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A Design of Pixel-based Reconfigurable Antenna for Fluid Antenna System

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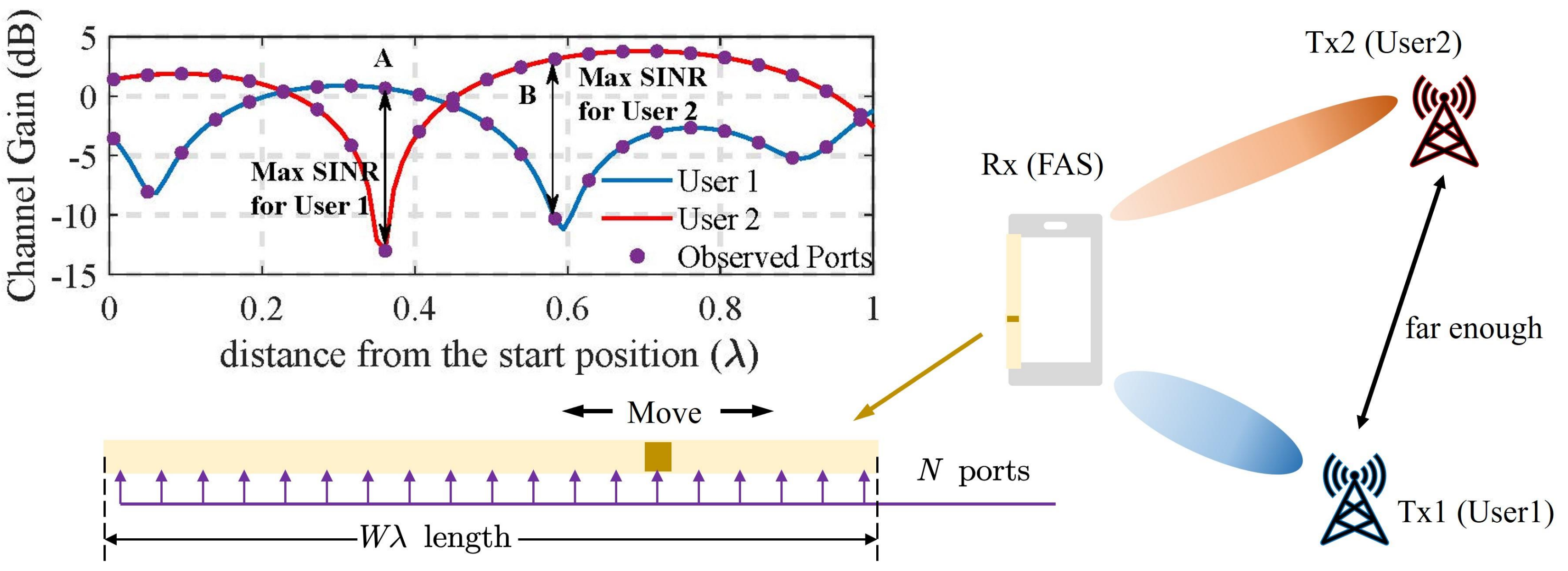
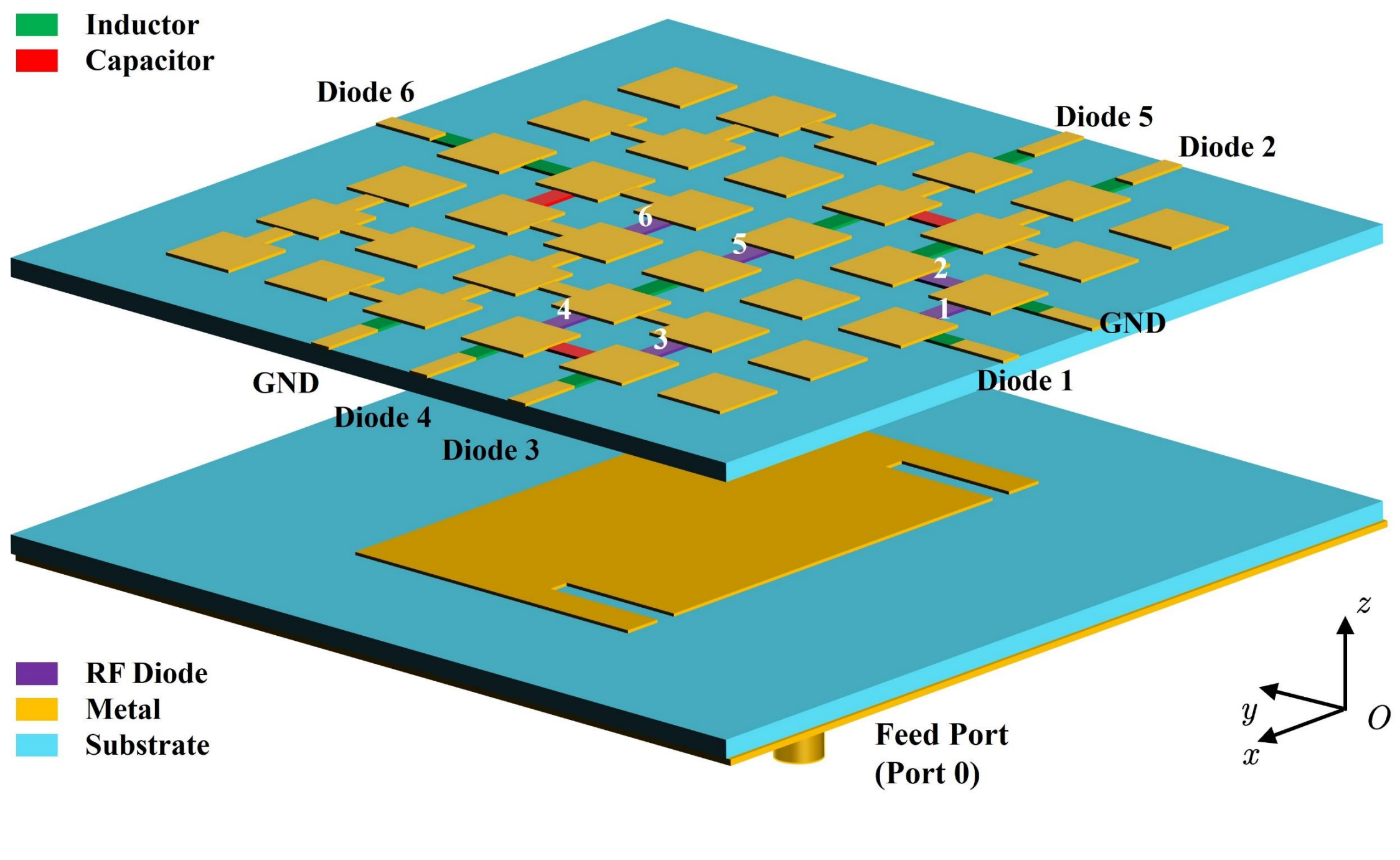
Abstract and Background



