Gu LIU, Jiajiang SHEN, Lei MA, Wei QIN, Wenwen YANG, Lei GUO, Jianxin CHEN, 2025. Port and radiation pattern decoupled metasurface-loaded patch antenna using deep-learning-assisted optimization for MIMO applications. *Frontiers of Information Technology & Electronic Engineering*, 26(10):2030-2040. https://doi.org/10.1631/FITEE.2500119

Port and radiation pattern decoupled metasurface-loaded patch antenna using deep-learning-assisted optimization for MIMO applications

Key words: Artificial neural network (ANN); Particle swarm optimization (PSO) algorithm; Mutual coupling; Radiation pattern restoration; Metasurface

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Motivation

1. Given the current decoupling technologies based on metasurfaces, it is still challenging to realize port decoupling and radiation pattern decoupling simultaneously.
2. For decoupling technologies based on metasurfaces, up to now, the decoupling performance enhancement still suffers from the complex numerical calculations.
3. For antenna decoupling applications, port decoupling and radiation pattern decoupling require a significant amount of simulation investment. In addition, the design of metasurfaces lacks design direction.

Main idea

1. With a deep-learning-assisted optimization method, the port and radiation pattern decoupling can be realized with high efficiency.

2. By modeling the metasurface by pixel, the proposed antenna has multiple implementation paths.

3. Compared with the conventional metasurface-loaded patch antenna, the proposed antenna can achieve port and radiation pattern decoupling simultaneously. Moreover, it can realize large mutual coupling level reduction.

Antenna structure

1. The proposed antenna is composed of two-layer PCB (radiated patch and metasurface). In addition, the metasurface includes 18 periodic unit cells and each unit cell is composed of 64 pixel patches.

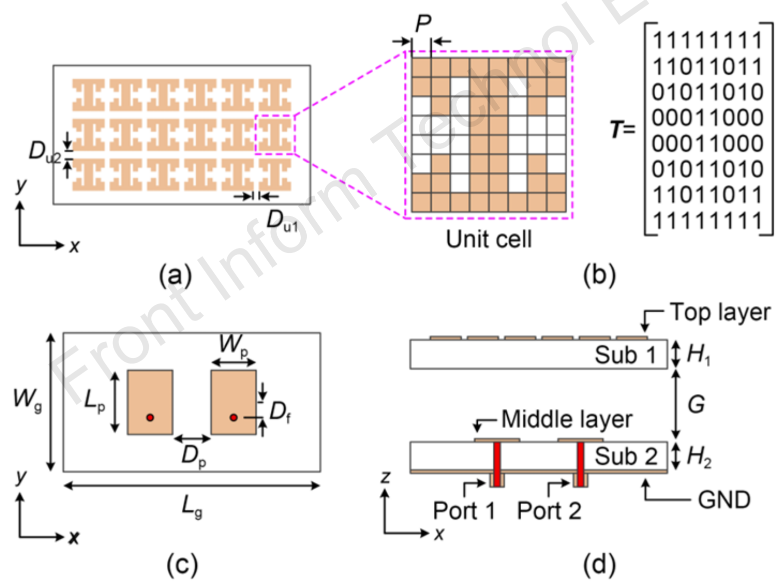


Fig. 1 Configuration of the proposed metasurface-loaded decoupled patch antenna: (a) top layer; (b) enlarged view of the unit cell; (c) middle layer; (d) side view. L_g=90, W_g=50, L_p=19.2, W_p=18, D_p=3, D_f=4, D_{u1}=1, D_{u2}=2, P=1, G=10, H_1=1.57, and H_2=0.787 (unit: mm)

Decoupling mechanism

2. There are two main coupling paths between two elements of the metasurface-loaded patch antenna. Path 1 is the direct coupling between elements. Path 2 is the coupled wave reflected by the metasurface. When the magnitudes of the coupled wave by the above paths are the same and the phases are opposite, the port and radiation pattern decoupling can be realized simultaneously.

