An Interdigitated Structure-Based, Electrically Small Dipole Antenna with Enhanced Bandwidth

Xiaoming Chen[1], Ming-Chun Tang[1], Da Yi[1]
[1]College of Communication Engineering
Chongqing University
Chongqing, China
cxm849895231@126.com, tangmingchun@cqu.edu.cn, yida_cqu@cqu.edu.cn

Richard W. Ziolkowski[2]
[2] Global Big Data Technologies Centre
University of Technology Sydney
Ultimo NSW 2007, Australia
richard.ziolkowski@uts.edu.au

***Abstract*—A wideband, electrically small dipole antenna with stable radiation performance is presented. Inspired by the recently proposed metasurface antennas, a coax-fed dipole antenna with the periodic patches as the near-field resonant parasitic (NFRP) elements is first investigated. It exhibits the identical operating mechanisms to the metasurface antennas with wide bandwidth property and uniform radiation patterns. Next, through utilizing the interdigitated structures on the NFRP element, an electrically small version is realized. A 14.4% −10-dB fractional impedance bandwidth along with a stable realized gain ~ 1.5 dBi over the entire band is achieved. The antenna has its potential applications in future wideband space-limited systems.**

Keywords — Electrically small antennas; interdigitated structure , near-field resonant parasitic elements

I. INTRODUCTION

As is well known, electrically small antennas (ESAs) suffer from narrow bandwidth and low radiation efficiency which hinder their practical applications in wideband wireless communication systems. There are many methods to address this issue. For example, one can place multiple near-field resonant parasitic (NFRP) elements around the driven elements [1]-[3] to exhibit wide bandwidth. Also, the active elements can be employed to integrate into the ESA systems [4]-[5]. In this paper, we shall introduce an ESA design with an interdigitated structure-based NFRP element. Its bandwidth is significantly enhanced without utilizing multiple NFRP elements or active elements.

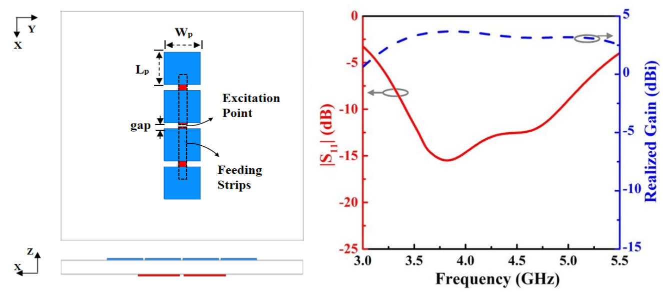
II. ANTENNA DESIGN

A. *Compact Metasurface-inspired NFRP antenna*

Inspired by the metasurface antenna design concept in [6]-[8], a NFRP antenna is proposed, as shown in Fig. 1(a). The NFRP antenna is driven by a simple center-fed dipole. A 4×1 array of metal patches acts as a set of NFRP elements. The driven dipole is located immediately beneath and is parallel to the patch array. The corresponding radiation performance of the antenna is also shown in Fig. 1(b). A wide fractional bandwidth of 34.7% together with stable realized gain of ~2.6 dBi is observed.

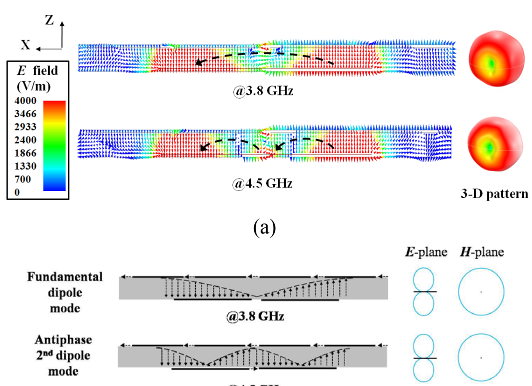
B. *Operating Mechanism*

Fig. 2 provides the *E*-field distribution between the NFRP patches and driven dipole on *zox*-plane at two resonant frequencies and corresponding operation mechanisms. At the lower resonant frequency 3.8 GHz, the *E*-field beneath the NFRP patches resembles the fundamental electric dipole mode, except the radiations from the gaps. When the antenna operates at 4.5 GHz, the orientation of the *E*-field at two sides of the ground slot is anti-parallel. This is due to the series and shunt capacitances that arise from the center gap and that between the patches and the dipole, respectively. As a result, the NFRP patches operate in the antiphase 2nd dipole mode and, hence, widen the operational bandwidth and yield uniform radiation patterns.