- Fluid Antenna Systems (FASs) have emerged as a promising solution to enhance wireless communication performance, offering flexible adaptation to wireless channels and utilizing spatial fading envelopes for diversity and capacity benefits.
- Past reported FAS antennas: mechanical movement or liquid-based
  → Antenna's reconfiguration speed is **not** fast enough.

Traditional position-flexible FAS antennas can be equivalent to **"fluid" pattern antennas**. A **pixel-based reconfigurable antenna (PRA-FAS)** equivalent to traditional FAS antenna with **W = 0.5, N = 12** is proposed, accelerating the switching speed to **microseconds**.

Proposed PRA-FAS



- **Parameters:**

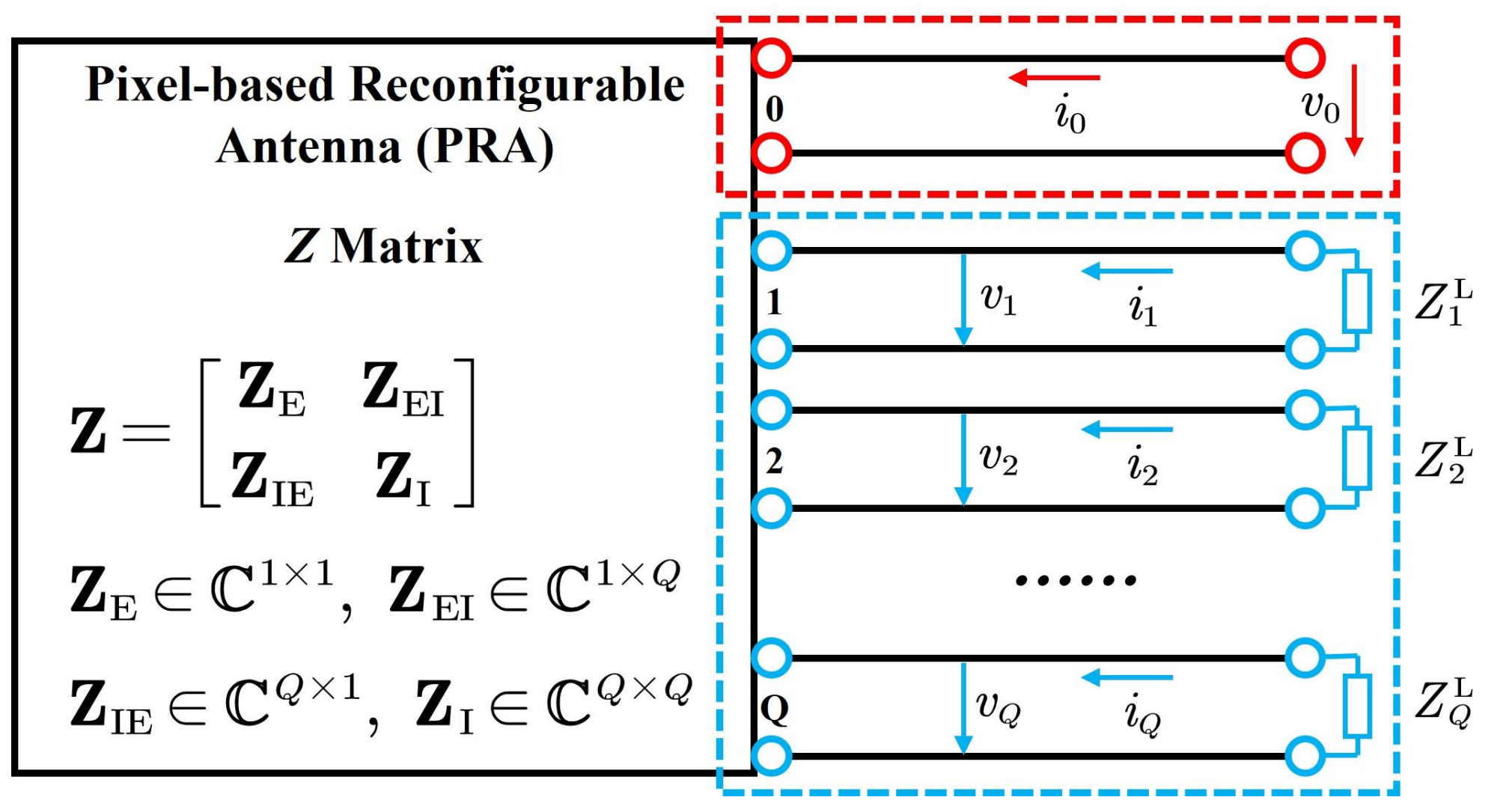
  Pixel ports: Q = 60,
  RF switches: P = 6,
  Reconfigurable states: N = 12

- **Upper Pixel:**

  Controlled by diodes
  → Reconfigurability.

Adjacent states (ports) have ***similar*** patterns, as well as ***high correlation***. Non-adjacent states' patterns are ***uncorrelated***.

