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Simultaneous wireless information and power transmission system based on a dual-frequency metasurface design

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Key words: Frequency diversity; Metasurface design; Simultaneous wireless information and power transmission (SWIPT); Sensor

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Motivation

- The emergence of SWIPT technology overcomes the limitations of traditional batteries and wired connections. Achieving efficient energy transmission and ensuring communication quality remain challenging, particularly in terms of realizing high port isolation, compactness, and high performance.
- Traditional rectifier antennas often require complex feed networks to achieve dual polarization or high port isolation. This added complexity not only increases energy loss but also enlarges the array during the design process. The spacing between antenna arrays must exceed half a wavelength, which presents a challenge for the miniaturization design of receiving antennas.

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Main idea

- We propose a receiving metasurface designed for the simultaneous wireless information and power transmission (SWIPT) system, which uses frequency diversity to achieve the reception of electromagnetic (EM) energy at 5.8 GHz and the transmission of sensor information at 2.45 GHz.
- Designing receiving antennas using metasurface structures can effectively reduce the spacing between units, enable a compact array structure, and meet the miniaturization requirements at the receiving antennas.
- Dual-frequency operation is achieved through a dual-square loop design, where the branches of the loops are based on free-space impedance matching and equivalent circuit design. This enables efficient electromagnetic wave absorption by adjusting the unit structure to match the free-space impedance.

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Method

1. Geometry of the metasurface

A dual-square loop design to realize the two frequencies: the outer loop operating at low frequency and the inner loop operating at high frequency. Miniaturization is achieved by adding branches to increase the current path.

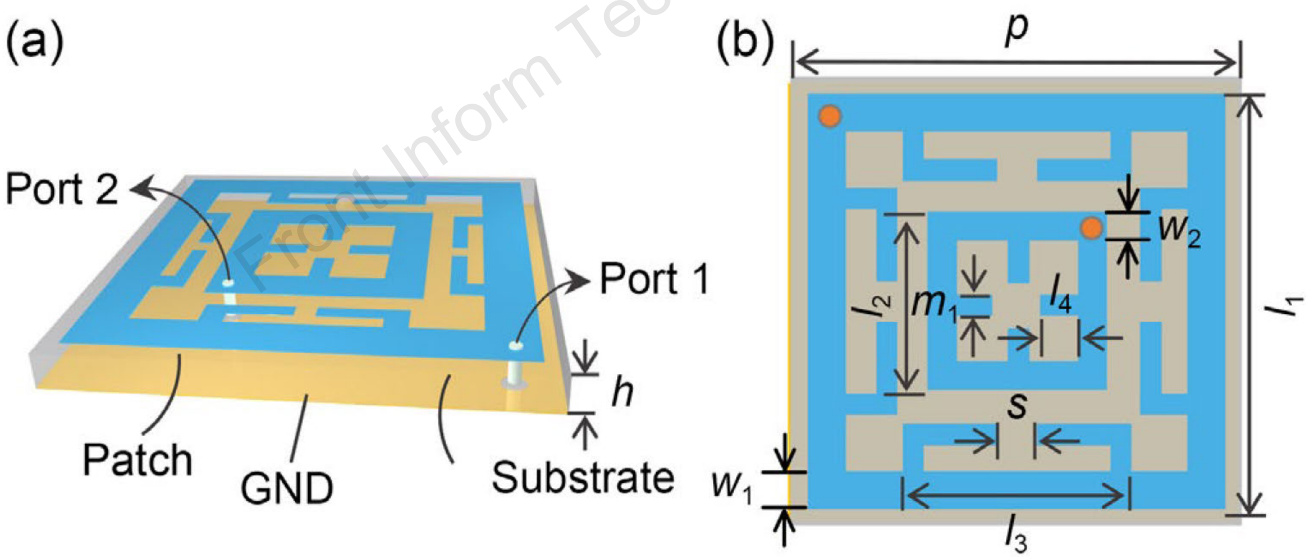

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Fig. 7 Layout of the metasurface: (a) stereo view; (b) top view

Method

2. Free-space impedance matching

By performing equivalent circuit analysis on the metasurface structure and modeling it as two parallel RLC circuits, impedance matching with free-space impedance can effectively enhance the metasurface's ability to efficiently absorb EM waves.