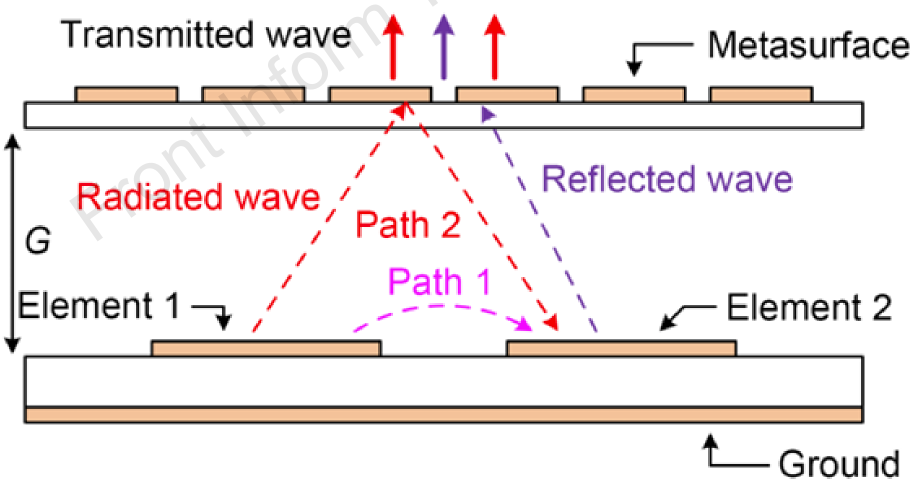


Fig. 2 Schematic diagram of coupling paths of a metasurface-loaded two-element patch antenna

Method

3. To avoid complex numerical calculations, a connection between antenna structure and antenna performance is established by a deep learning network.

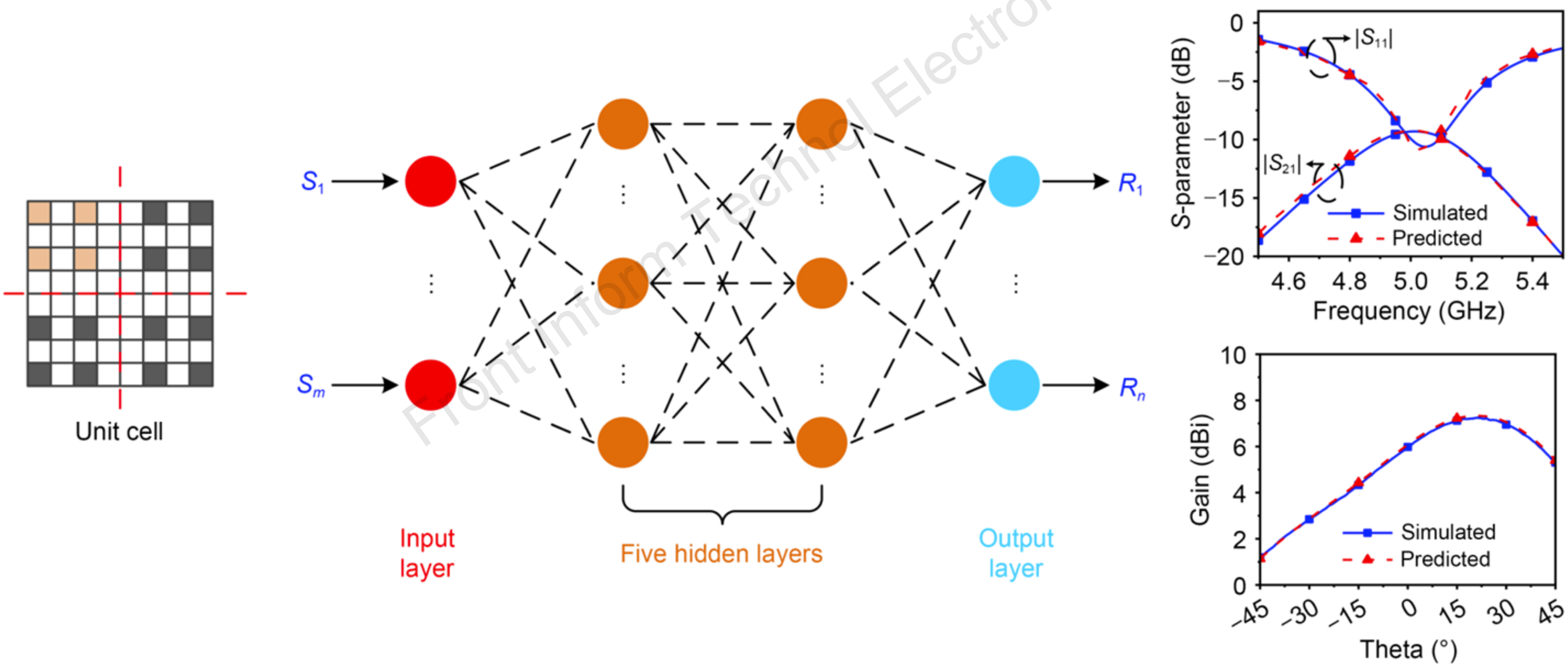


Fig. 3 Topology of an ANN with one input layer, five hidden layers, and one output layer

