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Performance enhancement for antipodal Vivaldi antenna modulated by a high-permittivity metasurface lens

Key words: Antipodal Vivaldi antenna (AVA); Ultra-wideband; High-permittivity; Dual-polarization; Metasurface lens (ML)

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Motivation

1. As the frequency increases, the phase difference between the currents on the two plates of the AVA is no longer stable, which will cause the directivity and radiation gain to deteriorate. It is a major challenge in AVA applications.
2. Some techniques have been studied to enhance the gain and radiation performance of the antenna. However, these methods make the structure of the antenna more complicated and even lose the advantage of low profile while improving the performance.
3. The existing studies have achieved good results in improving the radiation performance of the AVA, but there are still some limitations, such as the insignificant enhancement in the antenna gain and the narrow operating bandwidth of the metasurface lens.

Main idea

1. The designed metasurface lens unit (MLu) has a simple structure and is easy to implement. It can perform multi-octave bandwidth modulation of electromagnetic waves in two polarization modes.
2. Compared with the existing work, the designed MLu has a simpler structure, wider operating bandwidth, and can modulate two polarization modes electromagnetic waves.
3. Two types of metasurface lenses are designed and integrated into the aperture of the AVA, and the guidance and modulation effects on the radiation field are analyzed from the perspective of the electric field.

Method

1. To make the MLu have ultra-wideband operating characteristics, the proposed unit structure reduces unnecessary metal structures and retains only the metal arms that play a key role in modulating electromagnetic waves.

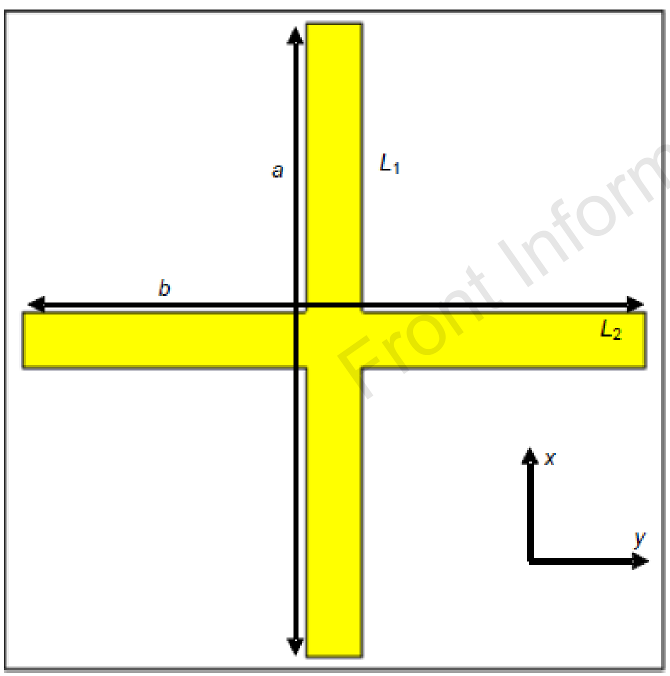

Fig. 3 Structure of the designed MLu

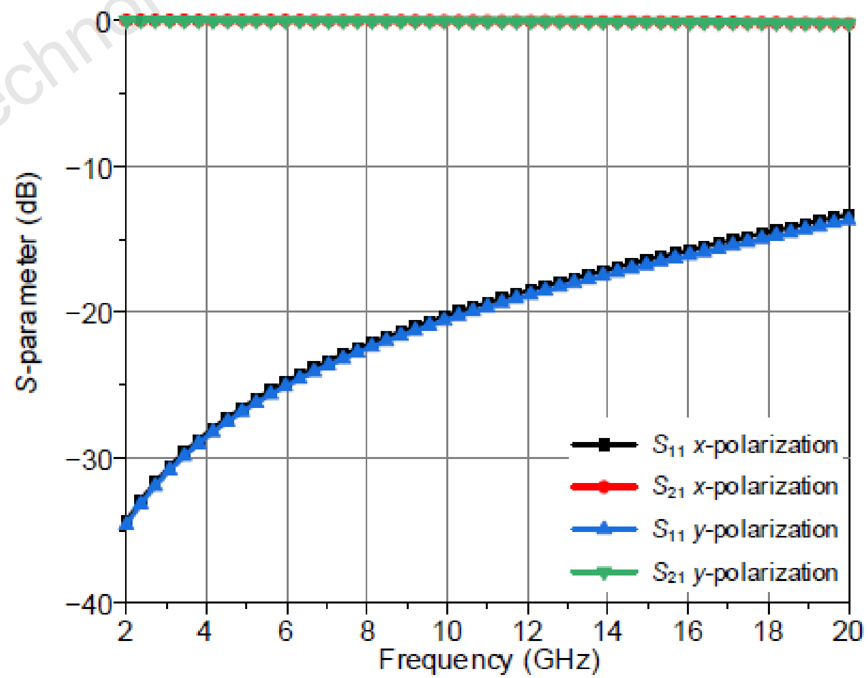

Fig. 4 Simulated *S*-parameters of MLu

Method (Cont'd)