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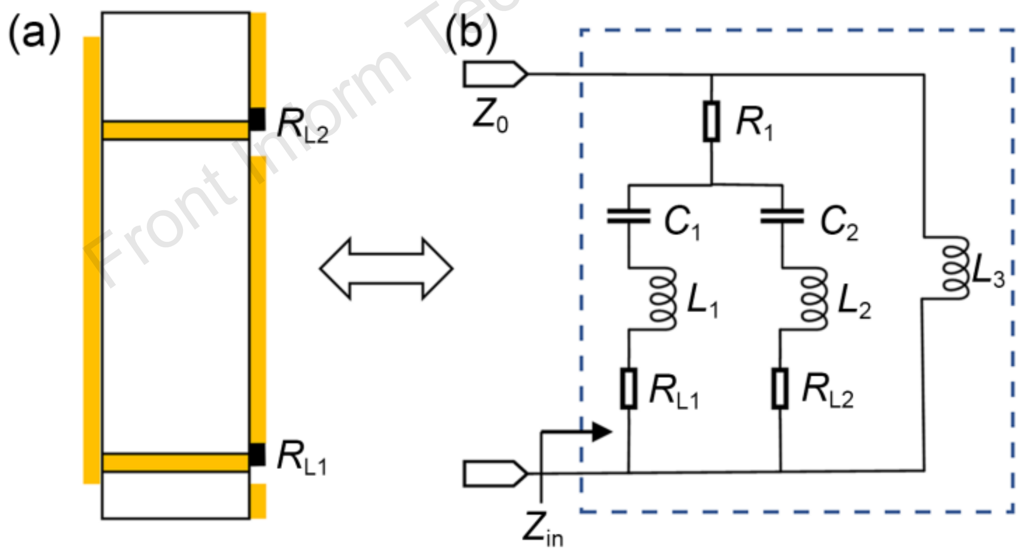

Fig. 4 Side view (a) and equivalent circuit (b) of the unit

Method

3. Rectifier design

To achieve the conversion of RF energy to DC power, a rectifier circuit integrated with the metasurface is designed to convert the RF energy absorption at the 5.8 GHz frequency band into DC power to directly power the sensors.

