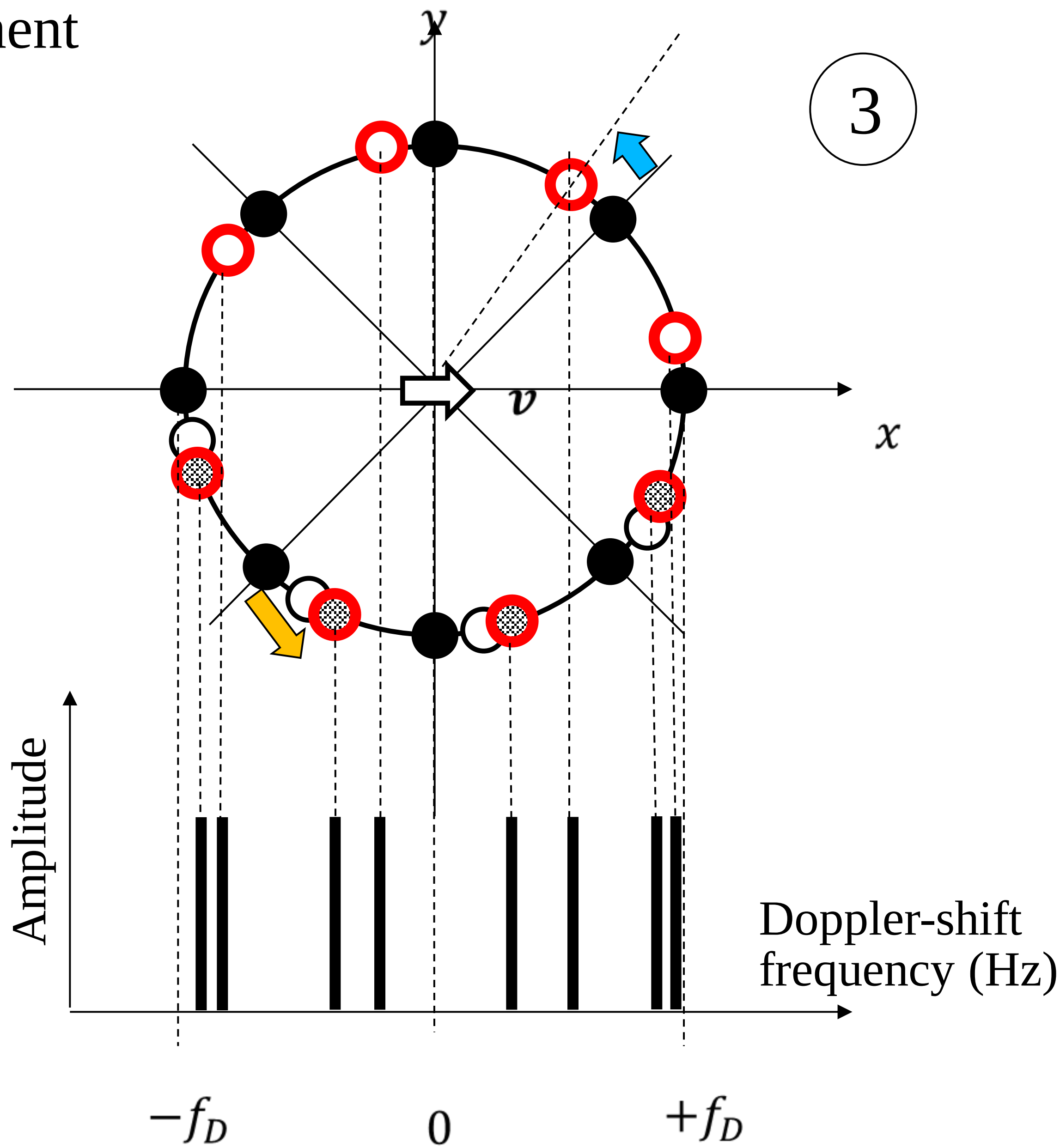
Probe antenna arrangement having all different Doppler-shift values



Regular arrangement with fixed offset

×

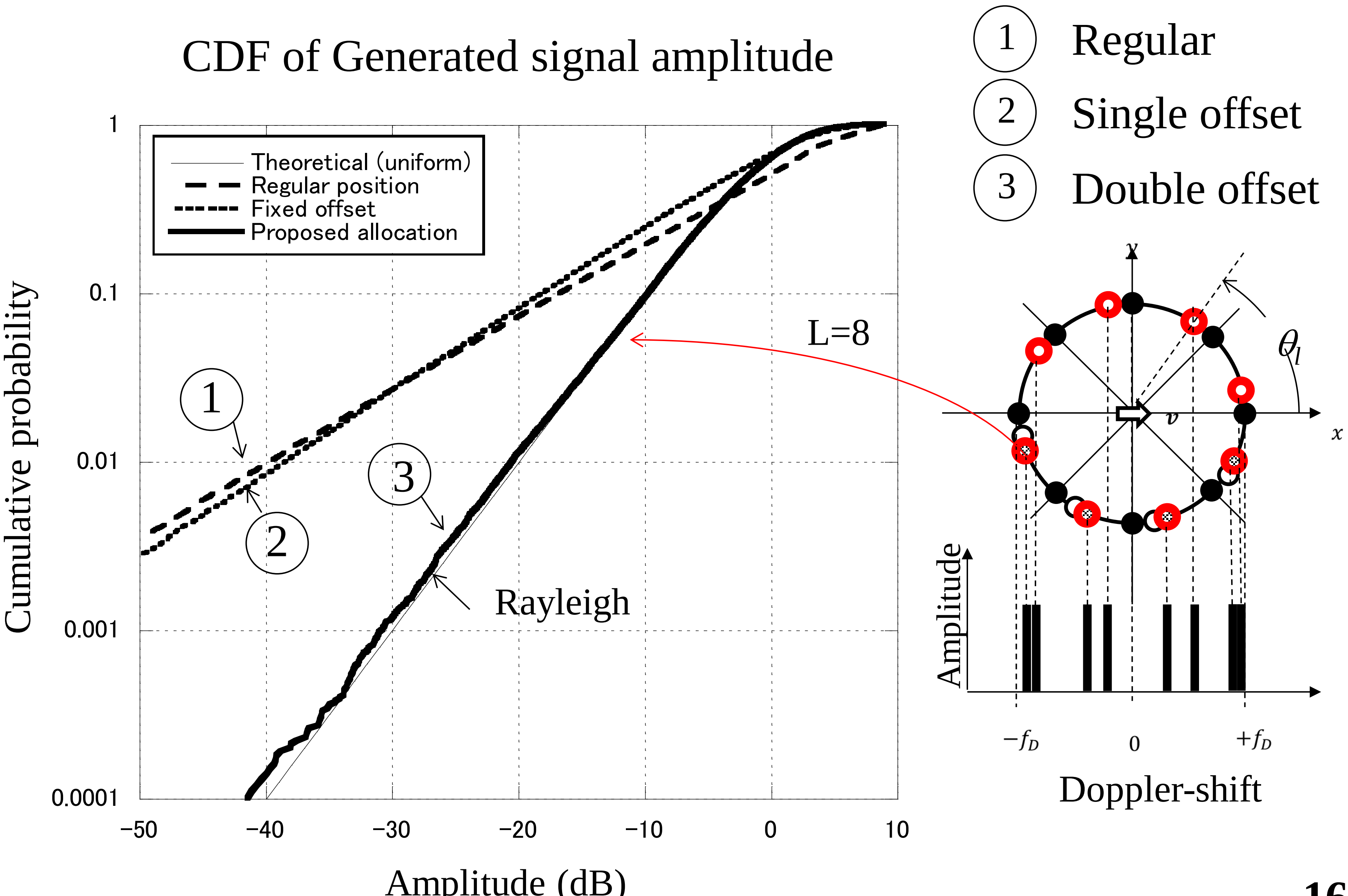
Probe antenna arrangement
having all different
Doppler-shift values