2. To achieve an independent modulation of the two polarization modes electromagnetic waves, the designed MLu is composed of two mutually perpendicular metal arms.

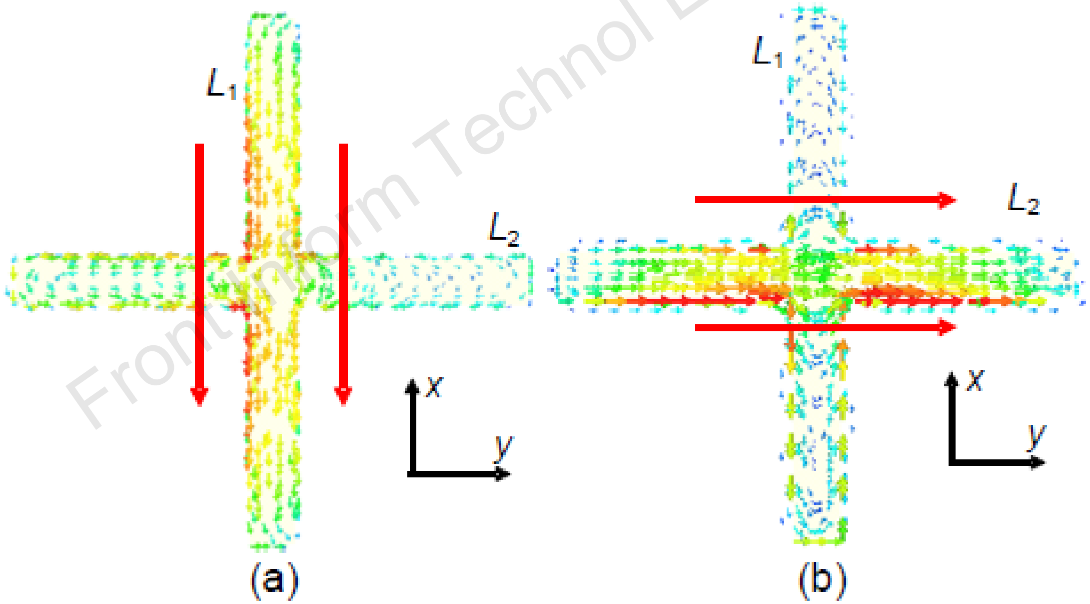

Fig. 5 Current distribution over the MLu at 14 GHz of *x*-polarization (a) and *y*-polarization (b)

Method (Cont'd)

3. To better enhance the directivity and radiation gain of the antenna, the distribution of the lens is optimized by analyzing the electric field distribution at the antenna aperture, so that the lens can more fully guide and modulate the radiation field of the antenna.