Design Methodology



Pixel-based Reconfigurable Antenna (PRA)

Z Matrix

$$\mathbf{Z}=\begin{bmatrix}\mathbf{Z}_{\mathrm{E}} & \mathbf{Z}_{\mathrm{EI}}\\ \mathbf{Z}_{\mathrm{IE}} & \mathbf{Z}_{\mathrm{I}}\end{bmatrix}$$

$$\mathbf{Z}_{\mathrm{E}}\in\mathbb{C}^{1\times1},\ \mathbf{Z}_{\mathrm{EI}}\in\mathbb{C}^{1\times Q}$$

$$\mathbf{Z}_{\mathrm{IE}}\in\mathbb{C}^{Q\times1},\ \mathbf{Z}_{\mathrm{I}}\in\mathbb{C}^{Q\times Q}$$

Open-circuit Patterns:

$$\mathbf{E}_{\mathrm{oc}}=[\mathbf{e}_0^{\mathrm{oc}},\mathbf{e}_1^{\mathrm{oc}},\mathbf{e}_2^{\mathrm{oc}},\cdots,\mathbf{e}_Q^{\mathrm{oc}}]$$

$$\mathbf{K}_{\mathbf{oc}}=\mathbf{E}_{\mathrm{oc}}^{\mathrm{H}}\mathbf{S}\mathbf{E}_{\mathrm{oc}}$$

Radiation Pattern:

$$\mathbf{e}_n=\sum_{i=0}^{Q}[\mathbf{i}_n]\mathbf{e}_i^{\mathrm{oc}}=\mathbf{E}_{\mathrm{oc}}\mathbf{i}_n$$

Input Impedance:

$$Z_{\mathrm{in}}=\mathbf{Z}_{\mathbf{E}}-\mathbf{Z}_{\mathbf{EI}}[\mathbf{Z}_{\mathbf{I}}+\mathbf{Z}^{\mathbf{L}}]^{-1}\mathbf{Z}_{\mathbf{IE}}$$

Step 1: IMPM (Internal multi-port method)

- Select random **pixel connections** & **switch positions**.
- Calculate the input impedances of all 2^P FAS states, among which M are matched.
- If $M\geqslant N$, run to the next step; or repeat.

Step 2: PCDM (Pattern correlation decomposition method)

- Pattern covariance matrix $\boldsymbol{\varrho}$: calculated by $\mathbf{e}_n\ \ (n=1,2\cdots N)$
- Simplify calculation by PCDM

$$\boldsymbol{\varrho}=\mathbf{C}\oslash\mathbf{G}\quad\rightarrow\quad\mathbf{C}=\mathbf{I}^{\mathrm{H}}\mathbf{K}_{\mathrm{oc}}\mathbf{I},\ \ [\mathbf{G}]_{i,j}=\sqrt{[\mathbf{C}]_{i,i}[\mathbf{C}]_{j,j}}$$

