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Mutual coupling reduction of multiple antenna systems

Key words: Mutual coupling; Multiple-input multiple-output; Antenna array; Metasurface; Decoupling

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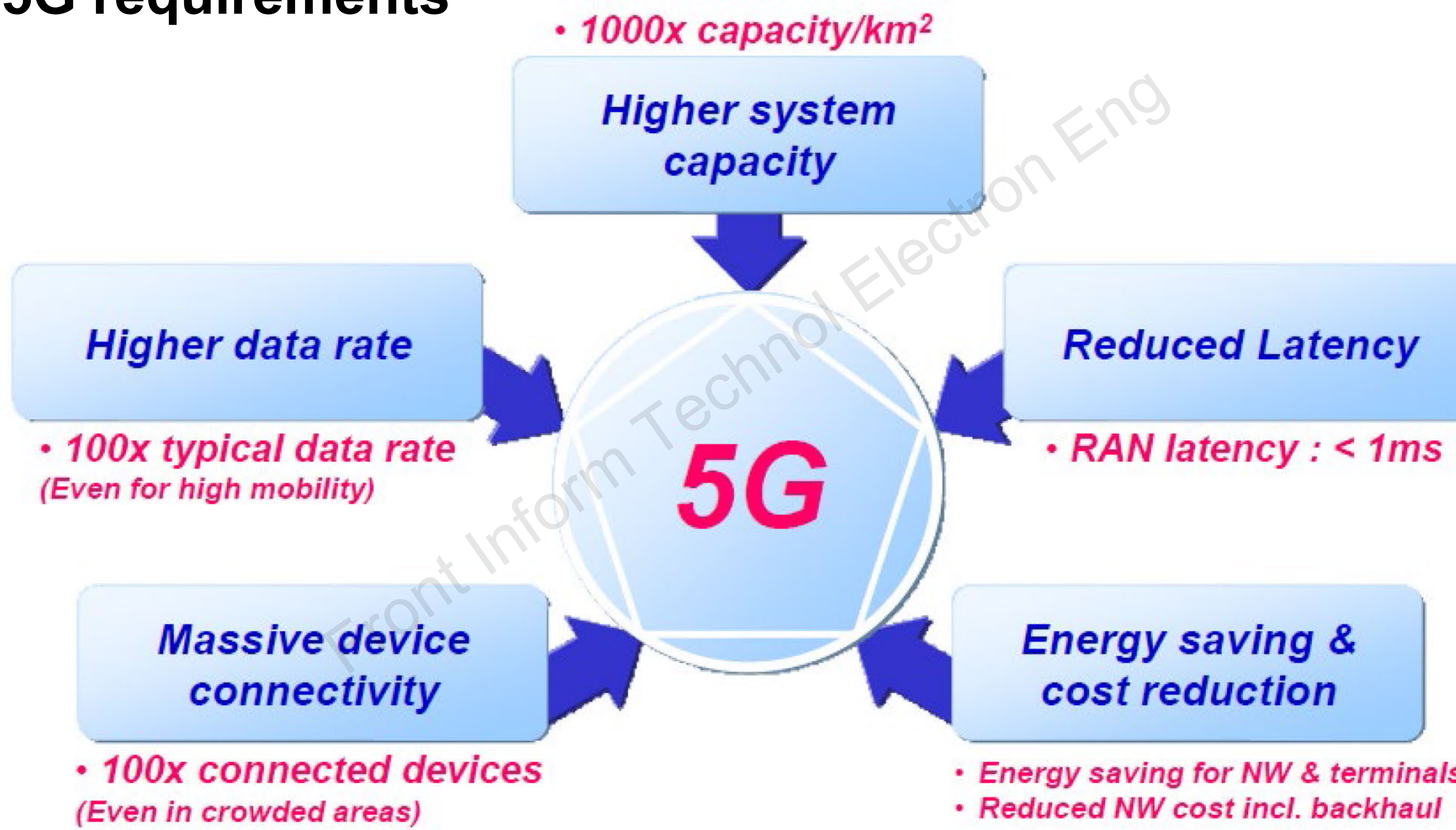
Background