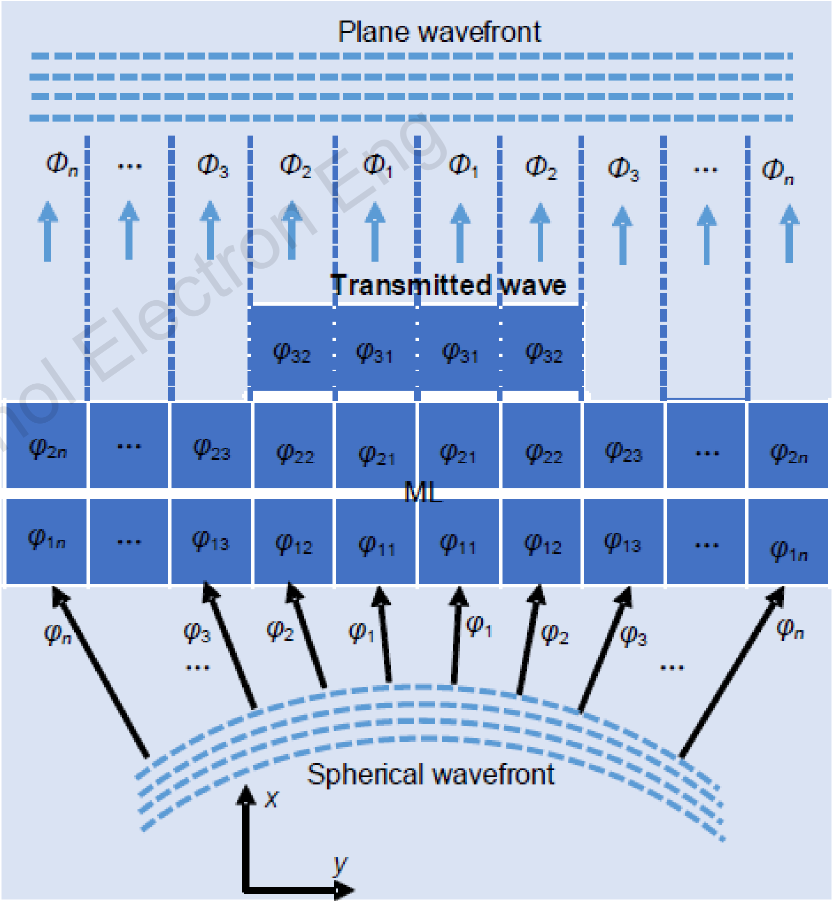

Fig. 14 Diagram of the ML which converts a spherical wavefront into a plane wavefront

Major results

Electromagnetic characteristic of the metasurface unit

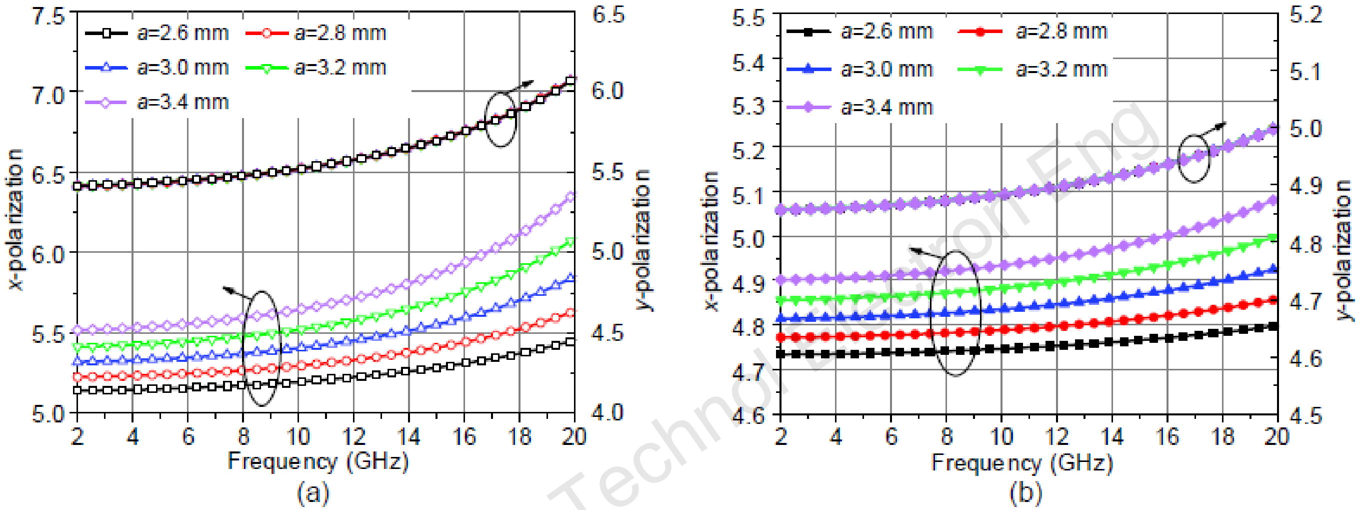

Fig. 6 Simulation results of the effective permittivity (a) and refractive index (b) of MLu with different *a* values