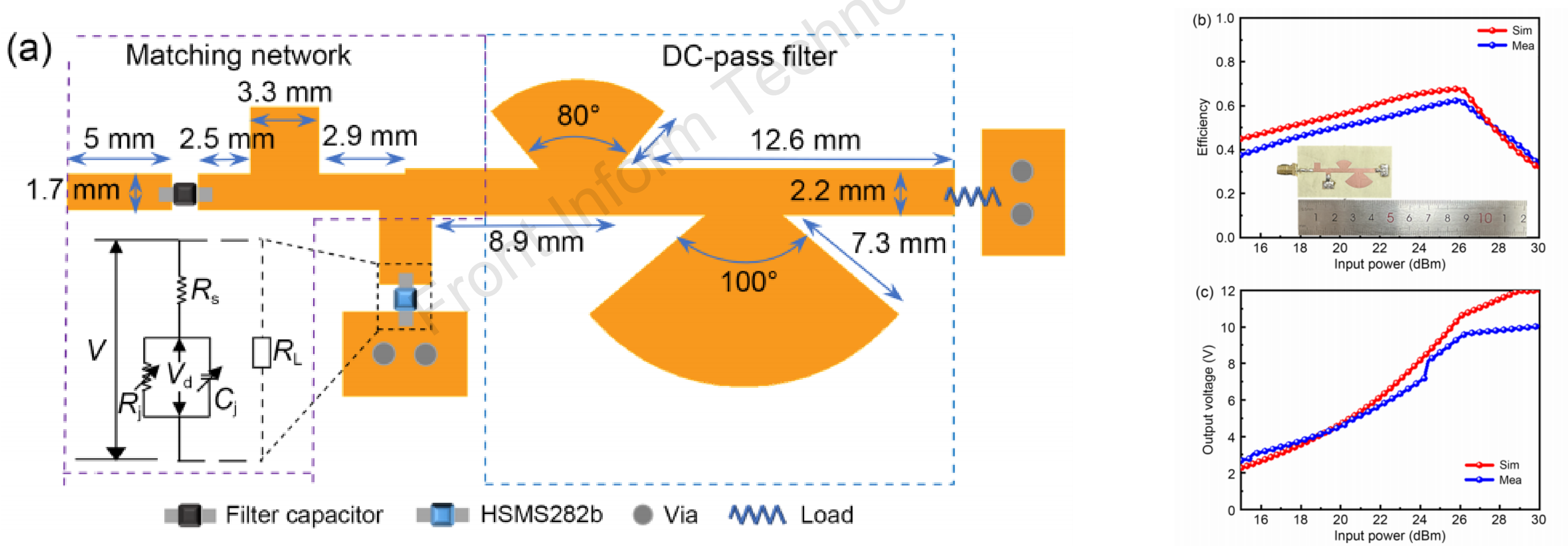

Fig. 12 Structure of the rectifier and relevant results: (a) structure of the rectifier; (b) simulated and experimental parameters of efficiency; (c) simulated and experimental parameters of output voltage. References to color refer to the online version of this figure

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Method

4. Geometry of the metasurface array

A 2×2 array is designed to validate the performance. A layer of dielectric substrate is added below the metasurface, and two 4-to-1 power combiners are used to combine the four ports at 5.8 GHz and 2.45 GHz into one port each.

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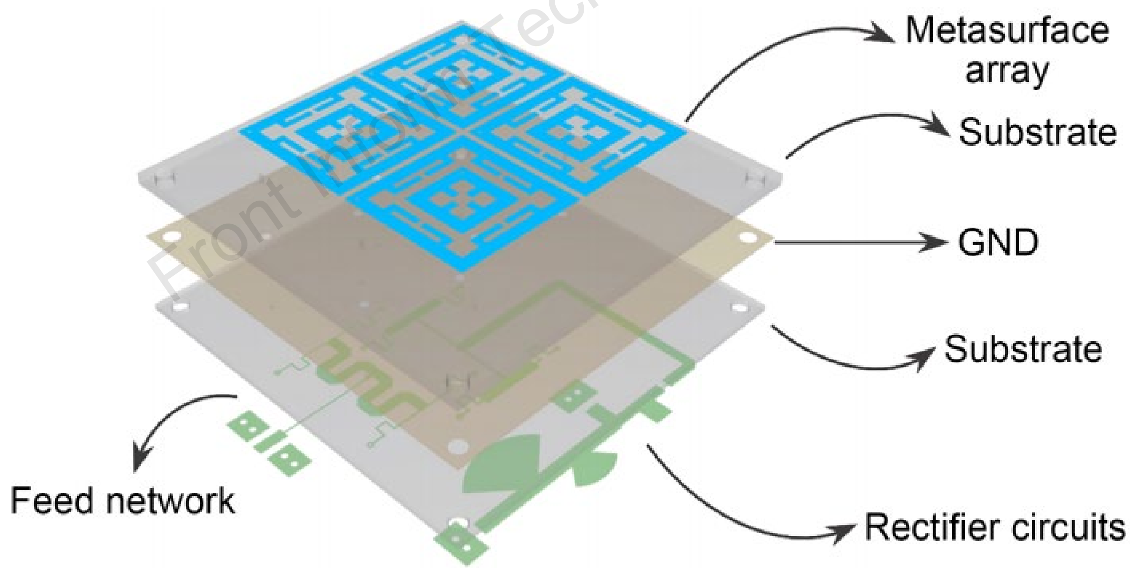