(a) (b)

Fig. 1. (a) Geometry of the proposed NFRP antenna. (b) Simulated $|S_{11}|$ and realized gain values of the antenna.



(a)

(b)

Fig. 2. (a) Simulated electric field distribution on *zox*-plane and radiation patterns at 3.8 and 4.5 GHz of the dipole-fed MSA and (b) the sketch of the operation mechanism.

C. *Further Miniaturization*

Here, the antenna size will be miniaturized from two aspects. The first is evolving gaps into interdigitated gaps.

Compared with the common gaps, interdigitated gaps can provide more capacities, lower the resonant frequency, and thus miniaturize the electric length. The second is decreasing height of the substrate, which can elevate the capacitance coupling level between the driven element and the NFRP patches, and lower the antenna's electrical profile. Fig. 3 shows the evolution of NFRP antennas. It is readily seen that when the finger length of the interdigitated gaps increases and the substrate height decreases, the antenna with a given size would work in a much lower frequency range, which demonstrates that the electrical size witnesses a strong decrease.

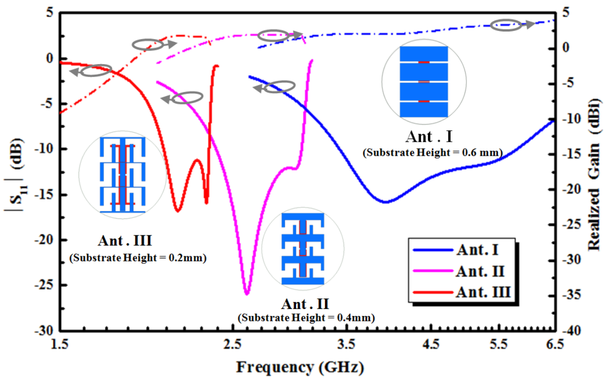


Fig. 3. The simulated $|S_{11}|$ and realized gain values as functions of the source frequency of the evolution of NFRP dipole antenna.

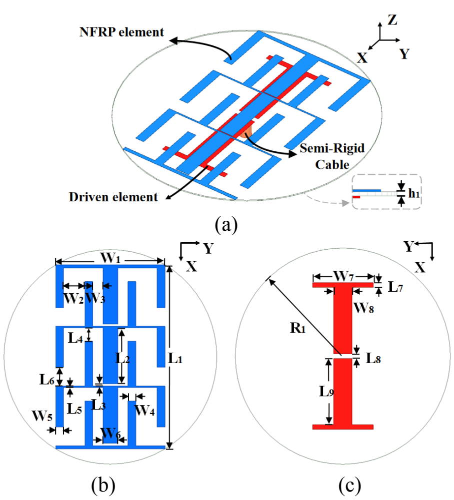


Fig. 4. Geometry of the optimized NFRP dipole ESA. (a) 3D view. (b) Top view of the NFRP element. (c) Bottom view of the top-hat loaded dipole.

TABLE I. DIMENSIONS OF THE WIDEBAND NFRP ESA (UNIT: MILLIMETERS)

h_1=0.203	L_1=39.48	L_2=12	L_3=0.5	L_4= 2.9
L_5=0.3	L_6=4.0	L_7=1.0	L_8=1.0	L_9=14.1
R_1=23	W_1=23.6	W_2=4.6	W_3=2.2	W_4=1.7
W_5=1.7	W_6=3.2	W_7=13	W_8=4.0	*null*

III. SIMULATED RESULTS

The most electrically small one from the above evolution process in Section II was proposed in Fig. 4. The optimized parameters are listed in Table I. The simulated $|S_{11}|$ and realized gain values are displayed in Fig. 5. It is observed that two resonant frequency points overlap over a wide bandwidth. The fractional bandwidth reaches 14.4%, which is ~ 2.5 times larger than that of a standard NFRP ESA with the same electrical size ka = 0.987. An average realized gain of ~1.5dBi together with uniform radiation patterns are also achieved.