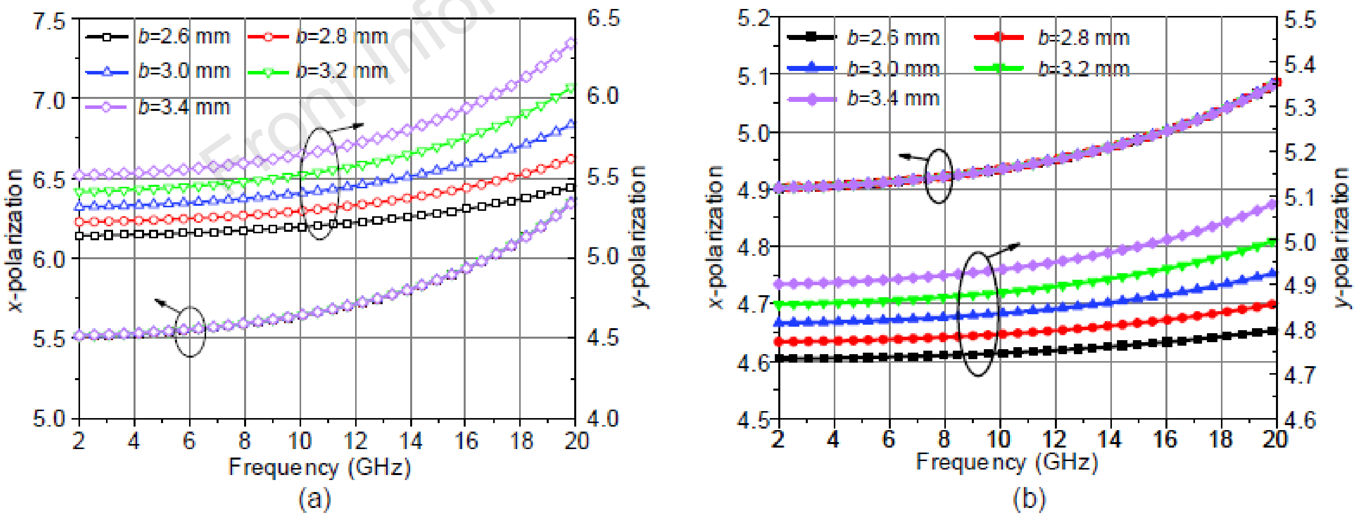

Fig. 7 Simulation results of the effective permittivity (a) and refractive index (b) of MLu with different *b* values

Major results (Cont’d)

Simulated radiation patterns (Ant2 is the proposed antenna)