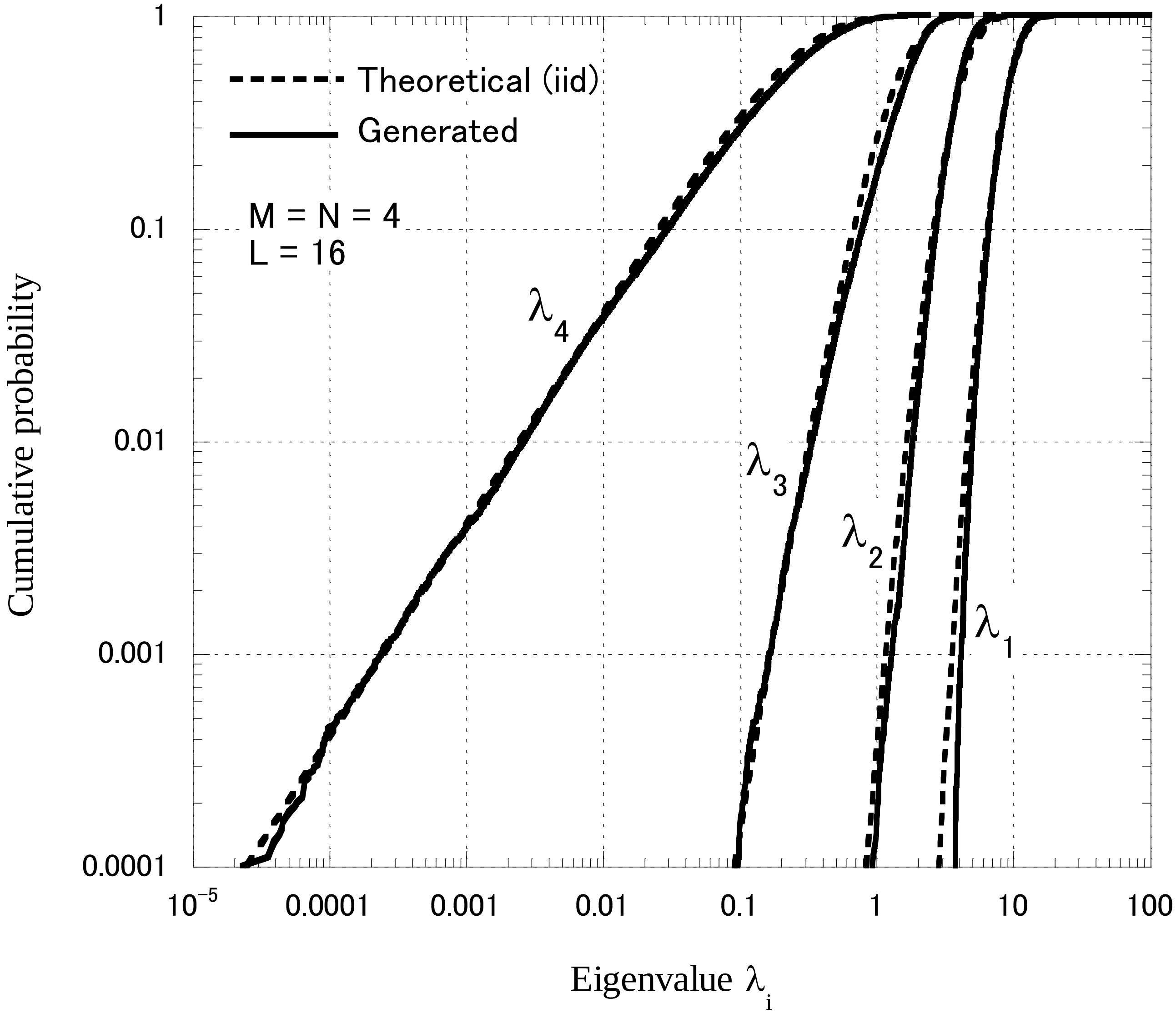
Proposed arrangement (double offset)

Non symmetrical arrangement for any combination of two antennas

CDF of Generated signal amplitude



Eigenvalue characteristics of 4 x 4 MIMO in i.i.d. condition



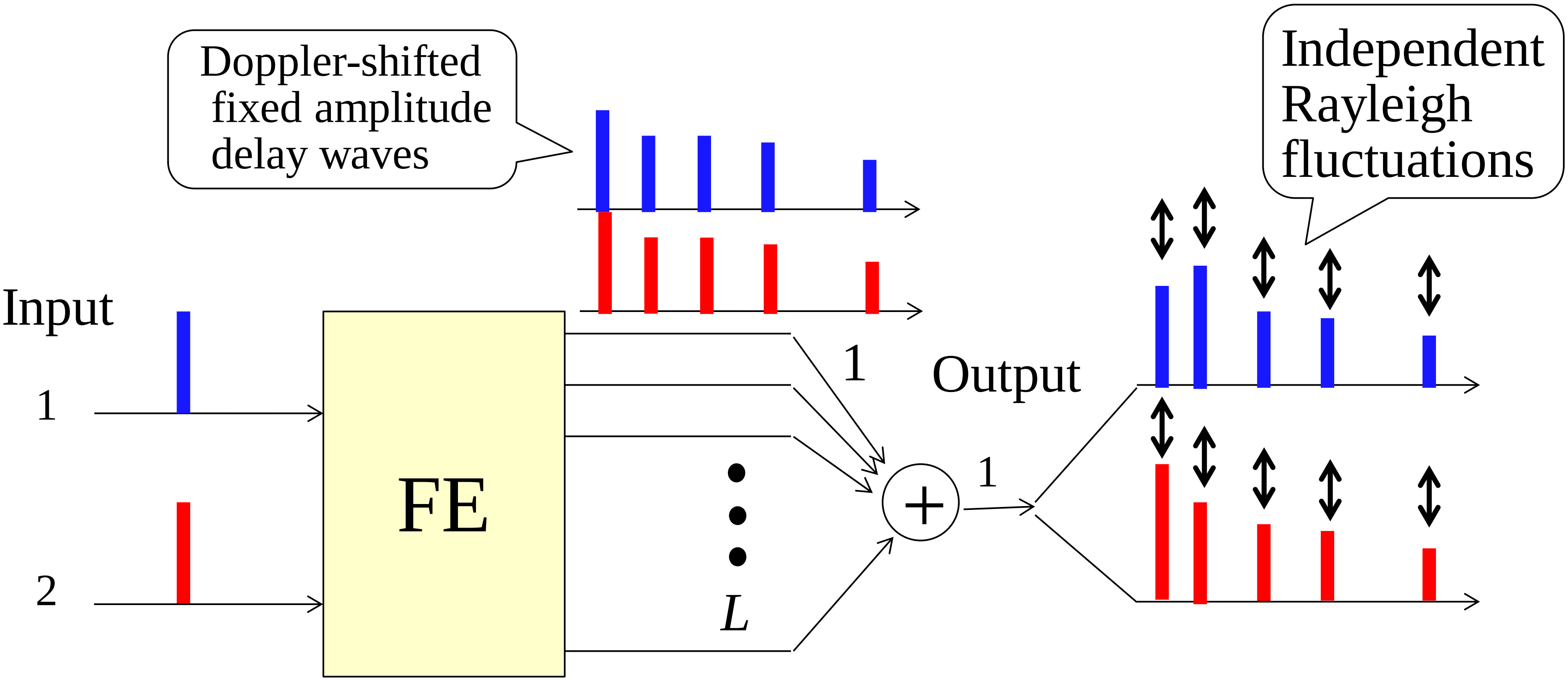
$\lambda_1 \sim \lambda_4$:

Eigenvalues of

$\boldsymbol{AA}^{\mathrm{H}}$

where $\boldsymbol{A}$ is channel matrix.

Weight Matrix (=Connection Matrix) for realizing independent fluctuations of all delayed paths



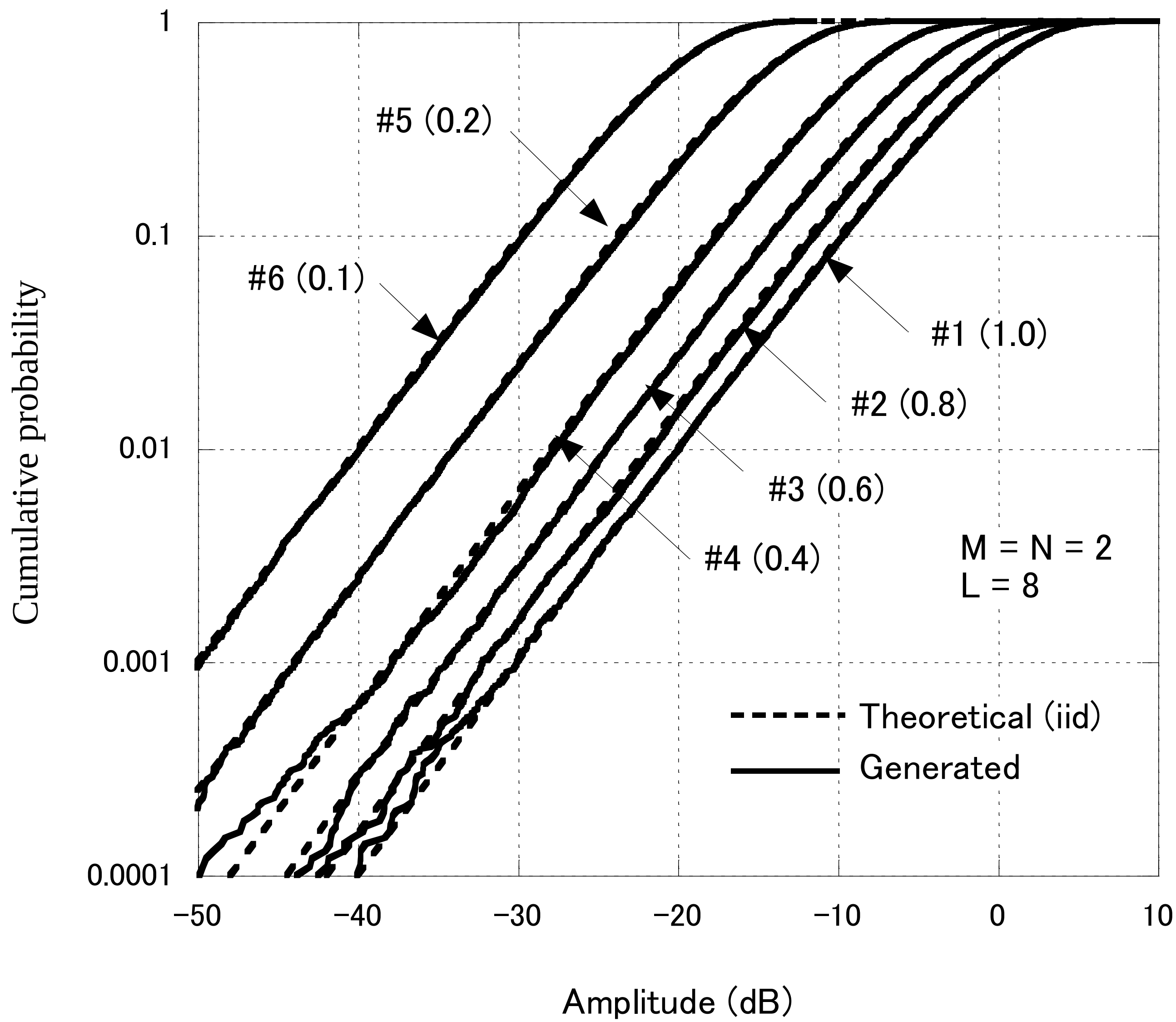
$$\boldsymbol{W}_{WH\_L} = \boldsymbol{W}_{WH\_delay} \otimes \boldsymbol{W}_{WH\_TX}$$