5G requirements



DOCOMO 5G White Paper, NTT DOCOMO, Inc., July 2014

Background

1. In Fig. 1a, when antenna 1 is excited to generate electromagnetic waves, a part of energy 2 is directly radiated into free space, and another part of energy 3 is coupled into the adjacent antenna 2. After receiving energy, antenna 2 generates current and radiates a part of energy 4 into space again. Another part of antenna 2’s energy 5 enters the signal source and is superimposed with the energy generated by antenna 2, which causes the antenna to be mismatched, thereby deteriorating the antenna array’s performance.

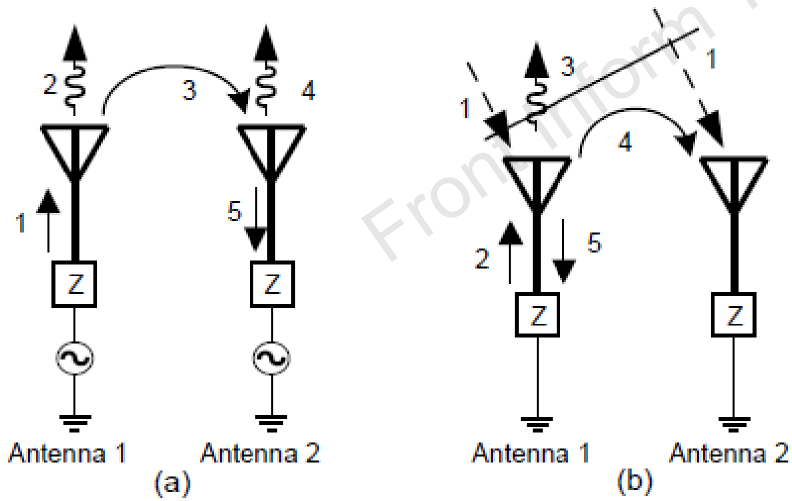


Fig. 1 Mutual coupling of antenna arrays: (a) transmitting antenna array; (b) receiving antenna array

2. Fig. 1b depicts the mutual coupling principle of the receiving antenna array, which is a process similar to that of the transmitting antenna array.

Several decoupling ways

1. Lumped element

Decoupling networks are generally applicable to the case where antenna element space is relatively close. Decoupling networks and antennas are designed separately and independently.

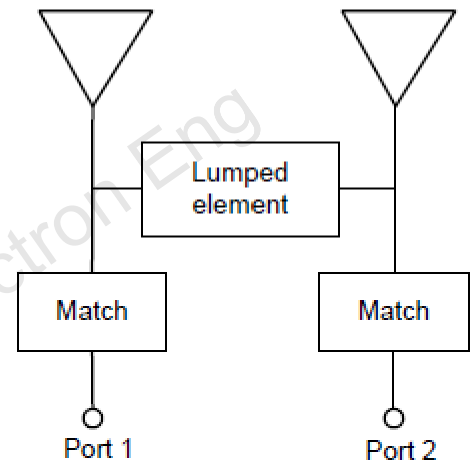


Fig. 2 Models using lumped elements for decoupling

2. Parasitic resonant unit

The decoupling method uses a parasitic resonant unit to introduce a coupled parasitic element between antenna elements to create an additional coupling path, using the inverse cancellation principle of the field to improve isolation between antenna elements.