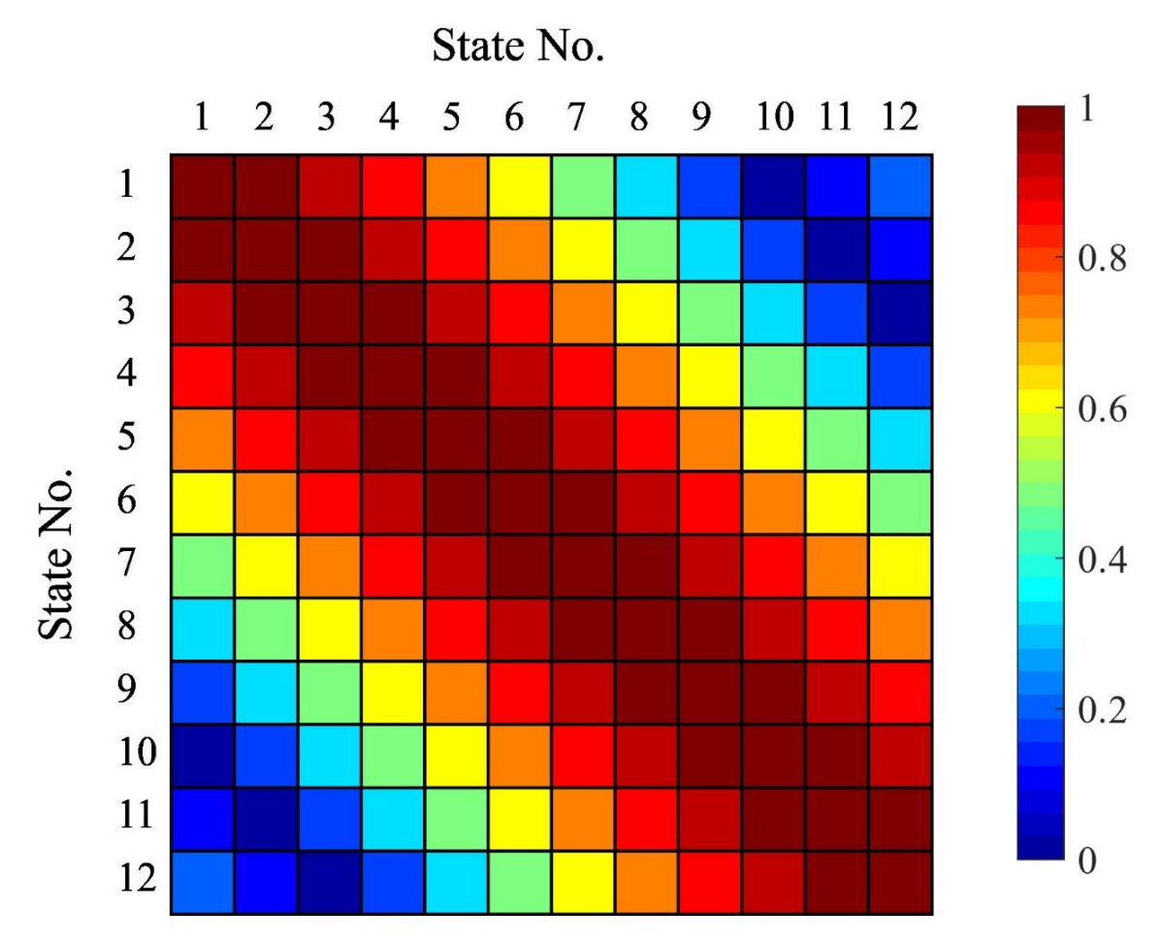
Optimization:

- Target: $\boldsymbol{\varrho}^*$, Ideal covariance matrix of FAS with W = 0.5 and N = 12.
  Each column & row: **standard Bessel function**.