Probe antenna weighting matrix (*KM*x*KM*)

Delay signal connection matrix (*K*x*K*)

Tx-port signal connection matrix (*M*x*M*)

Amplitude distribution of each generated delay paths



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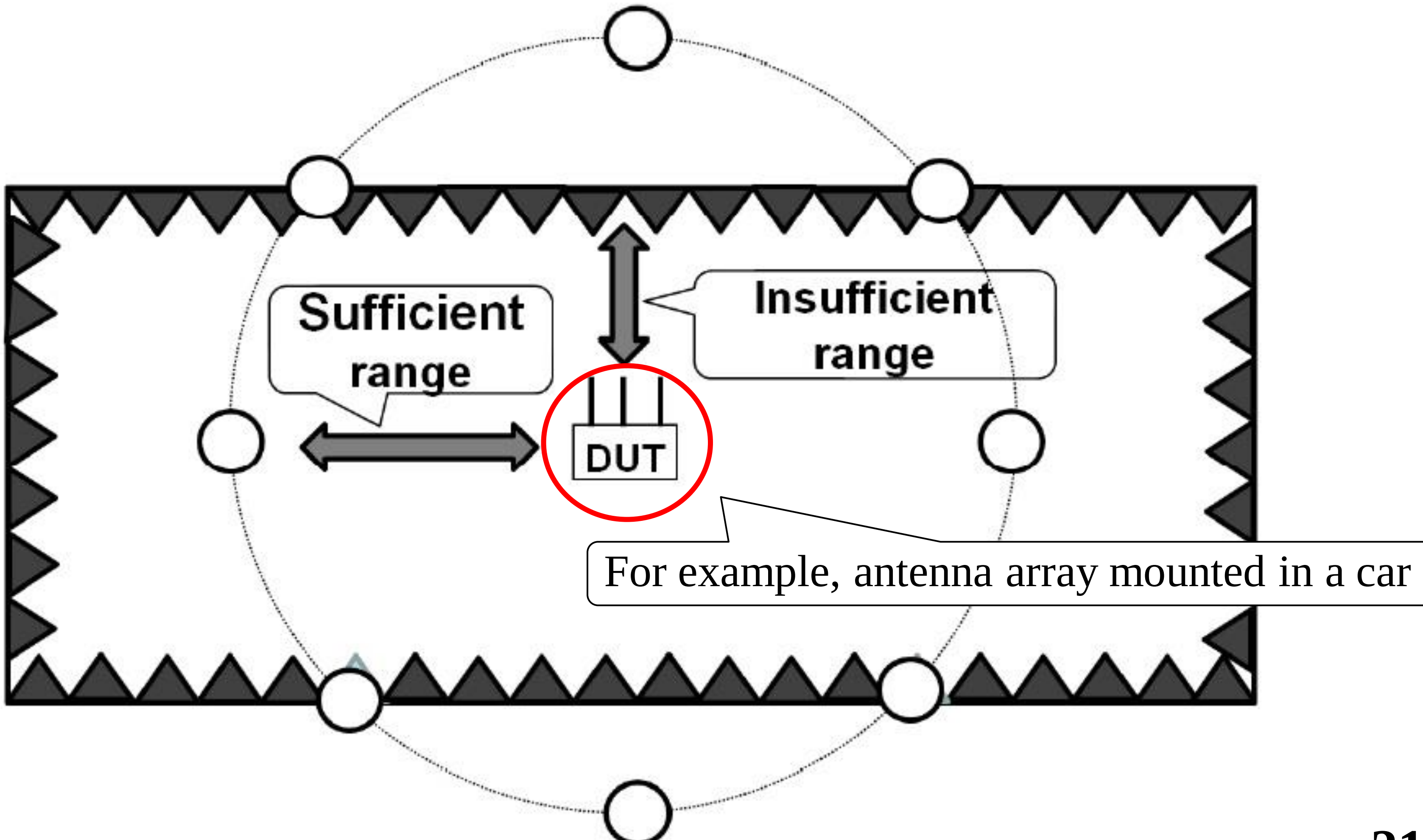
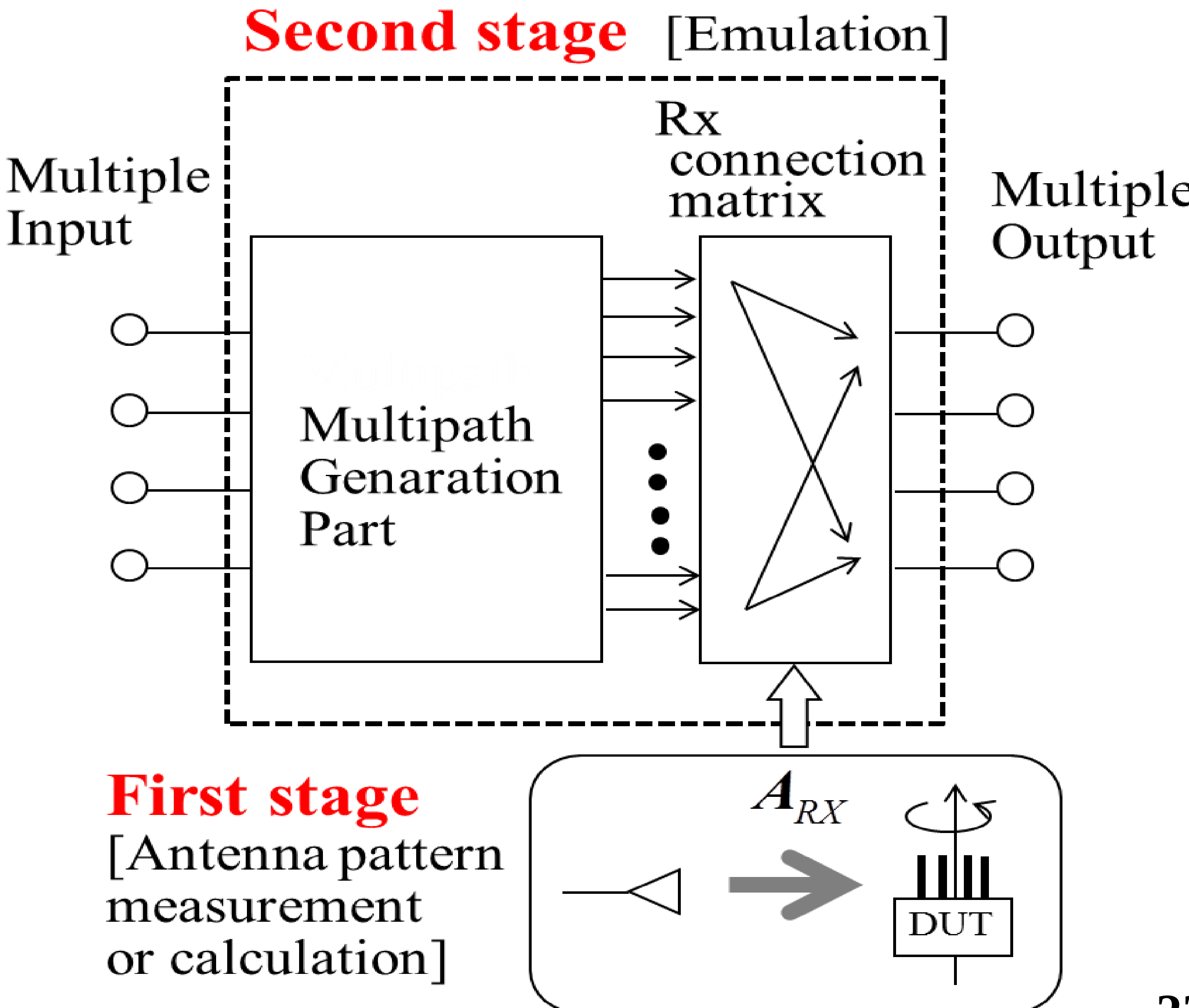
When the chamber space is not sufficiently large to arrange the probe antennas in the chamber, and if the range in one direction is enough, then ….