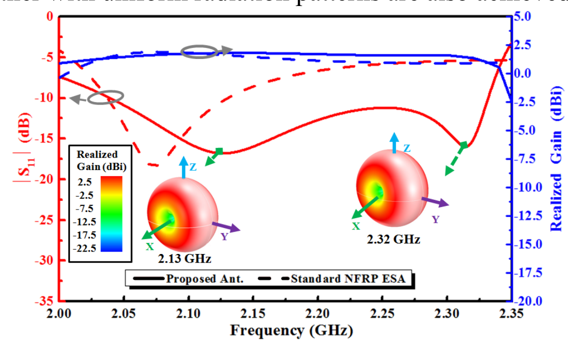


Fig. 5. Simulated $|S_{11}|$ and realized gain values of the proposed antenna and standard NFRP ESA. Inset are 3-D radiation patterns at resonant frequencies.

IV. CONCLUSION

An interdigitated structure-based, electrically small antenna with stable radiation performance is presented. It utilizes only one NFRP element to realize the miniaturization, relatively wide bandwidth, and stable radiation behavior. The introduction of the interdigitated NFRP element could do good to reduce its electrical length but maintain the stable radiation characteristics. Finally, a 14.4% fractional impedance bandwidth, which is ~2.5 times wider than a standard NFRP ESA with the same electrical size, is achieved. Its performance characteristics are attractive for future wideband space-limited communication systems.

REFERENCES

[1] R. W. Ziolkowski, P. Jin, and C.-C. Lin, "Metamaterial-inspired engineering of antennas," *Proc. IEEE*, vol. 99, no. 10, pp. 1720–1731, Oct. 2011.

[2] P. Jin, R. W. Ziolkowski, "Multi-frequency, linear and circular polarized, metamaterial-inspired, near-field resonant parasitic antennas," *IEEE Trans. Antennas Propag.*, vol. 59, no. 5, pp. 1446–1459, May 2011.

[3] M.-C. Tang, X. Chen, M. Li, and R. W. Ziolkowski, "Particle swarm optimized, 3-D-printed, wideband, compact hemispherical antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 17, no. 11, pp. 2031–2035, Nov. 2018.

[4] T. Shi, M.-C. Tang, Z. Wu, H-X. Xu, and Richard W. Ziolkowski, "Improved signal-to-noise ratio, bandwidth-enhanced electrically small antenna augmented with internal non-Foster elements," *IEEE Trans. Antennas Propag.*, vol. 67, no. 4, pp. 2763–2768, Nov. 2019.

[5] M.-C. Tang, and R. W. Ziolkowski, "Frequency-agile, efficient, near-field resonant parasitic monopole antenna," *IEEE Trans. Antennas Propag.*, vol. 62, no. 3, pp. 1479–1483, Mar. 2014.

[6] W. Liu, Z. N. Chen, and X. Qing, "Metamaterial-based low-profile broadband mushroom antenna," *IEEE Trans. Antennas Propag.*, vol. 62, no. 3, pp. 1165–1172, Mar. 2014.

[7] W. Liu, Z. N. Chen, and X. Qing, "Metamaterial-based low-profile broadband aperture-coupled grid-slotted patch antenna," *IEEE Trans. Antennas Propag.*, vol. 63, no. 7, pp. 3325–3329, Jul. 2015.

[8] F. H. Lin and Z. N. Chen, "A method of suppressing higher order modes for improving radiation performance of metasurface multiport antennas using characteristic mode analysis," *IEEE Trans. Antennas Propag.*, vol. 66, no. 4, pp. 1894–1902, Apr. 2018.