Method

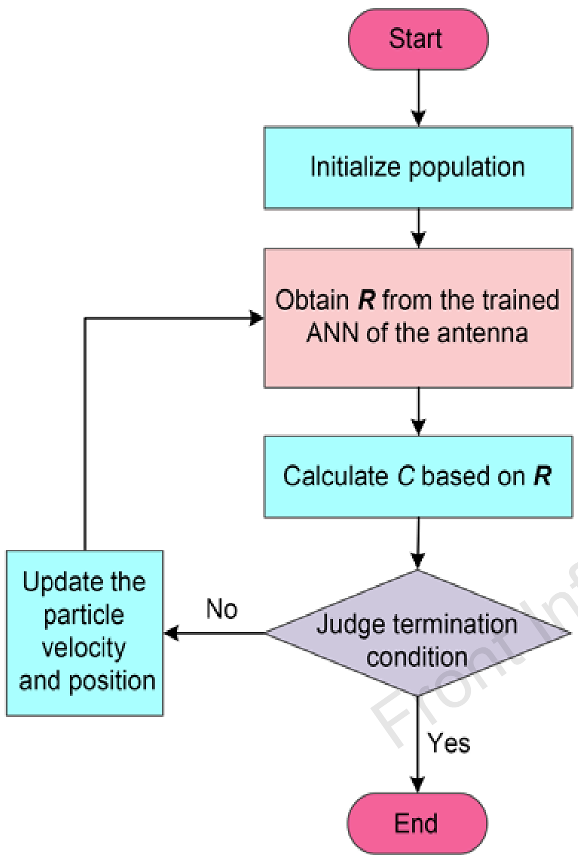


Fig. 7 PSO algorithm flowchart for optimization of the metasurface-loaded patch antenna

4. To search for the desired results, the PSO algorithm is used to combine the DNN constrained by the cost function (*C*).

$$C = w(s_{11} - m) + w(s_{21} - n) + (1 - 2w)\left(\sum_{k=0}^{45} \left|(s_{(k)} - s_{(-k)})\right|\right)$$