Two-Stage Scheme

MIMO Fading Emulator



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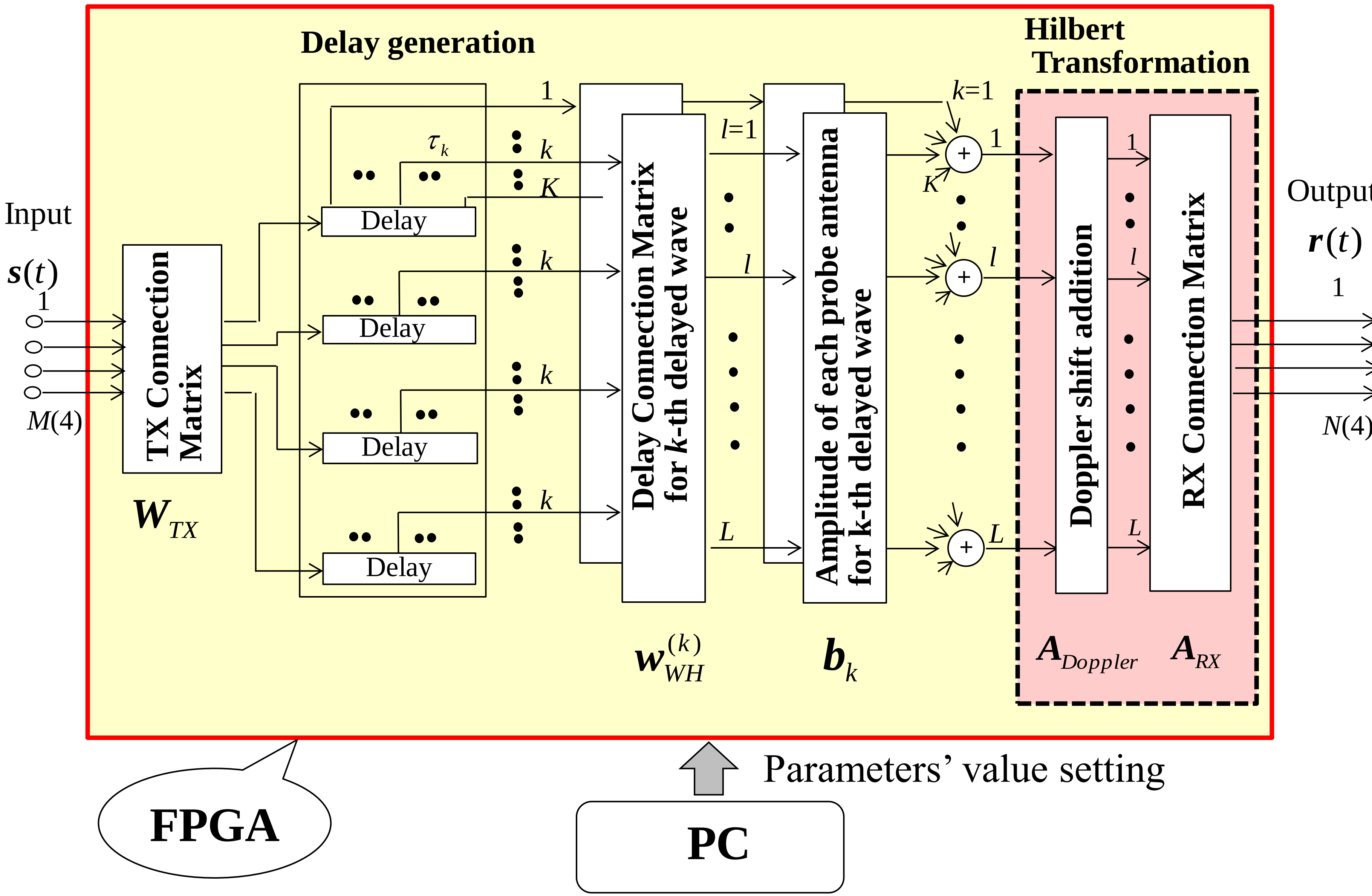
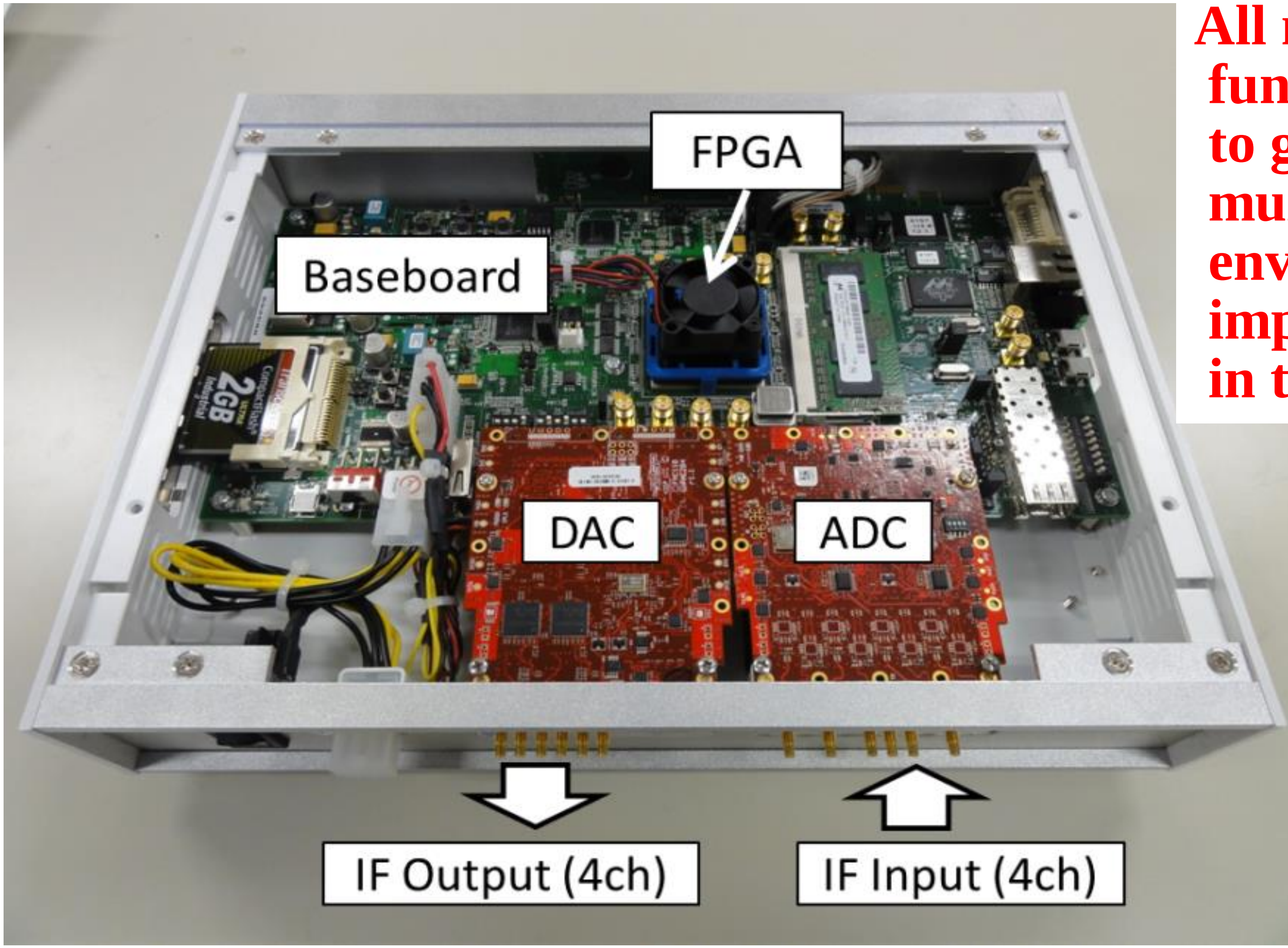
Specification and Performance of Developed System based on Two-Stage Scheme

FPGA IC	XILINX Virtex 6 LX240T
Baseboard	XILINX ML605
Input/Output	
ADC	4DSP FMC104 (14bit)
DAC	4DSP FMC204 (16bit)
Input ports M	4
Output ports N	4
Signal processing	
Clock frequency f_s	160MHz
IF frequency	40MHz
Bandwidth	40MHz (max)
Propagation parameters	
Probe antennas L	16 or 32
Delay paths K	8
Maximum delay	50μs (*for* $k=1\text{-}6$), 200μs ($k=7,8$)
Delay resolution	6.25ns (when f_s =160MHz)
Doppler frequency	up to10kHz

