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Characteristic-Mode-Guided Suppression of Cross-Band Scattering and Coupling in Antenna Array

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***Abstract*—Cross-band scattering and coupling in a closely spaced dual-band antenna array are effectively suppressed over a wide band. Guided by characteristic mode analysis (CMA), a segmented spiral is efficiently developed as a dipole radiator to mitigate cross-band scattering and coupling while preserving the radiation performance of the antenna. Assisted by serial resonators, impedance matching of the spiral dipole is achieved within the low band (LB) of 0.69-1.00 GHz (36.7%). In comparison to a traditional tube-based dipole, a reduction in radar cross-section (RCS) is observed for the spiral dipole over 1.10-4.29 GHz (118%). High band (HB) antennas, operating in 1.63-2.83 GHz (53.8%), are collocated with the LB spiral dipole, constituting a dual-band antenna array. The array maintains stable radiation patterns without distortions across the HB, and cross-band isolations in the HB are improved to over 20 dB.**

I. INTRODUCTION

The advancement of wireless communication technology demands antennas to cover an increasing number of frequency bands. To reduce construction cost and spatial occupation of base stations, multi-band antenna arrays with space-efficient designs have emerged as the prevailing solution. However, the proximity of different antennas leads to cross-band scattering and coupling, manifested respectively in the distortion of radiation pattern and the reduction of isolation.

Many techniques have been developed to suppress cross-band scattering or coupling. Chokes, slots, or metasurfaces are co-designed with the radiators of antennas to effectively suppress cross-band induced currents and allow waves to pass through normally, restoring the antenna's radiation pattern [1], [2]. Filtering structures, such as parasitic loops and branches, can impede the flow of induced currents at different frequencies into the antenna ports, thereby improving cross-band isolation [3]. Nevertheless, these technologies are all single-functional, and there is an ongoing pursuit of methods that can suppress scattering and coupling across a wide bandwidth.

II. CHARACTERISTIC-MODE-GUIDED DESIGN OF SPIRAL

When the low band (LB) antenna is positioned adjacent to the radiating high band (HB) antennas, as depicted in Fig. 1, HB currents are induced on the LB radiator under the excitation of the HB wave. These induced currents result in cross-band scattering and coupling in the HB. From the perspective of characteristic mode analysis (CMA), the HB induced currents can be suppressed by reducing the modal weighting coefficient (MWC) values associated with the significant modes of the LB antenna [4].

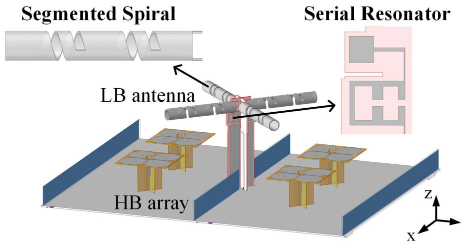
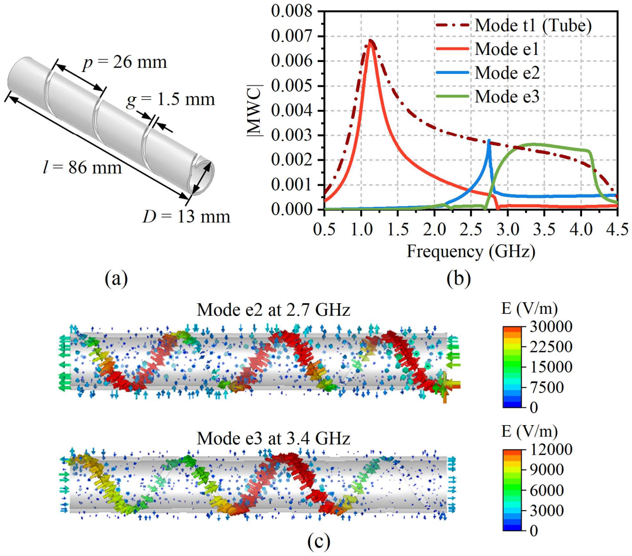


Fig. 1. Configuration of the dual-band antenna array.



(a) (b)

(c)

Fig. 2. (a) Geometry of even spiral, (b) |MWC| of even spiral excited by plane wave, and (c) modal E-field distribution of Mode e2 and Mode e3.

As illustrated in Fig. 2, the even spiral structure presented in [1] can effectively suppress Mode t1 of tube to Mode e1 over HB. However, it introduces higher-order Modes e2 and e3, which reduce the suppression bandwidth. As observed from the current distribution shown in Fig. 2(c), the modal E-field of Mode e2 is significantly stronger in the middle part and the two regions near the ends of the slot. As for Mode e3, the E-field is also stronger in the middle part. To broaden the suppression band, these two higher-order modes can be eliminated by short-circuiting the slots in areas with strong E-fields.

After short-circuiting the even spiral, Modes e2 and e3 are eliminated successfully as evidenced in Fig. 3(b). However, another higher-order mode named Mode 2 appears. As shown in Fig. 3(c), the areas with the strongest E-field are located in the two slots. To suppress Mode 2, the slot widths of the two segmented spirals are modified. As the slot width (g) increases

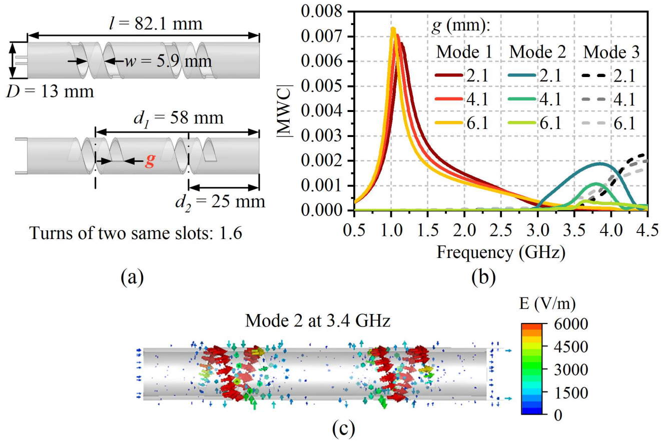


Fig. 3. (a) Geometry of segmented spiral, (b) |MWC| of segmented spiral excited by plane wave, and (c) modal E-field distribution of Mode 2.