Fig. 10 An exploded diagram of the metasurface array

Major results

1. Simulation results of the unit

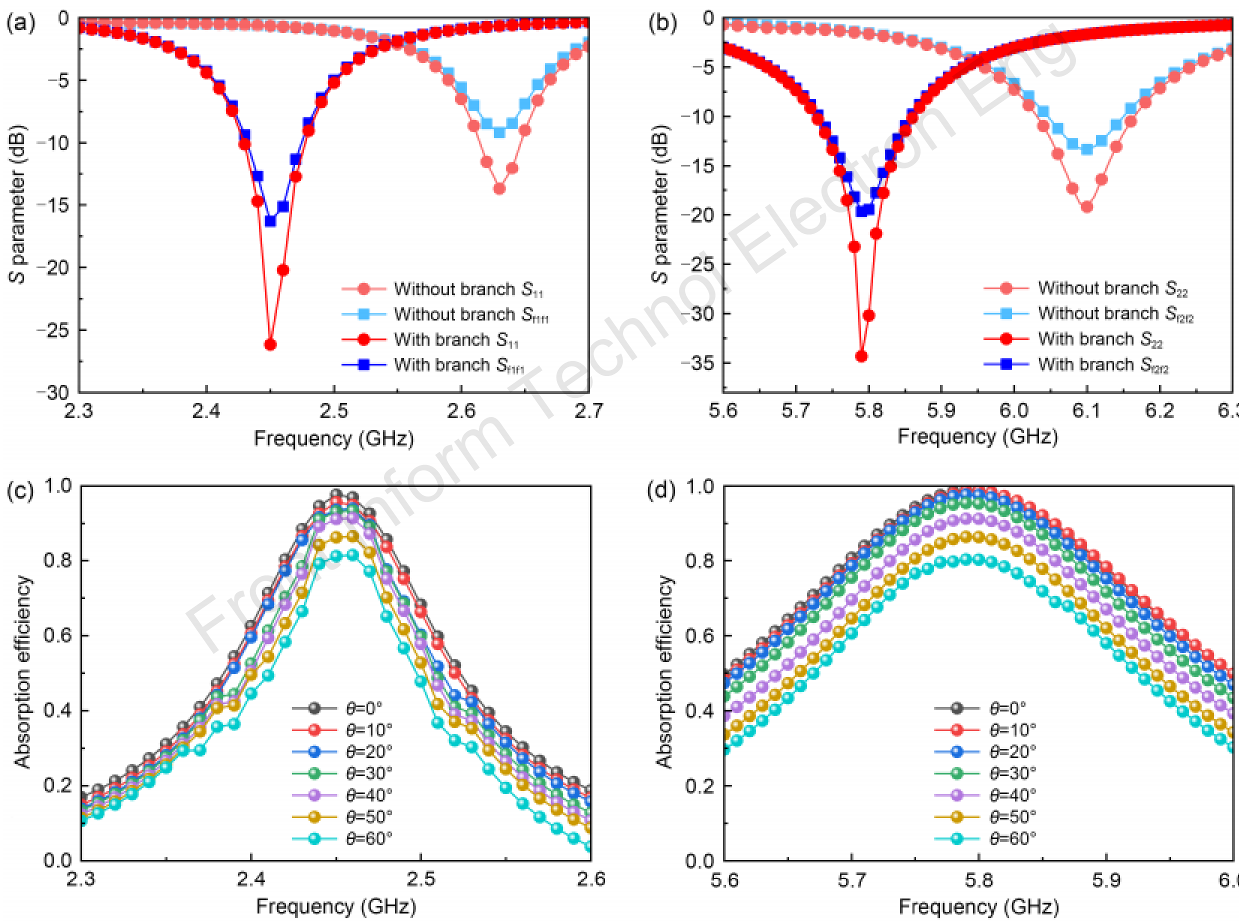

Fig. 8 Reflection coefficient with/without branch and absorption efficiency at different angles of incidence: (a) reflection coefficient at 2.45 GHz; (b) reflection coefficient at 5.8 GHz; (c) absorption efficiency at 2.45 GHz; (d) absorption efficiency at 5.8 GHz. References to color refer to the online version of this figure