FPGA Implementation of 4x4 MIMO Fading Emulator



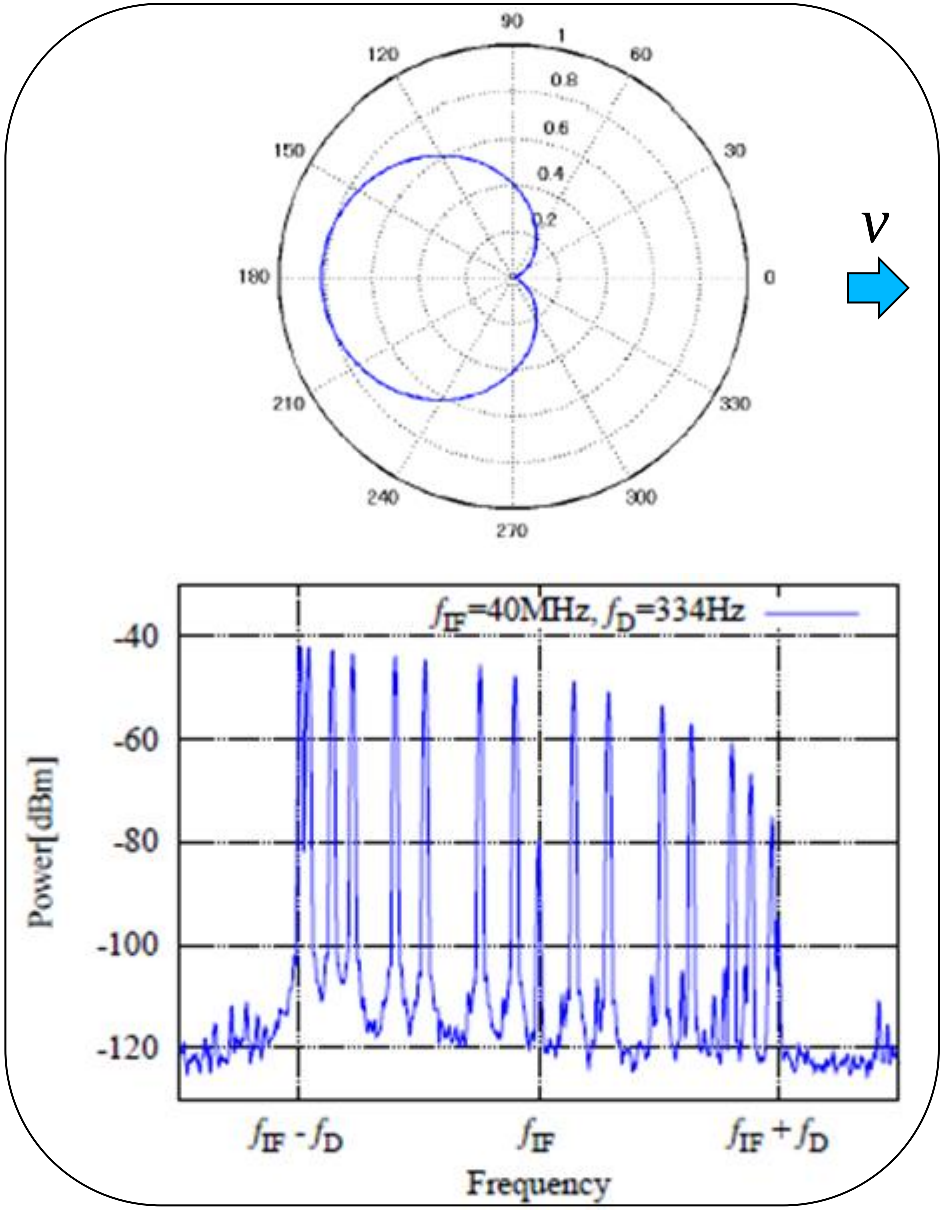
Developed MIMO Fading Emulator with FPGA Implementation

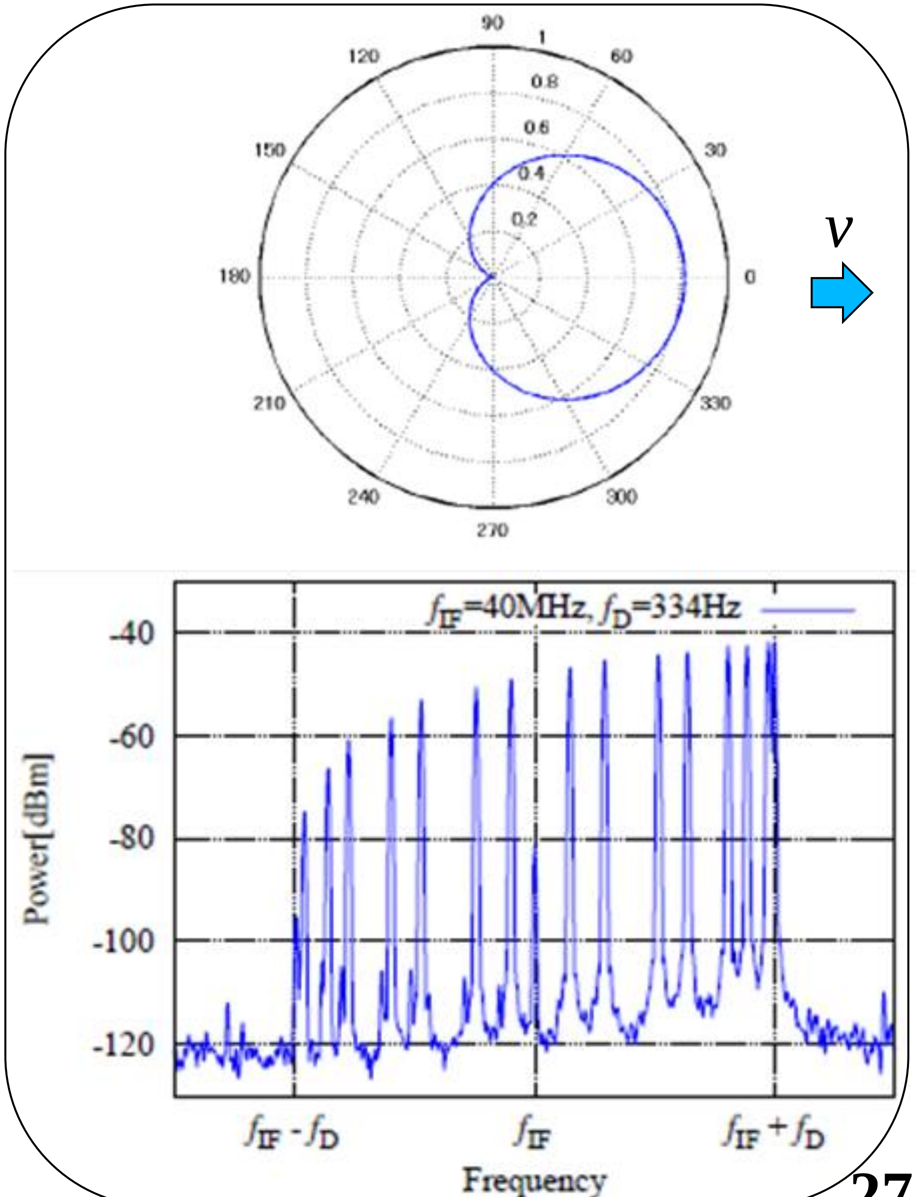


All necessary functions to generate multipath environment is implemented in this small box.

(Size: 28cm × 22cm × 5cm)

Element pattern pattern and corresponding Doppler spectrum





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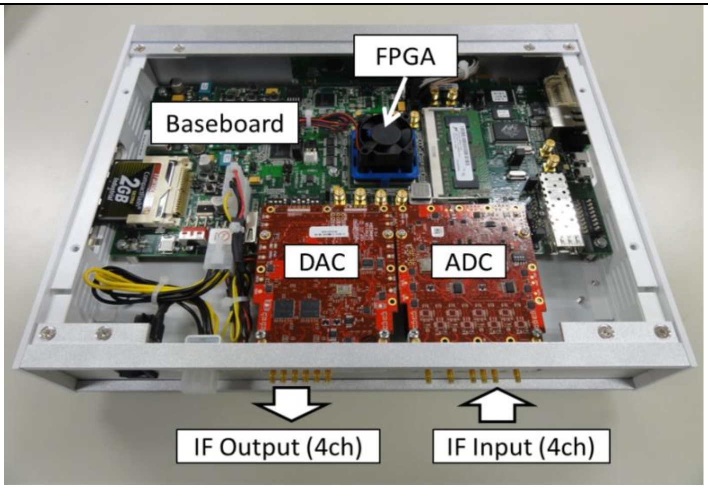
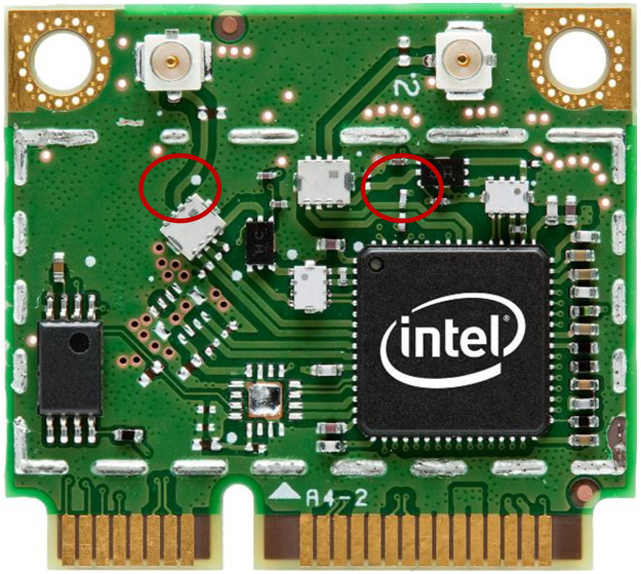
Application Example 1: WLAN (IEEE 802.11n) Throughput Evaluation