Major results

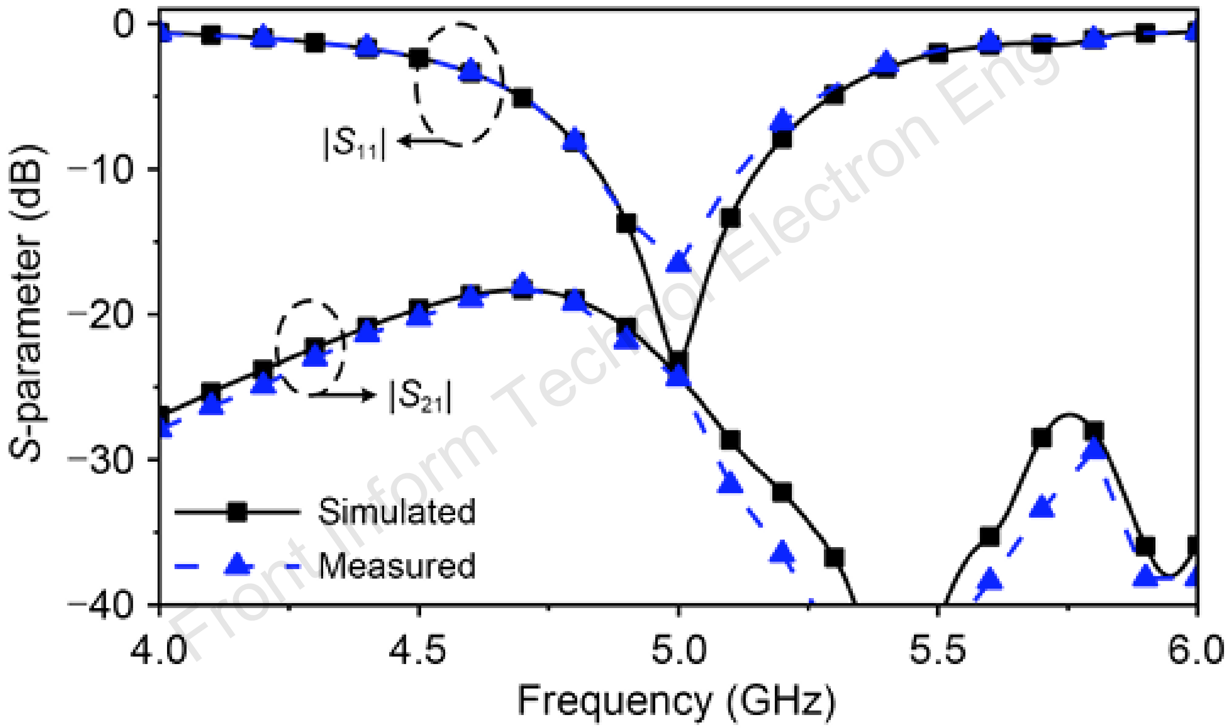


Fig. 14 Simulated and measured *S*-parameters of the proposed antenna

Major results

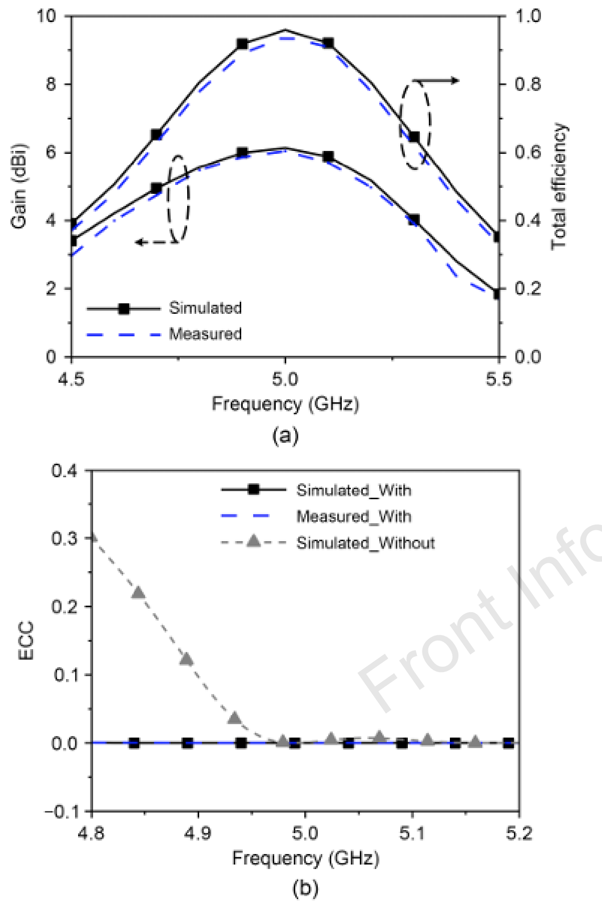


Fig. 15 Simulated and measured gain and total efficiency (a) and ECC (b) of the proposed patch antenna

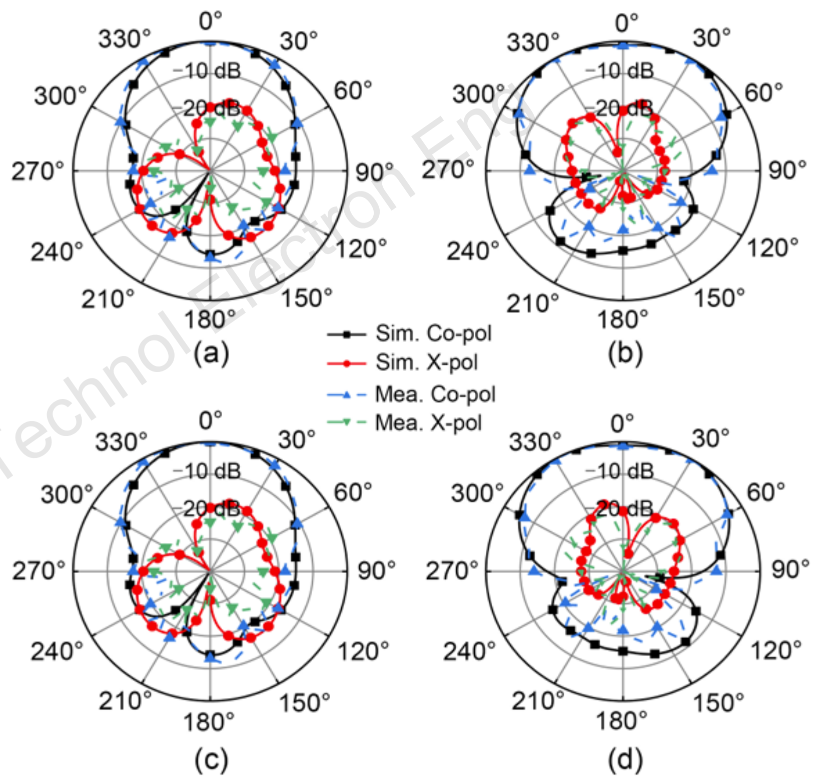


Fig. 16 Simulated and measured radiation patterns of the proposed antenna at 5 GHz for two ports: (a) E-plane of port 1; (b) H-plane of port 1; (c) E-plane of port 2; (d) H-plane of port 2