$$[\boldsymbol{\varrho}^*]_{i,j}=J_0\left(\frac{2\pi|i-i|W}{N-1}\right)$$

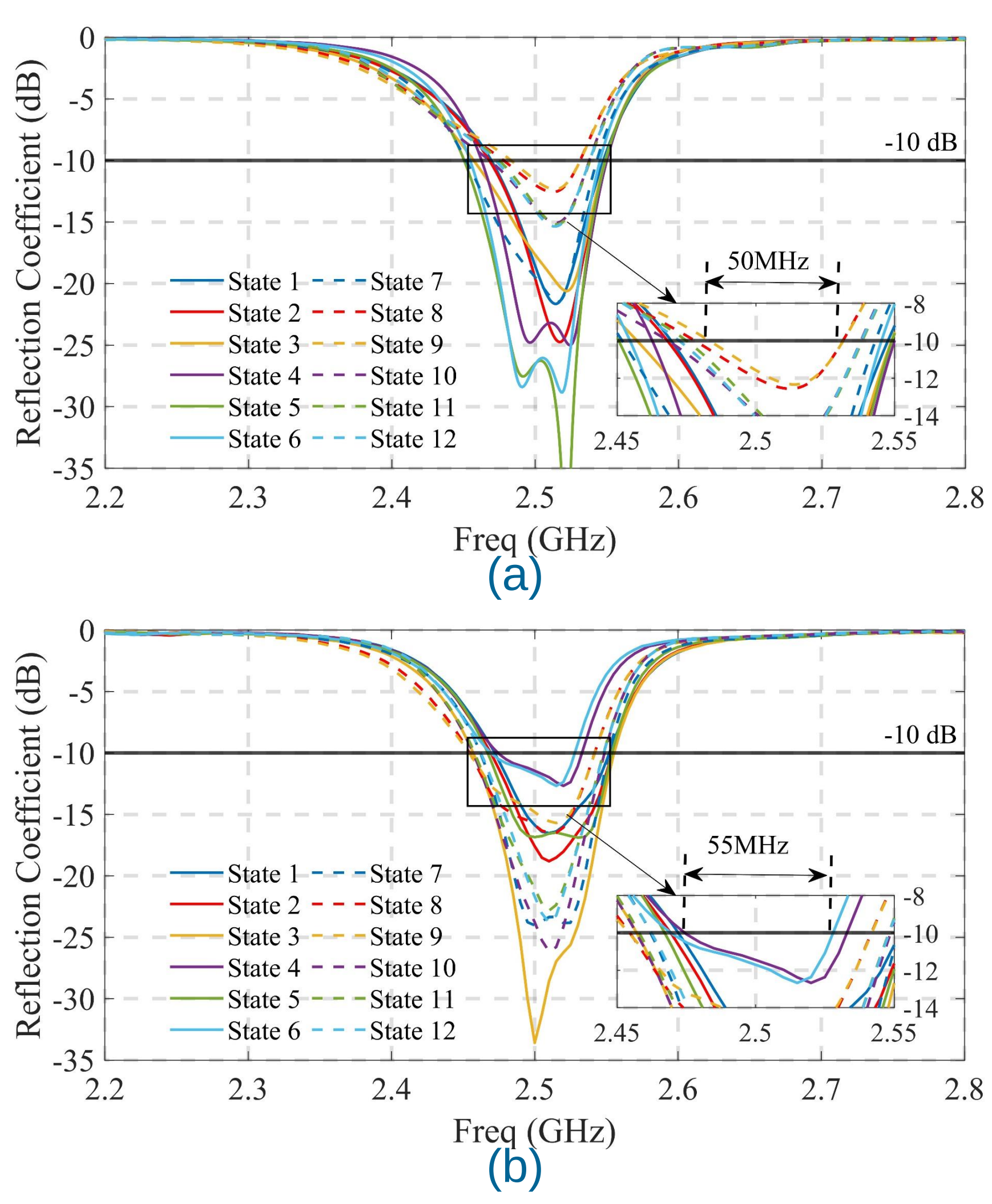
- Variable: $\mathbf{D}$ → the order of M matched states.
- Optimize: minimal average relative error: $\delta_{\mathrm{e}}(\mathbf{D})$

$$\delta_{\mathrm{e}}(\mathbf{D})=\frac{\Delta(\mathbf{D})}{N^2}=\frac{\sum_{n=1}^{N}\sum_{n'=1}^{N}\left||[\boldsymbol{\varrho}(\mathbf{D})]_{n,n'}|-|[\boldsymbol{\varrho}^*]_{n,n'}|\right|}{N^2}$$