AP

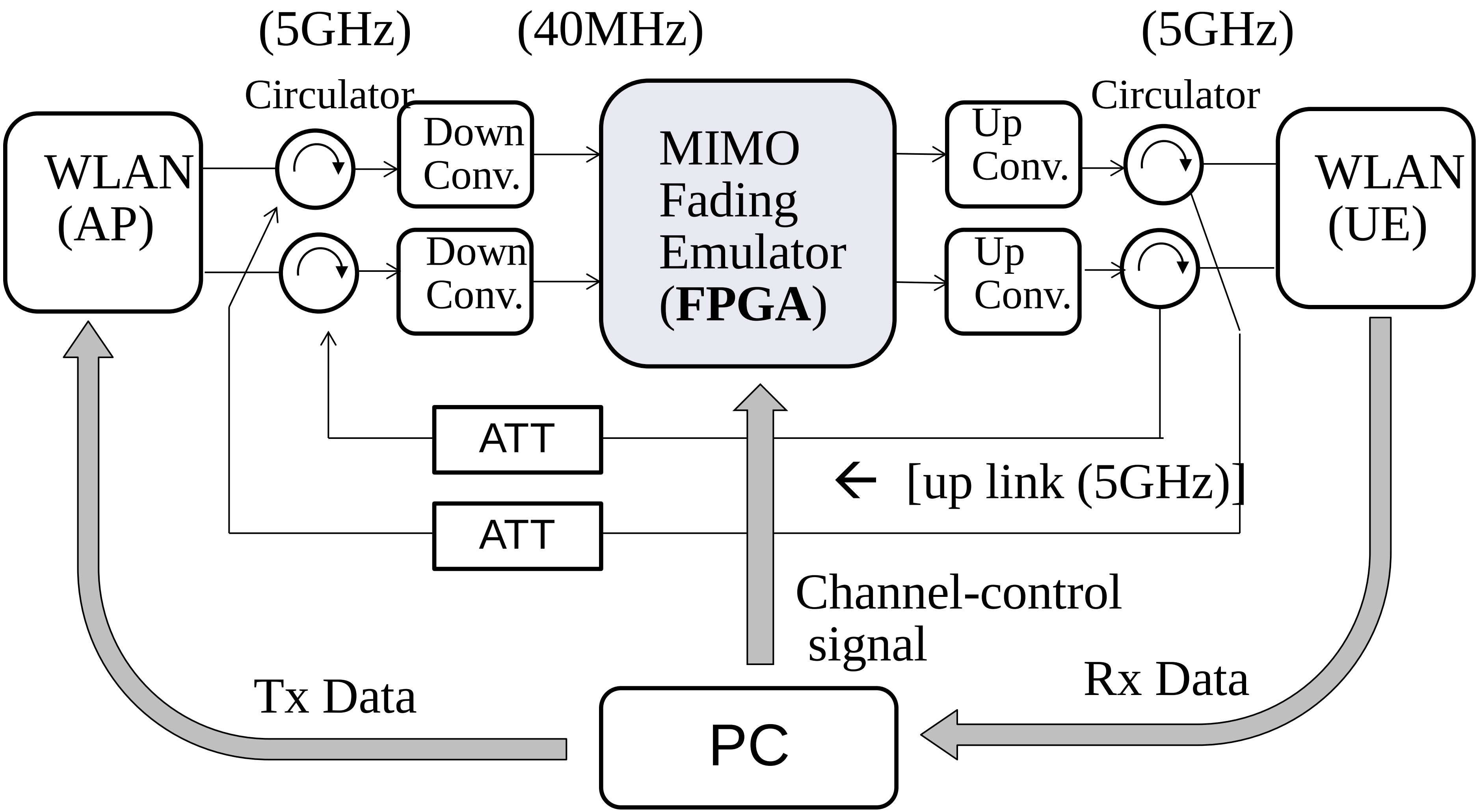
UE/UT



WZR-AMPG300NH

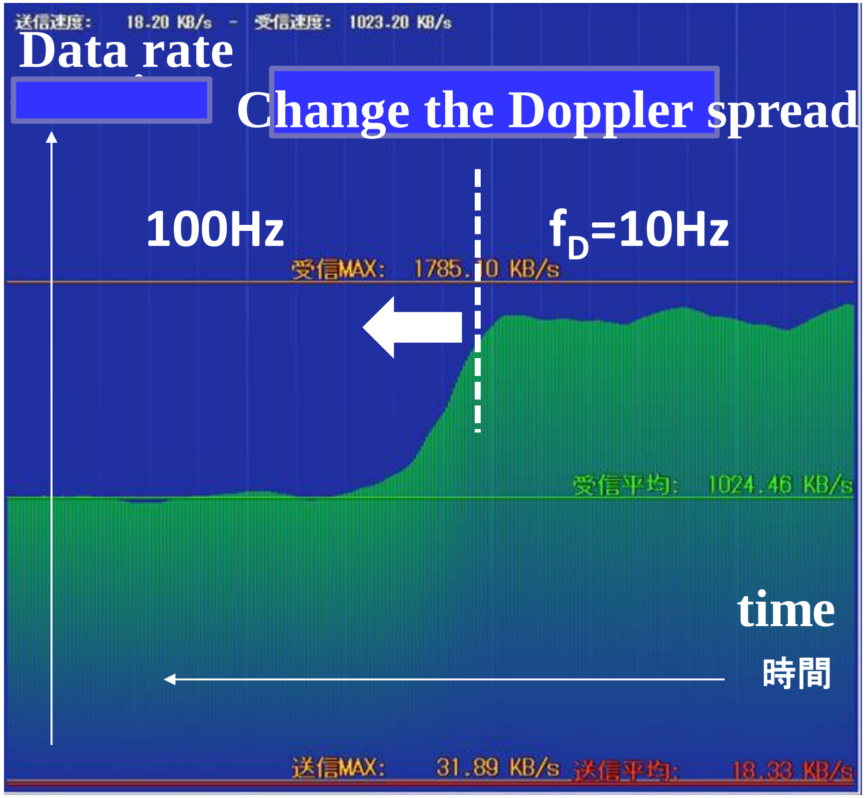
Intel Centrino Advanced-n 6200

Application Example 1: WLAN (IEEE 802.11n) Throughput Evaluation

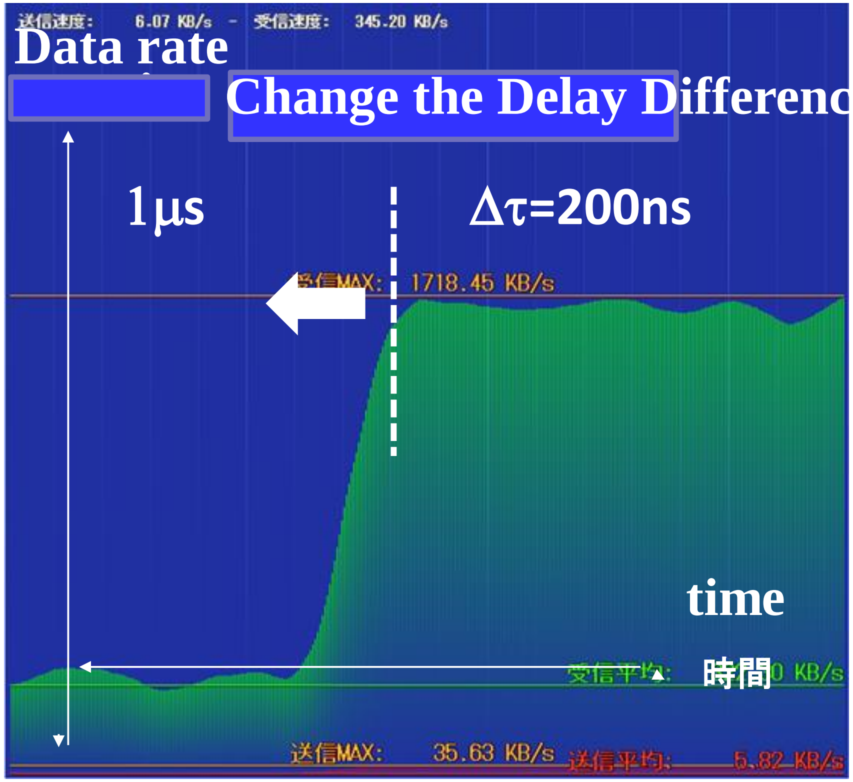


AP: BUFFALO WZR-AMPG300NH
UE: Intel Centrino Advanced-N 6200

Evaluation Examples