Major results

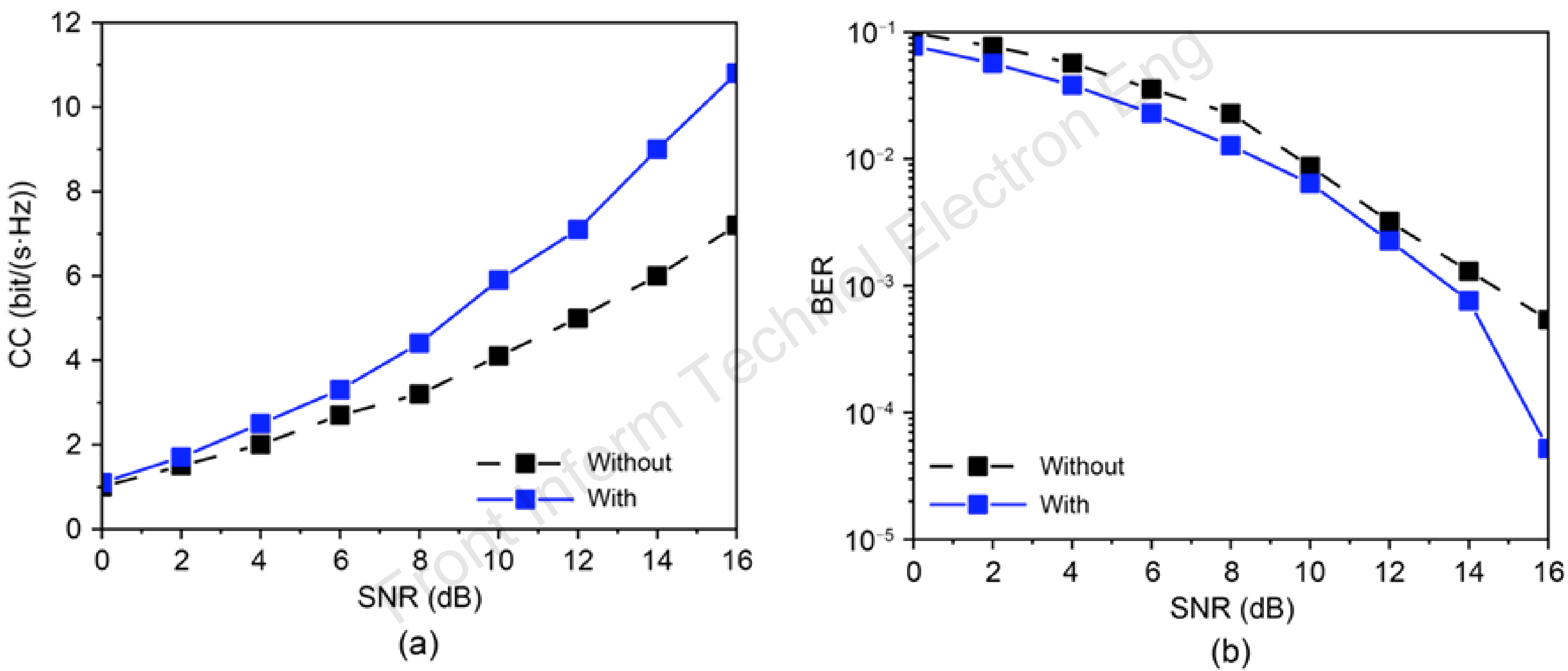


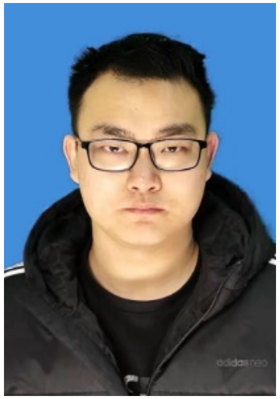
Fig. 17 Channel capacity (a) and bit error rate (b) for the proposed antenna before and after loading the metasurface at 5 GHz

Conclusions

1. With deep-learning-assisted optimization technology, a metasurface-loaded patch antenna realizing port and radiation pattern decoupling simultaneously has been proposed for MIMO applications.

2. With pixel structure, the metasurface with more freedom supported the port and radiation pattern decoupling simultaneously.

3. The proposed antenna showed great mutual coupling level reduction. The center-to-center space of elements was only $0.35\lambda_{0.}$



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