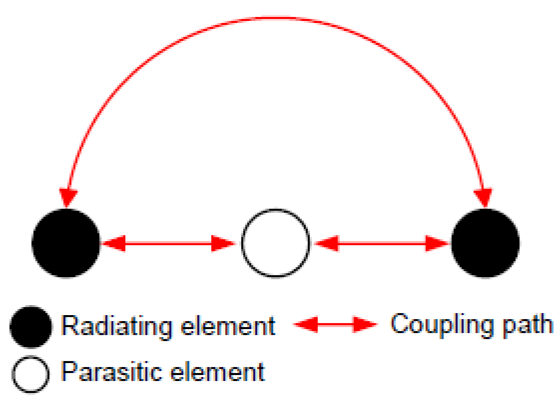


Fig. 5 Models using a parasitic element for decoupling

Several decoupling ways

3. Defected ground structures

Decoupling with defected ground structures is used to etch periodic or non-periodic structures on the ground of the antenna. These structures have band-stop filtering characteristics, thus changing the microwave transmission characteristics to achieve decoupling design.

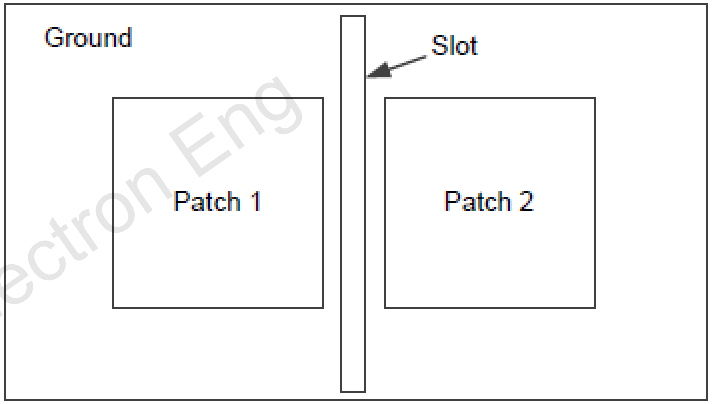


Fig. 7 Models with a rectangular slot for decoupling

4. Pattern diversity

The pattern diversity method increases isolation between antenna elements and improves the radiation pattern by properly designing the antenna, so the main lobe of the antenna radiates in different directions.

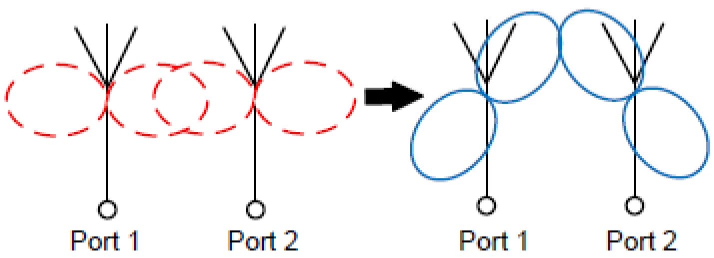


Fig. 8 Schematic of pattern diversity

Antenna structure coupled in the H-plane

The metasurface is composed of pairs of cut wires, which are printed on the F4B substrate. The bowtie antennas and the feed structure are fabricated on the FR4 substrate. Meanwhile, to show the metasurface's decoupling effect, a coupled antenna without metasurface is simulated and analyzed as a reference.