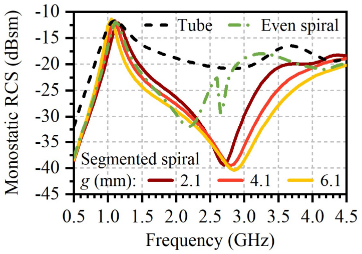


Fig. 4. Monostatic RCSs of the tube, even spiral, and segmented spirals with different *g*.

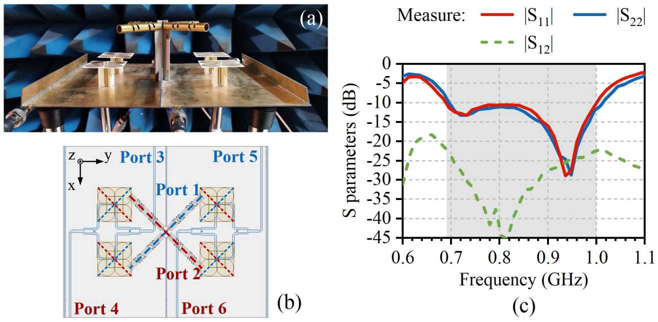


Fig. 5. (a) Prototype of the dual-band antenna array, (b) configuration of the dual-band antenna array, and (c) measured S parameters of the LB antenna.

from 2.1 mm to 6.1 mm, the |MWC| of Mode 2 gradually decreases, widening the suppression band.

In Fig. 4, monostatic radar cross sections (RCSs) of the segmented spirals are compared to those of the reference cylindrical tube and the even spiral. Compared to the tube, the even spiral can reduce the RCS but is only effective in a limited frequency range. In contrast, when g = 4.1 mm, the segmented spiral effectively reduces the RCS across a much wider band of 1.10-4.29 GHz (118%). In addition, a larger g broadens the suppression bandwidth with lower RCS, which is consistent with the |MWC| values in Fig. 3(b).

Facilitated by the serial resonators shown in Fig. 1, impedance matching for the spiral dipole is achieved in the LB. The prototype and configuration of the dual-band antenna array are given in Fig. 5(a) and (b), respectively. The measured reflection coefficients of the LB dipoles are less than -10 dB in 0.69-1.00 GHz, and the port isolation exceeds 22 dB.

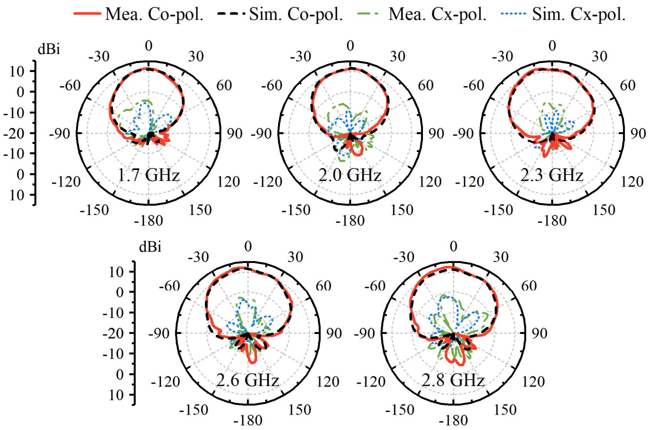


Fig. 6. Measured and simulated radiation patterns of the HB antennas in the *yoz* plane when Port 3 is excited.

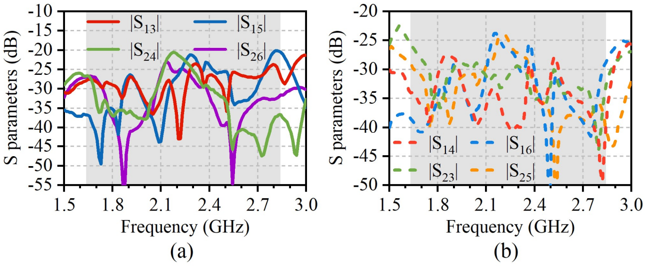


Fig. 7. Measured transmission coefficients between (a) co-polarized LB and HB antennas, and (b) cross-polarized LB and HB antennas.

As shown in Fig. 6, the measured and simulated HB patterns without distortions are achieved in the 1.63-2.83 GHz (53.8%) despite the presence of the LB antenna in the antenna array, demonstrating the effectiveness of the segmented spirals. In addition, the segmented spiral also has the capability to suppress cross-band coupling in the HB. As given in Fig. 7, the co-polarized and cross-polarized isolations between the LB and HB dipoles are improved to 20 dB and 24 dB, respectively.

III. CONCLUSION

Under the precise guidance of CMA, a dual-functional segmented spiral is developed as the radiator of the LB antenna, which mitigates the higher-order modes responsible for the scattering and coupling. In the dual-band antenna array, HB radiation patterns maintain stable without distortions, and cross-band isolations in the HB are improved to over 20 dB.

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