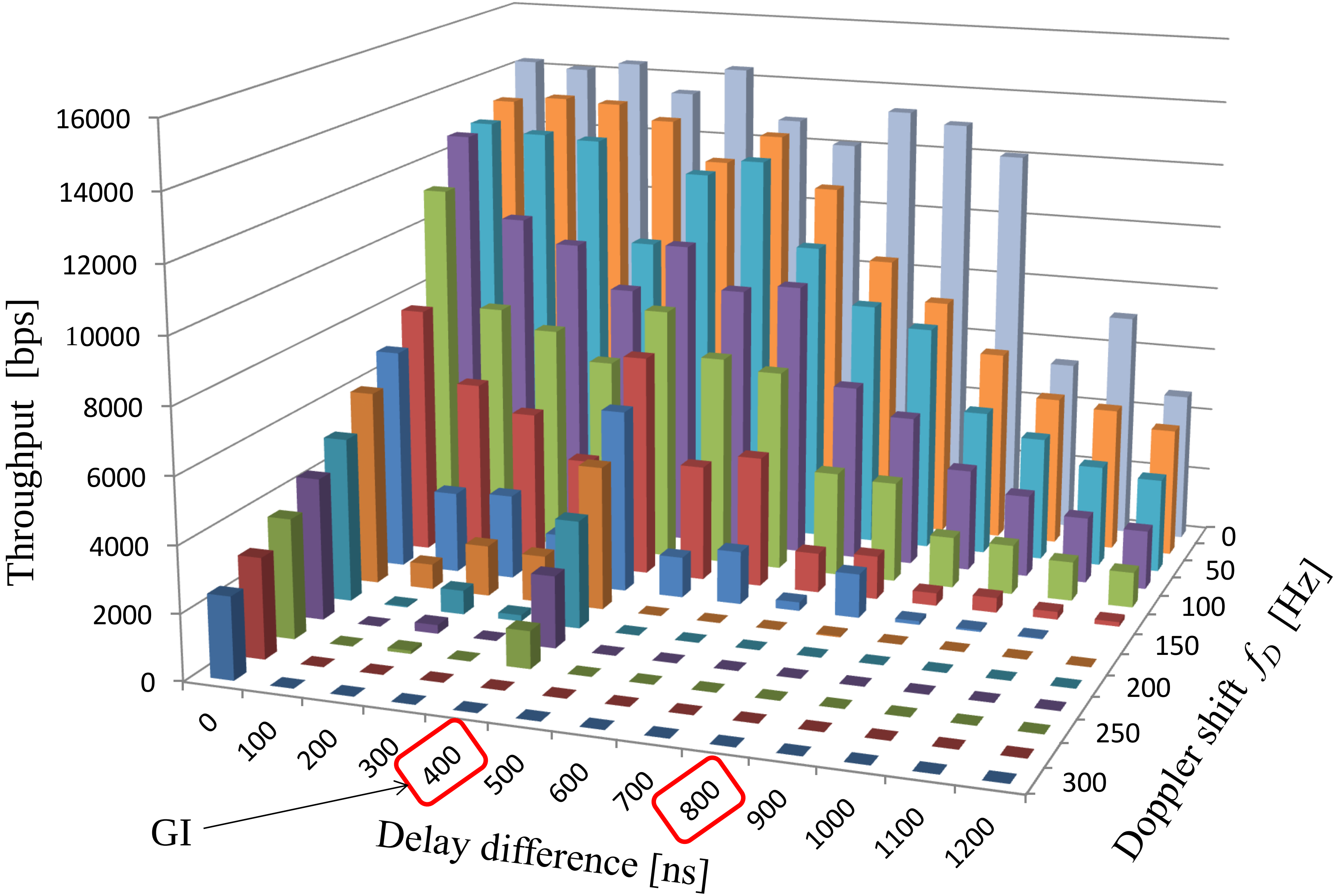


Change of Doppler spread

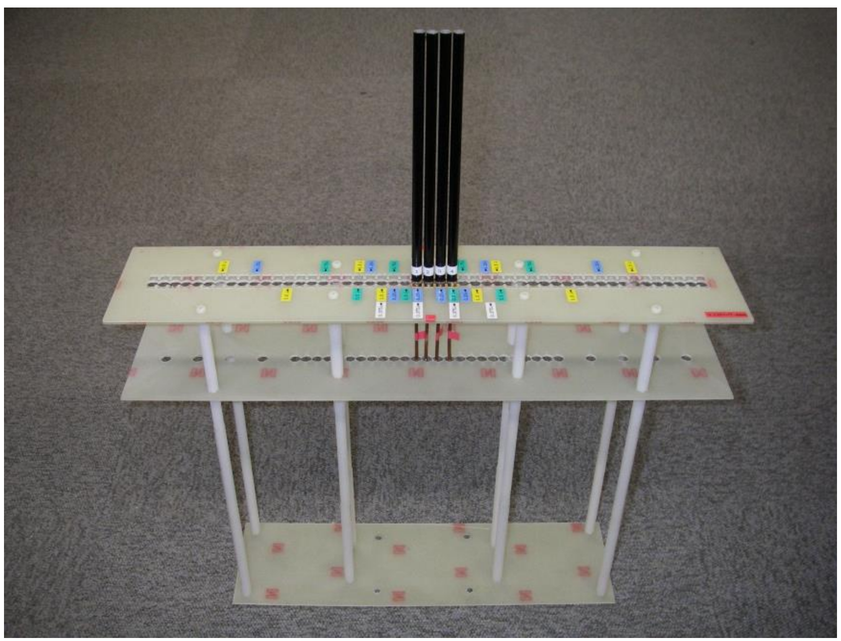


Change of delay difference

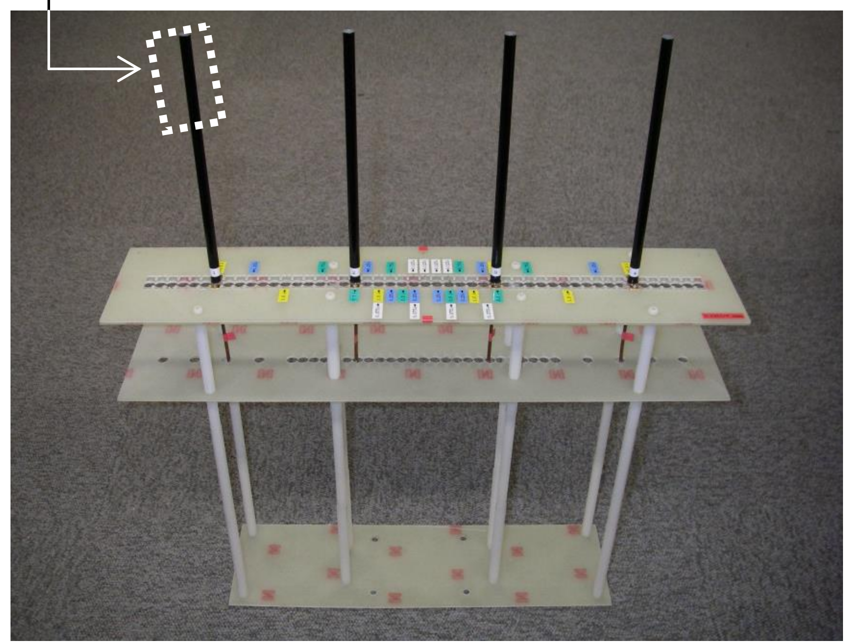
Evaluation example in Rayleigh fading environment



Application 2: Channel Capacity Evaluation in the case of Antenna Coupling and Spatial Correlation