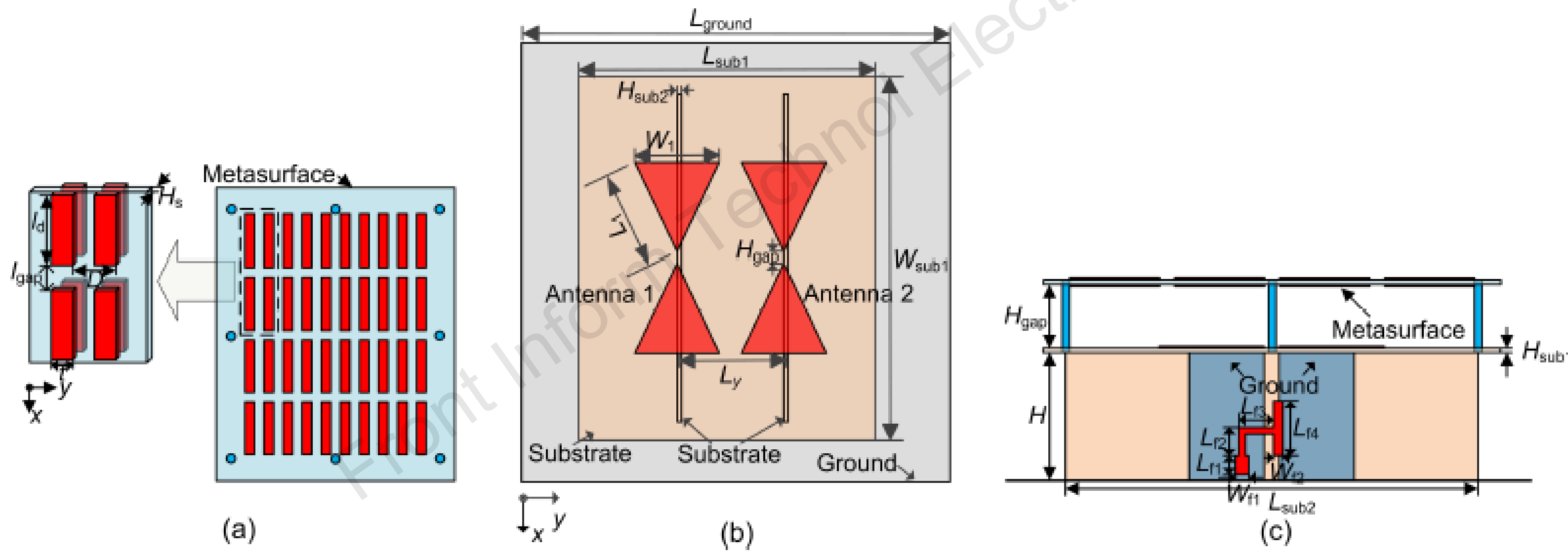


Fig. 14 Top view of the metasurface (a), two bowtie antennas (b), and side view of the two bowtie antennas (c)
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Liu F, Guo JY, Zhao LY, et al., 2018. A meta-surface decoupling method for two linear polarized antenna array in sub-6 GHz base station applications. *IEEE Access*, 7:2759-2768. https://doi.org/10.1109/ACCESS.2018.2886641

Antenna structure coupled in the H-plane

The decoupled and coupled antenna arrays both resonate at 2.5 GHz, while the operating bandwidth of both the antennas covers 2300-2690 MHz. However, after loading the proposed metasurface, the isolation of the antenna array can be improved from about 10 dB to more than 25 dB in the operating band, which proves that the proposed metasurface has good decoupling effect.

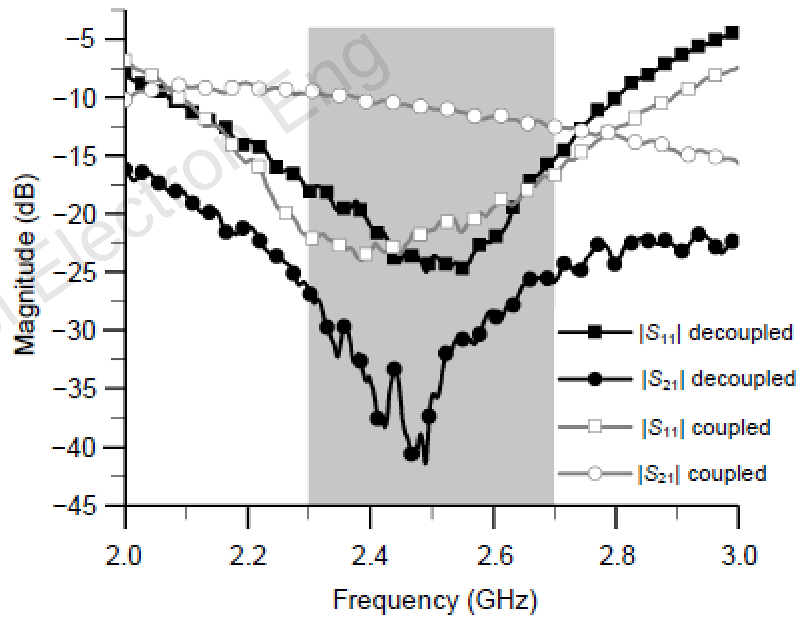

Fig. 15 Measured *S* parameters of the antenna arrays with and without metasurface

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Antenna structure coupled in the H-plane

It is shown that the total efficiency of the decoupled antenna increases by 10% in the operating band (2300–2690 MHz), and that the envelope correlation coefficient (ECC) reduces from 0.35 of the coupled antenna to 0.13 of the decoupled antenna.