Major results

2. Simulation and measurement results of the metasurface array

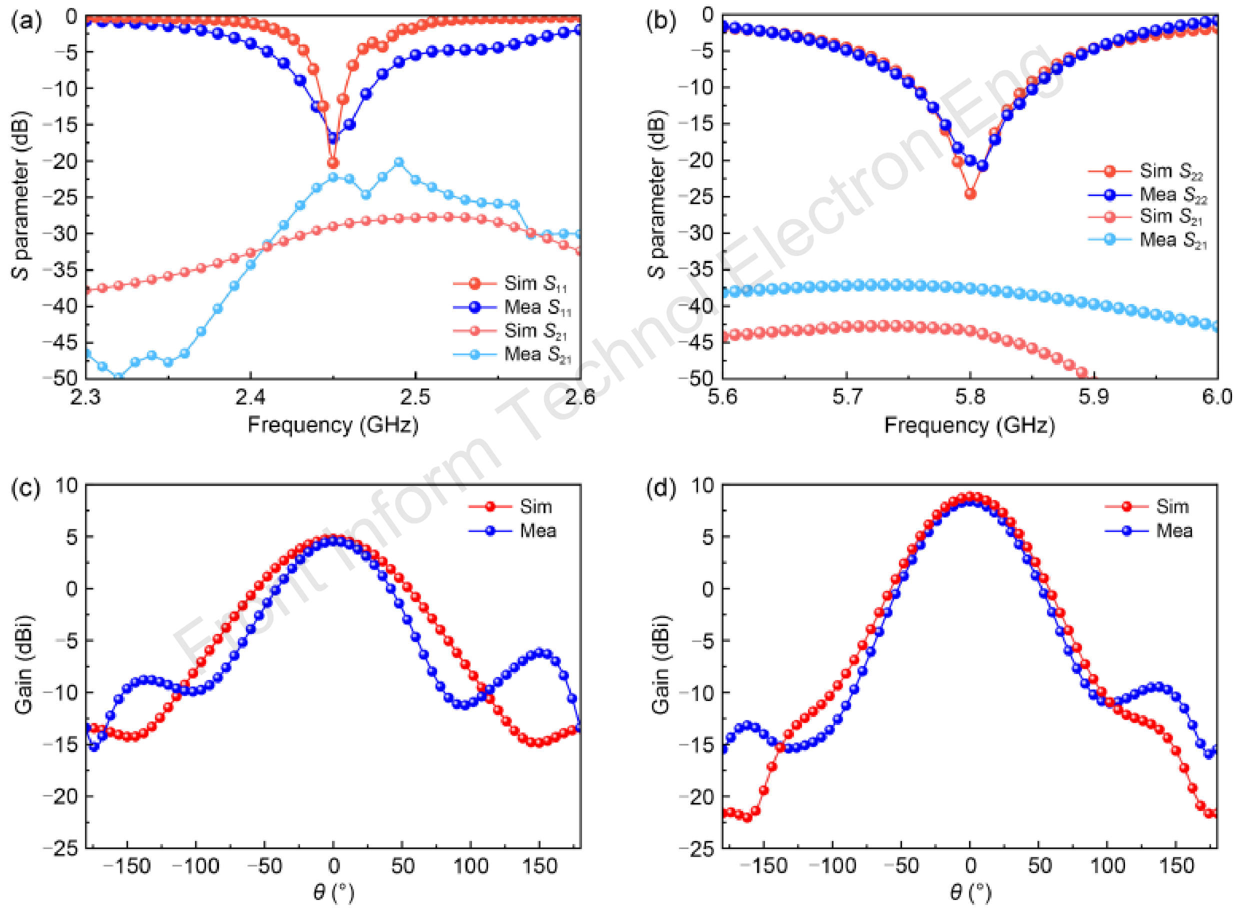

Fig. 11 Reflection coefficients and radiation pattern of the metasurface array: (a) reflection coefficient at 2.45 GHz; (b) reflection coefficient at 5.8 GHz; (c) radiation pattern at 2.45 GHz; (d) radiation pattern at 5.8 GHz. References to color refer to the online version of this figure