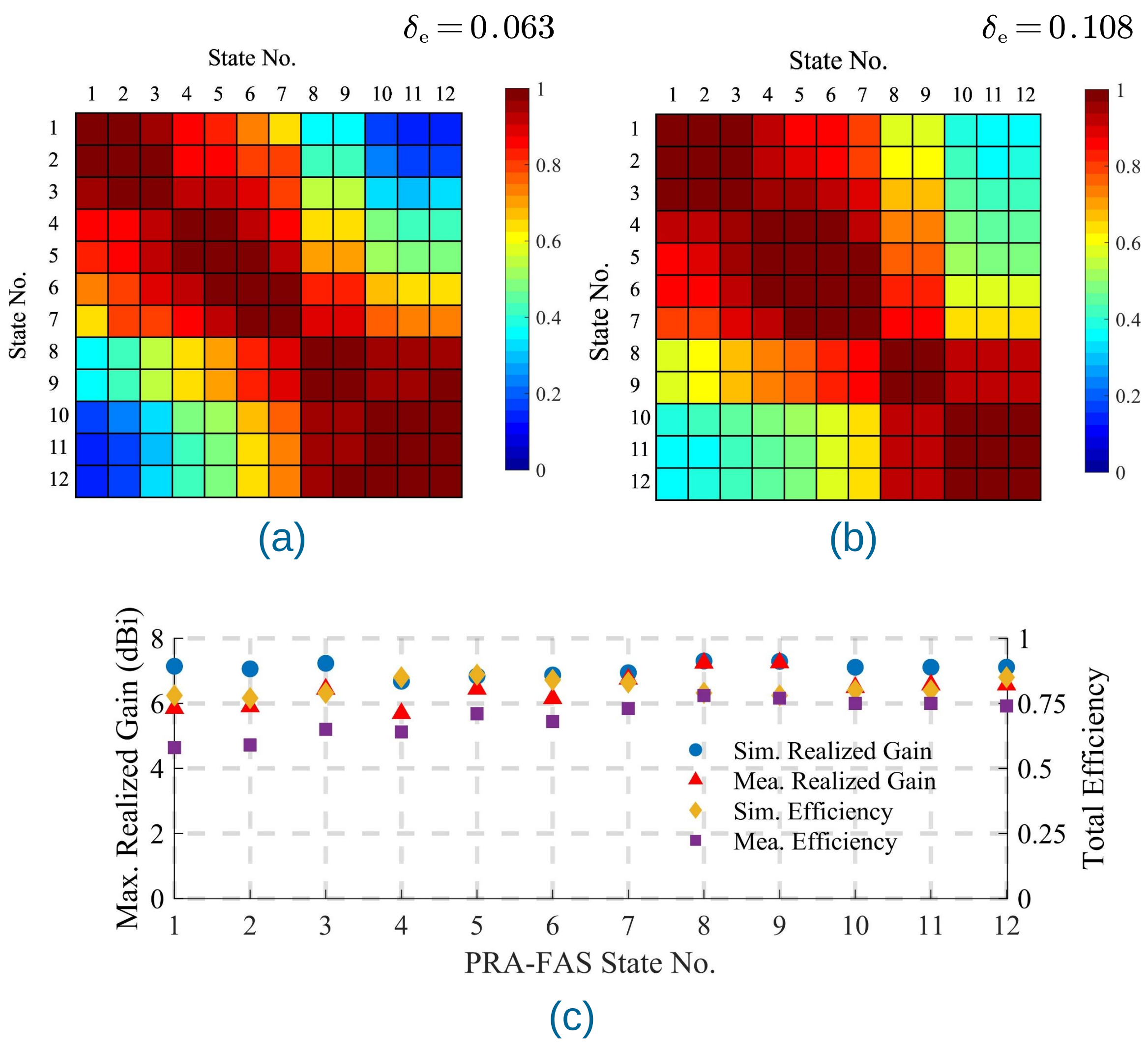
Ideal covariance matrix of FAS with W = 0.5 and N = 12.