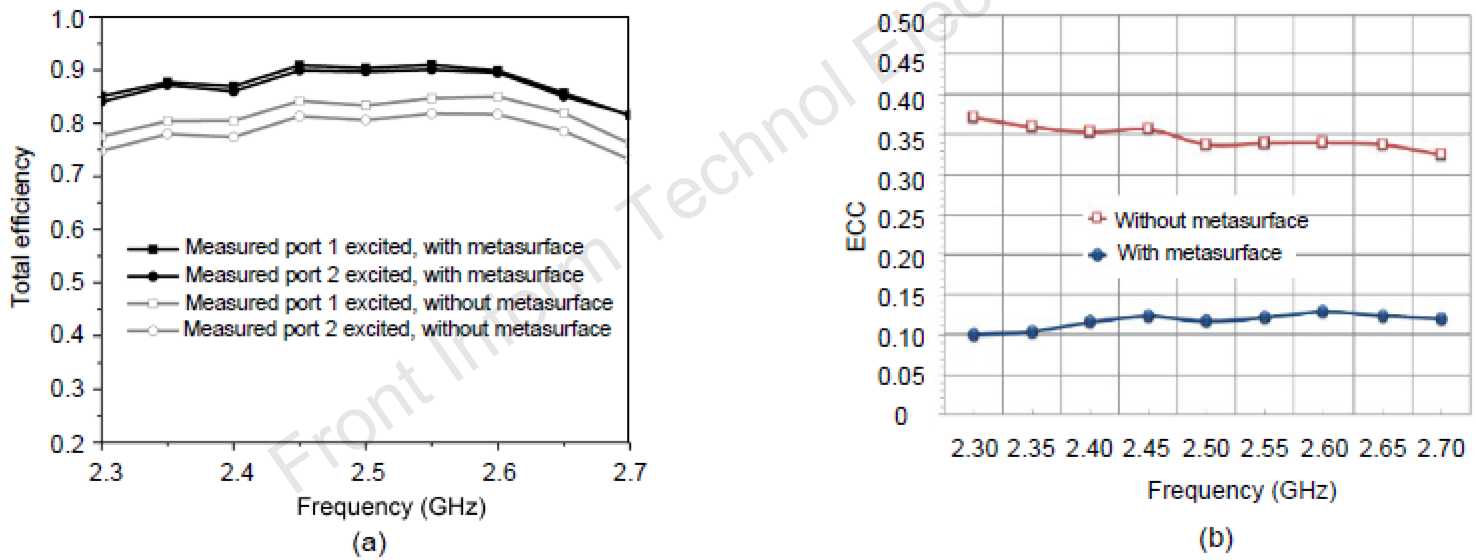

Fig. 18 Total measured efficiency (a) and calculated envelope correlation coefficient (ECC) (b) of two antenna arrays coupled in the H-plane without and with metasurface

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Antenna structure coupled in the E-plane

As shown, two square ring-shaped dipole (SRD) antennas are arranged along the E-plane. The metasurface placed above the antennas is used to reduce the mutual coupling of the antenna array coupled in the E-plane. The initial antenna array without the metasurface is analyzed as a reference antenna.