Major results

3. Measurement of the system

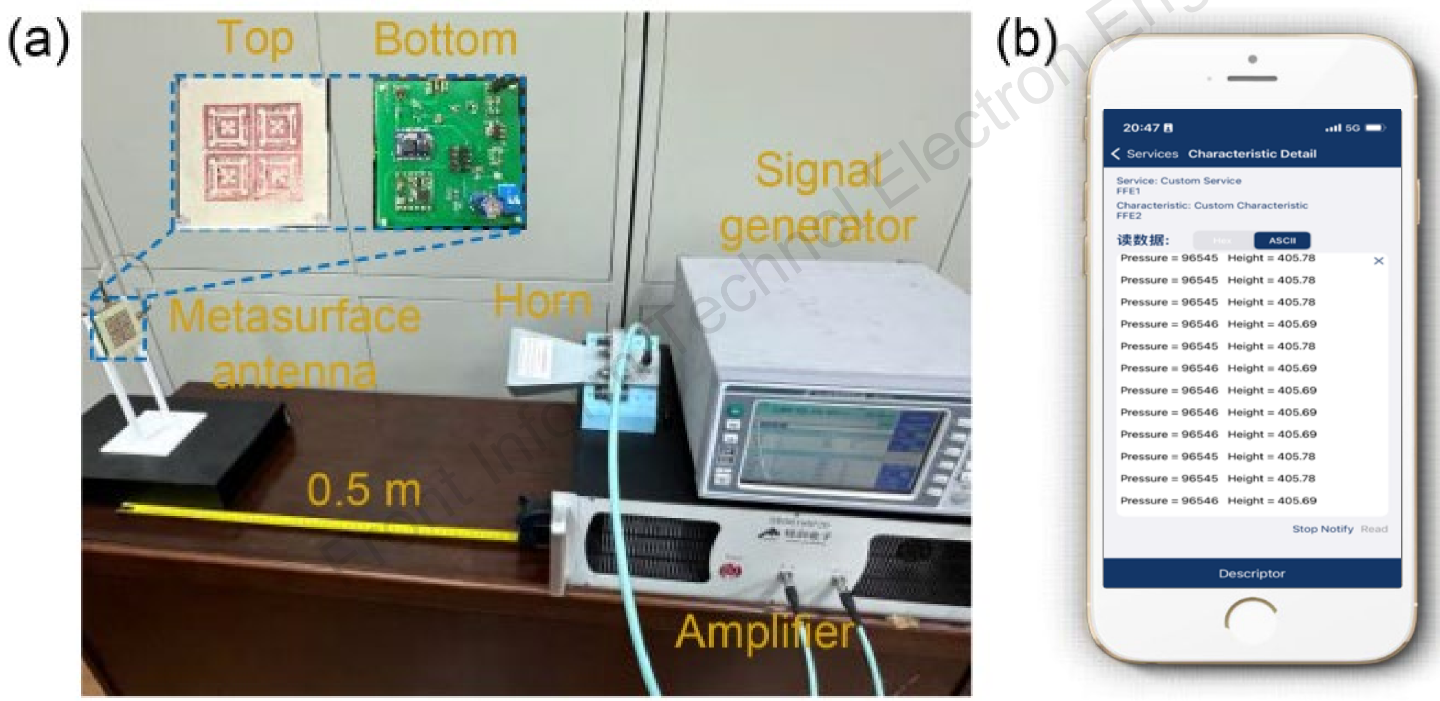

Fig. 14 Measurement of the system (a) and the information received by mobile phone (b)

Conclusions

1. A receiving metasurface designed for the SWIPT system has been proposed, which uses frequency diversity to achieve the reception of EM energy at 5.8 GHz and the transmission of sensor information at 2.45 GHz.

2. The advantages of the metasurface such as compact layout (unit size of $0.16\lambda_0 \times 0.16\lambda_0 \times 0.012\lambda_0$, where λ_0 is the wavelength at 2.45 GHz), high isolation ($S_{21} < -20$ dB within the operating frequency band), and insensitivity to incident angles (efficiency over 80% within 60°).

3. Integrated with rectification circuits and sensors, it efficiently converts EM waves received by the metasurface into DC power for sensor operation.

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