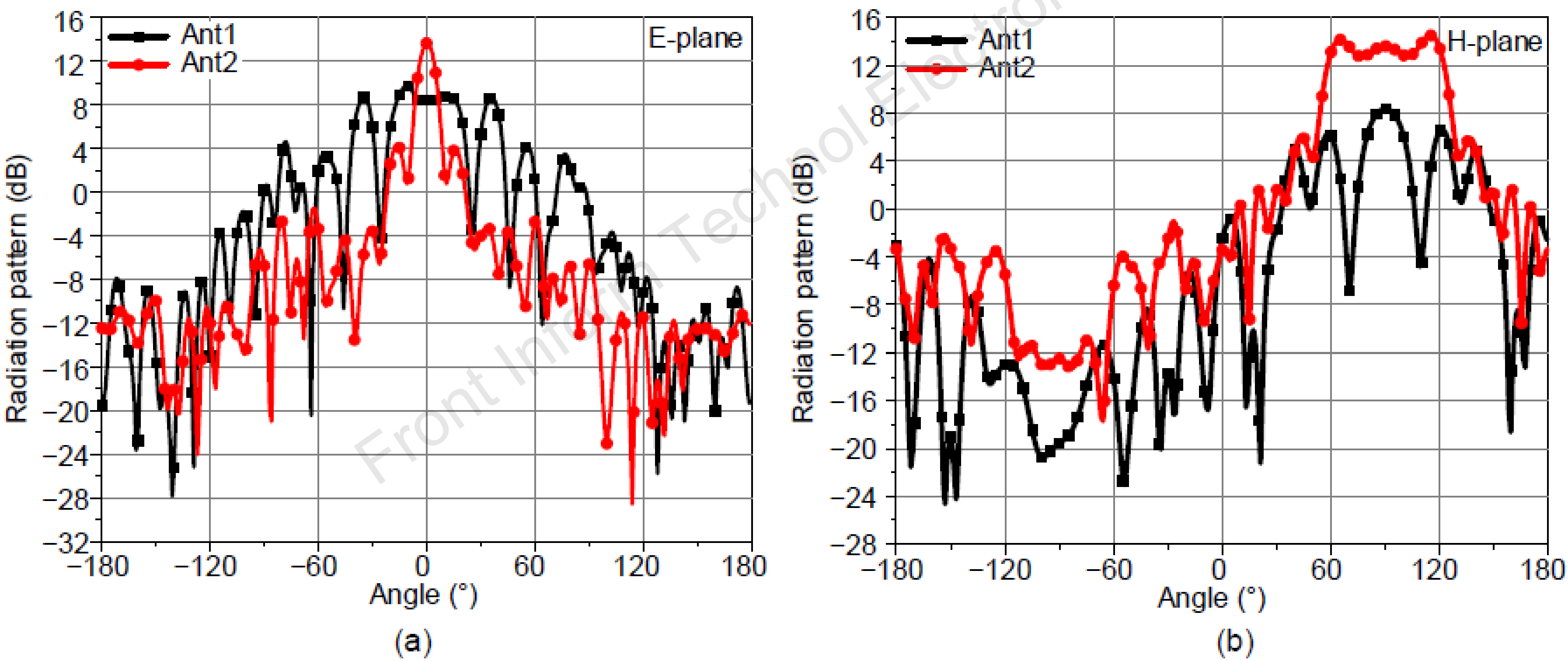

Fig. 17 Simulated E-plane (a) and H-plane (b) radiation patterns of Ant1 and Ant2 at 18 GHz

Major results (Cont'd)

Electric field distribution (Ant2 is the proposed antenna)

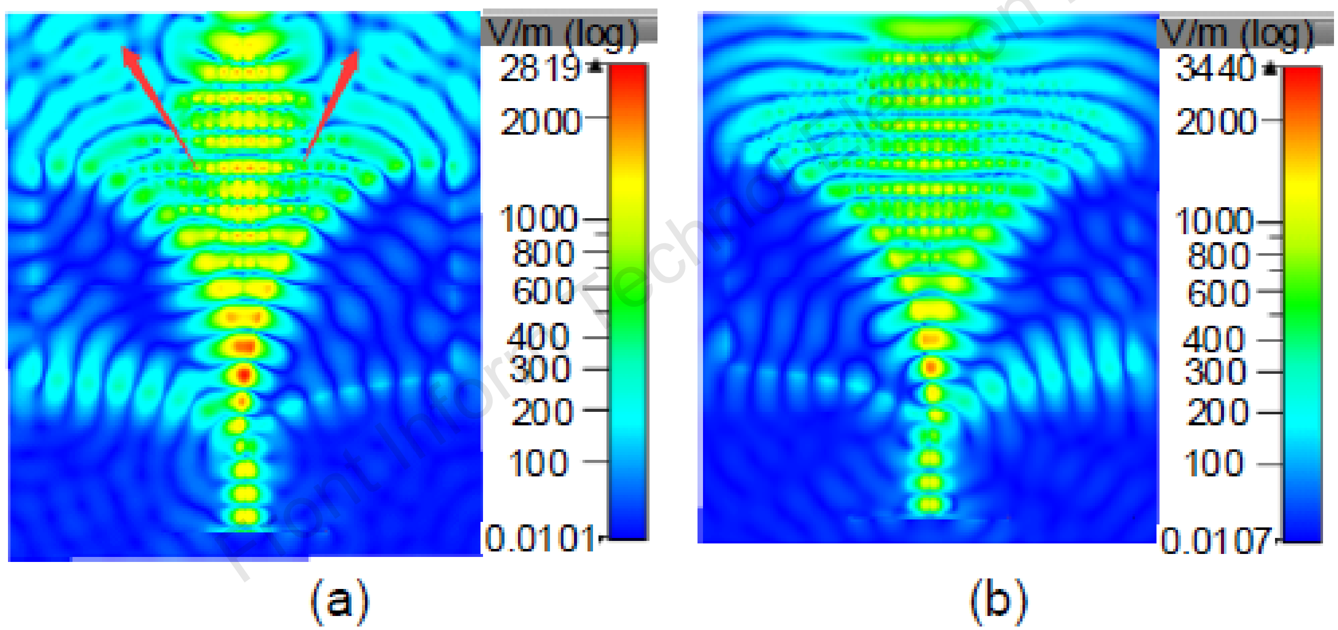

Fig. 18 Simulated 2D electric field on the E-plane of Ant1 (a) and Ant2 (b) at 18 GHz

Major results (Cont'd)