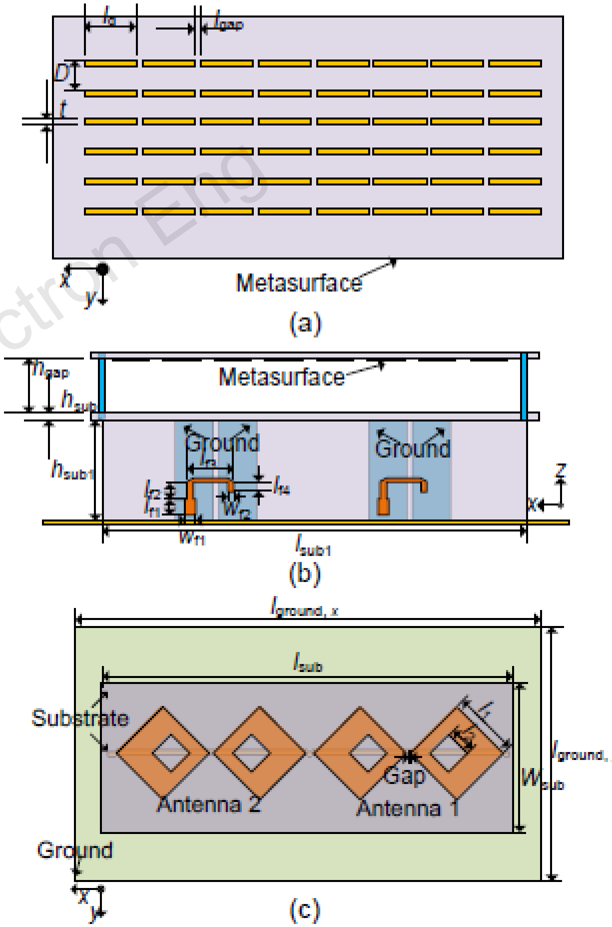

Fig. 19 Top view of the metasurface (a), side view of two square ring-shaped dipole (SRD) antennas (b), and top view of the two SRD antennas (c)
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Guo JY, Liu F, Zhao LY, et al., 2019. Meta-surface antenna array decoupling designs for two linear polarized antennas coupled in H-plane and E-plane. *IEEE Access*, 7:100442-100452. https://doi.org/10.1109/ACCESS.2019.2930687

Antenna structure coupled in the E-plane

The decoupled antenna array can achieve an isolation improvement about 15 dB in the operating band (3.3–3.7 GHz) when it is well matched.

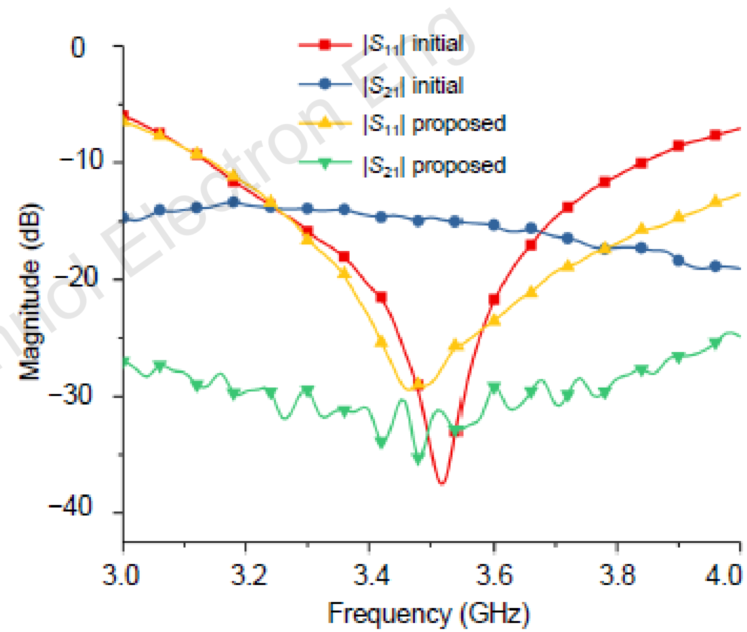

Fig. 20 Measured *S* parameters of antenna arrays with and without metasurface

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Antenna structure coupled in the E-plane

Compared with the antenna before decoupling, the decoupled antenna's overall efficiency increases by about 5%, and the ECC reduces in the operating band (3.3–3.7 GHz).