Simulation and Experimental Results



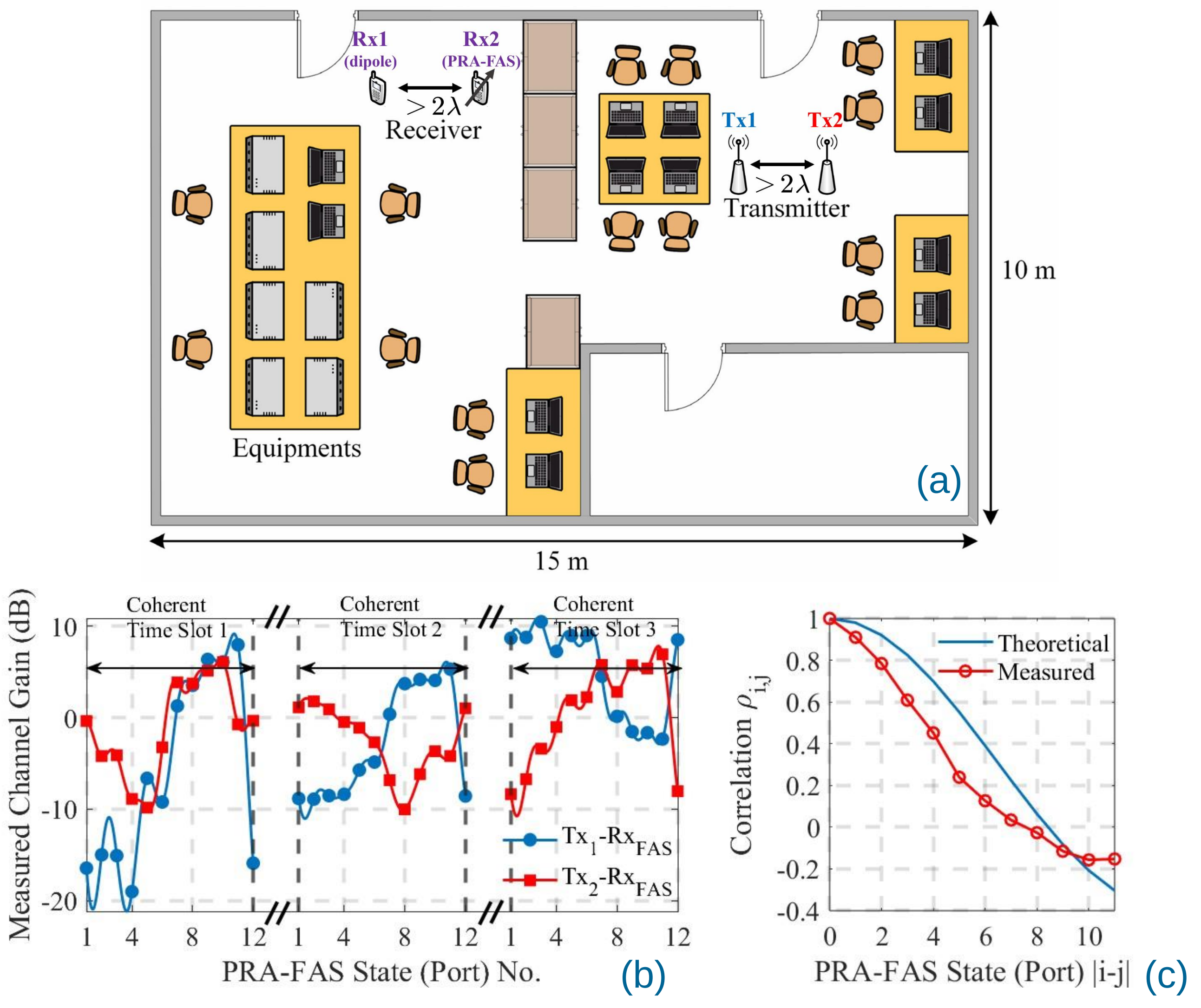
S-Parameters

(a) Simulated and (b) measured reflection coefficients (S11) of all 12 reconfigurable states of the proposed PRA-FAS. All the 12 states match well within the desired operating bandwidth.



Far-field Test

(a) Simulated and (b) measured covariance matrices of far-field patterns for N = 12 states of the proposed PRA-FAS with W = 0.5. Compared with the ideal covariance matrix, the average relative error is acceptable. (c) Simulated, measured maximum realized gain (all > 6.6 dBi) and the total efficiency (all > 80%) of all 12 states at 2.5 GHz, sufficient for application.



FAS Test in a Rich Scattering Environment

(a) Testing environment (2×2 MIMO channels, one of the Rxs is PRA-FAS) with rich scatterings, blocking the LOS. (b) Two FAS channels of the 12 PRA-FAS states (ports) for three different stationary channels, where the diversity for multi-users is obvious. (c) Measured port correlation of the PRA-FAS, close to the theoretical correlation, i.e., a standard Bessel curve, indicating the effectiveness of our design.

Related Publication

J. Zhang, J. Rao, Z. Ming, Z. Li, C. Chiu, K. Wong, K. Tong, R. Murch, "A pixel-based reconfigurable antenna design for fluid antenna systems," ***arXiv preprint***, arXiv:2406.05499, Jun. 2024.

arXiv

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