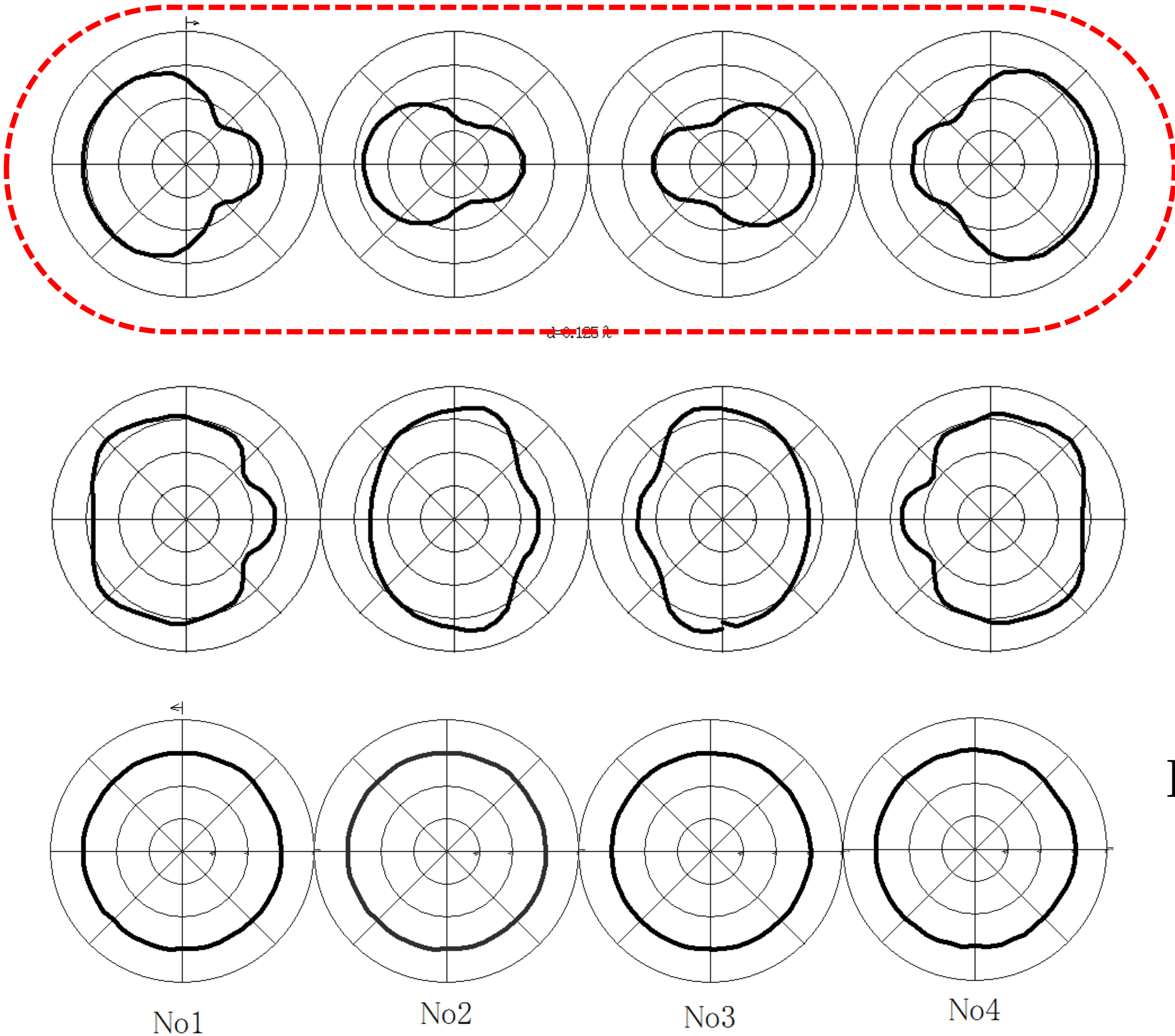


(a) $d_r = (1/8)\,\lambda$



(b) $d_r = (3/2)\,\lambda$

Element Antenna Pattern for N=4

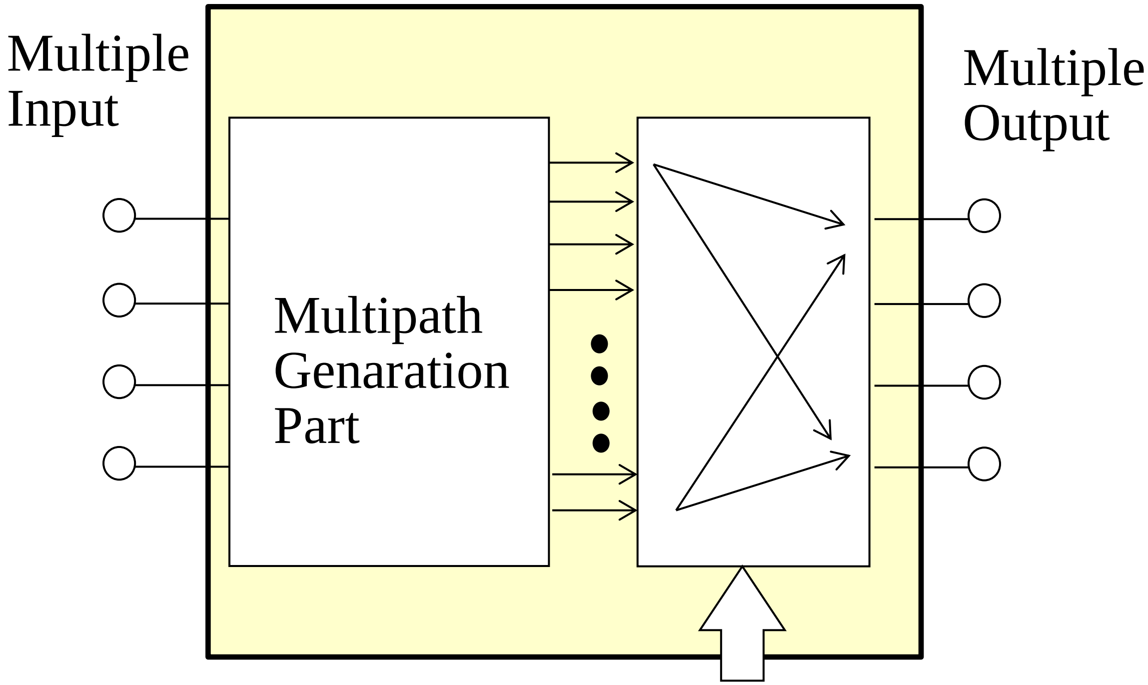


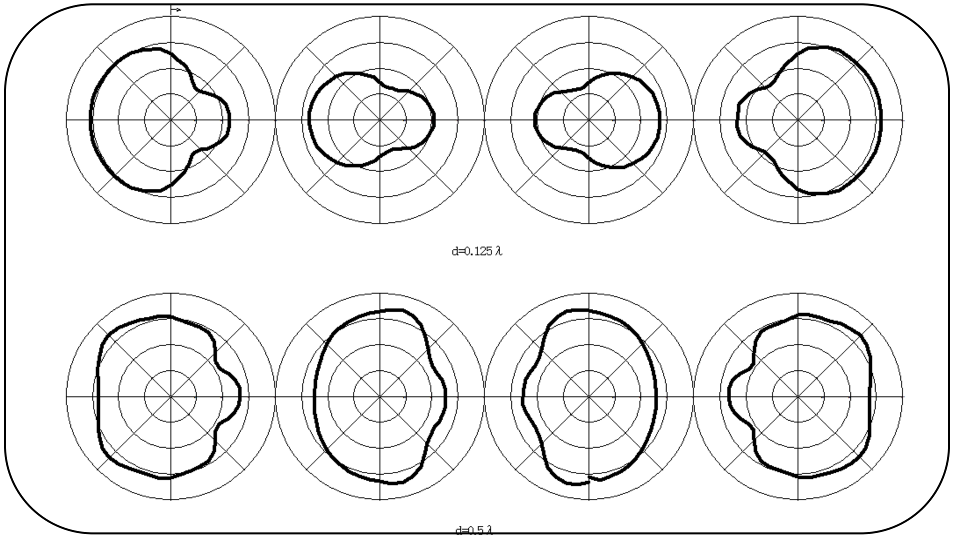
$d=(1/8)\,\lambda$

$d=(1/2)\,\lambda$

Each element pattern without coupling

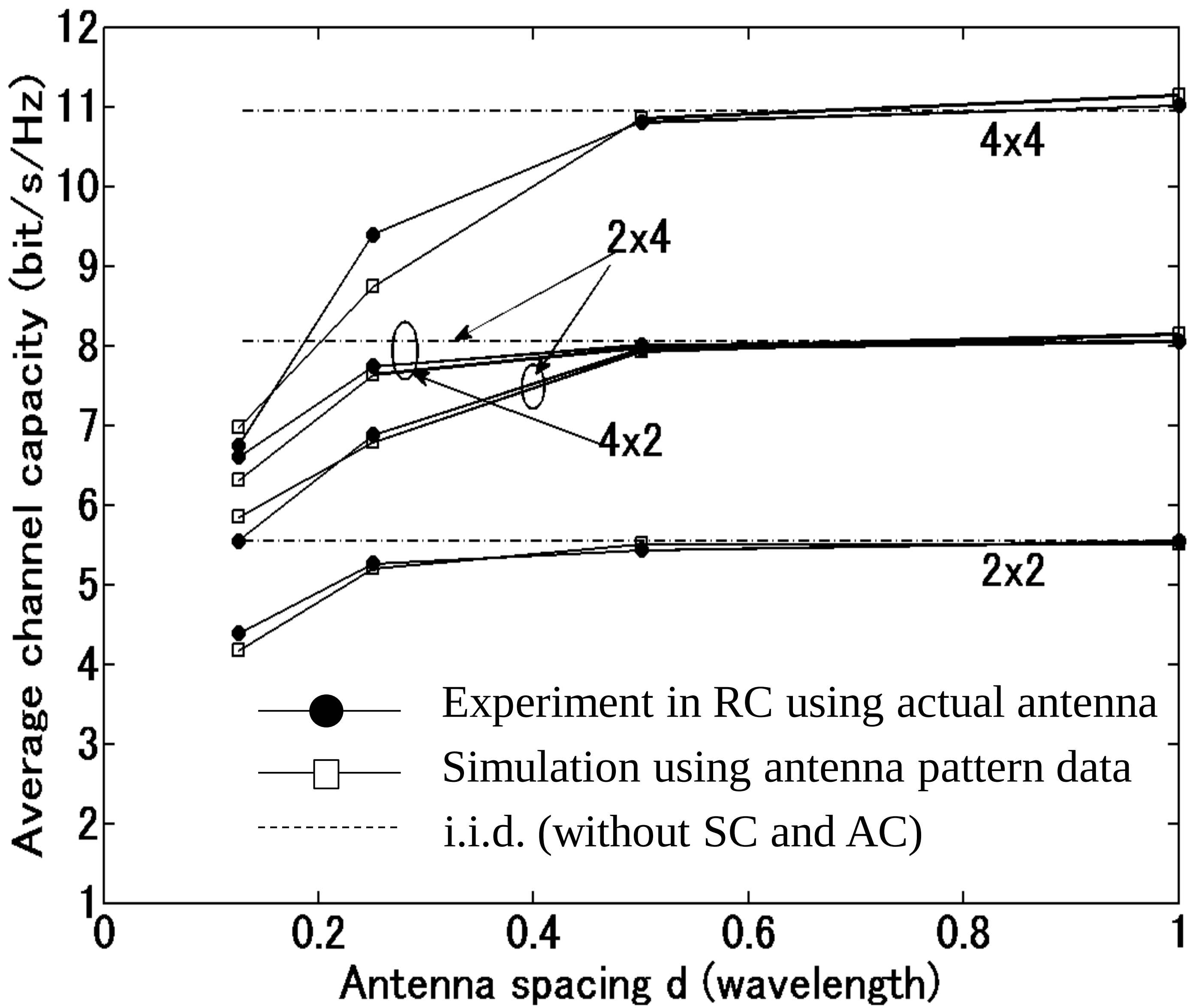
Developed MIMO Fading Emulator





Measured Antenna Pattern data

MIMO Channel Capacity Decrease due to Antenna Coupling



Conclusions

- We discussed a propagation channel model for OTA test systems.
- One of the primary practical advantages of the proposed scheme is the realization of a flexible MIMO OTA testing system in a very simplified configuration without the loss of necessary functions.
- Due to the way that the fading functions are configured in a cascade, an implementation of the scheme into FPGA circuit is promising from a practical viewpoint.
- We showed detailed performance of the FPGA-implemented fading emulator and a couple of applications of the system to wireless communication performance evaluations.

What I want to say is

MIMO Fading Emulator/Simulator
having all necessary propagation functions
can be realized easily without expensive cost.

Thank you very much for your kind attention!!