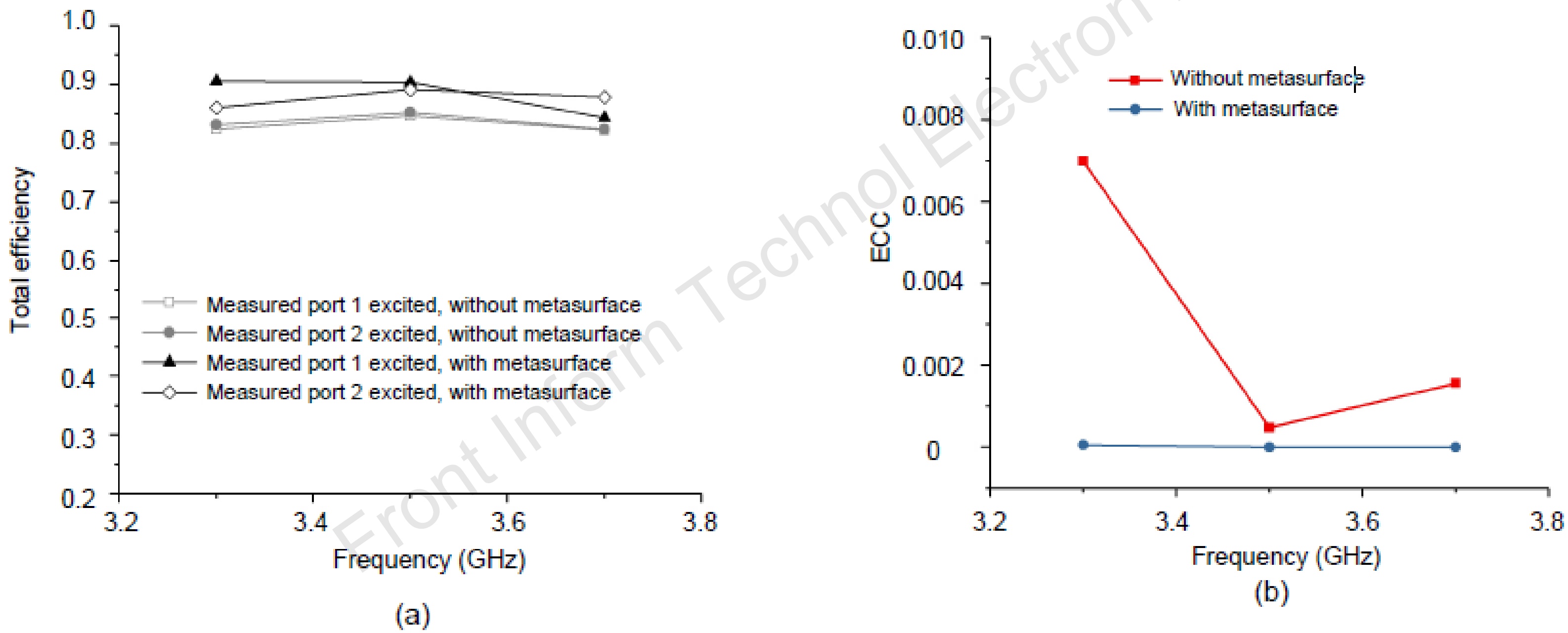

Fig. 22 Total measured efficiencies (a) and calculated envelope correlation coefficient (ECC) (b) of two antenna arrays coupled in the E-plane without and with metasurface

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Conclusions

Multiple-input multiple-output (MIMO) technology plays an extremely important role in improving spectrum use and data transmission reliability. We have classified and analyzed the methods of mutual coupling reduction introduced in recent works, which is used as a basis for the novel work on antenna array decoupling. Results showed that the proposed decoupling method suppresses the mutual coupling of antennas arranged along not only the H-plane, but also the E-plane, which ensures good decoupling performance.