Measurement and simulation results

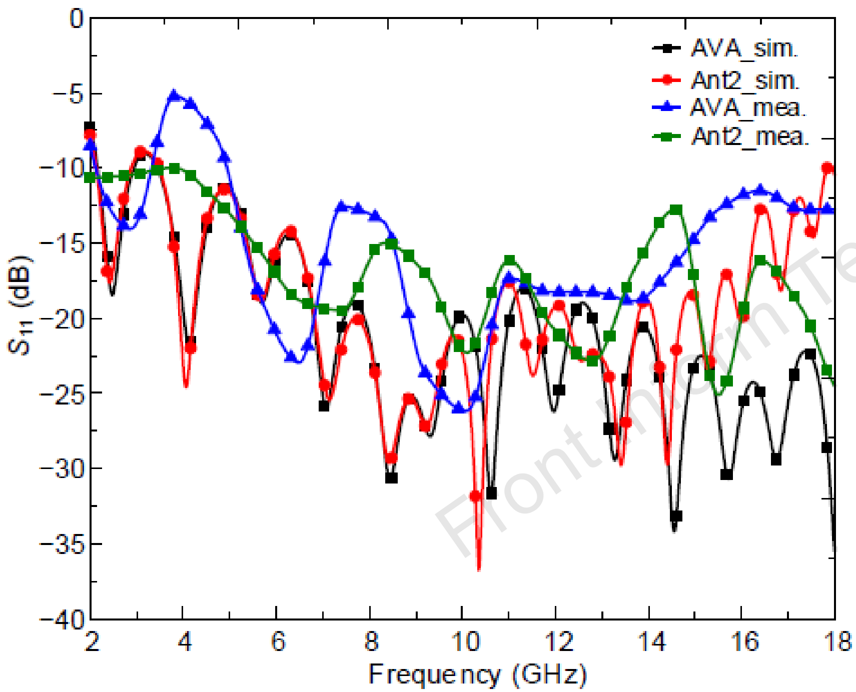

Fig. 22 Measured and simulated S_{11} results of the AVA and proposed Ant2

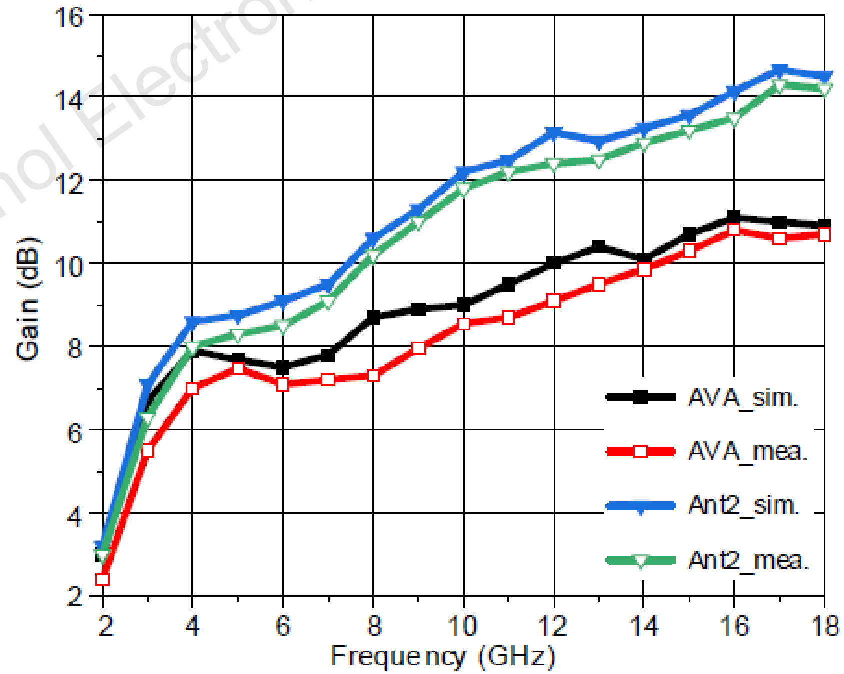

Fig. 24 Measured and simulated gain of the AVA and Ant2

Conclusions

1. A multi-octave bandwidth MLu operated at 2–20 GHz is designed. Through the analysis of effective permittivity and the refractive index of the MLu, good independent modulation ability of the MLu for two polarization modes electromagnetic waves is verified.

2. Two MLs are proposed and integrated into the aperture of the AVA. The guidance and modulation effects of the ML on the electric field are analyzed, and the final ML loading method and antenna form are determined.

3. The AVA and designed Ant2 are fabricated and measured. Compared with the AVA, the Ant2 gain is enhanced by 0.6–3.7 dB in the 2–18 GHz frequency band and there is a significant enhancement in radiation performance.