Broadband Conformal End-fire Monopole Log-periodic Antenna Array

Chao Chen, Jiandan Zhong, and Yi Tan

College of Communication Engineering
Chengdu University of Information Technology, Chengdu, 610225, China
tang59690508@163.com, heke79382@163.com, colorfulyn@163.com

Abstract **─** The paper presented a broadband conformal end-fire monopole log-periodic dipole antenna array that can cover 2GHz-18GHz and have a good end-fire radiation pattern. The proposed monopole log-periodic antenna has a simple feed network, which uses slot microstrip lines as the feed network. The monopoles are designed on both sides of the copper substrate according to certain rules. The proposed 2G-18GHz conformal monopole log-periodic antenna array that consists of a metal cylinder, antennas fixed in metal inverted cone, and twelve monopole log-periodic antenna arrays. Two types monopole log-period antenna arrays conforming to a metal cylinder consisting of 2GHz-6GHz monopole log-periodic antenna unit and 6GHz-18GHz antenna unit 30° evenly placed in a wedge-shaped groove of a metal cylinder. The measured results show that the 2GHz-18GHz end-fire antenna array are available and have good end-fire radiation.

Index Terms **─** Conformal antenna, end-fired, monopole log-periodic antenna array, metal cylinder.

I. INTRODUCTION

In 1957, Rumsey first proposed non-frequency-variable antennas, and developed various types of broadband antennas [1]. In 1960, Dwigt Isbell of the University of Illinois proposed a log-period array of antennas [2]. In 1961, R. L. Carrel used the transmission line theory to propose the equivalent circuit of the log-periodic antenna [3]. For nearly 60 years, the design rules for log-period dipole antennas (LPDA) have been based primarily on the results of two researchers, Isbell and Carrel [3-6].

From the analysis of LPDA antenna array structure, the research on LPDA mainly focuses on three aspects: (1) designing a wide-band feeding structure [7,8]; (2) changing the shape of the dipole unit [9,10]; (3) combine broadband feed networks with new vibrator unit structures [11,12]. From the perspective of LPDA antenna array performance, the research mainly focuses on three aspects: (1) low profile [13]; (2) dual polarization [14]; (3) miniaturization technology [15]. Since the longest and the shortest vibrators of the logarithmic period antenna array determine the lowest frequency and the highest frequency of the LPDA antenna array, the bandwidth of the antenna is determined. The broadband monopole log-periodic is designed according to the principle that is proposed in [16]. In today's increasing miniaturized electronic devices, how to reduce the size of the antenna in the case of satisfying the antenna performance. Generally, the method of miniaturizing the antenna is mainly (1) loading method; (2) dipole folding method; (3) dipole tilt method; (4) reducing feed structure; but the antenna is generally miniaturized while having a wide frequency band width and reduced gain, etc.

In this paper, we designed 2G-6GHz end-fire monopole antenna array and 6G-18GHz end-fire monopole antenna array. The designed end-fire monopole log-periodic antenna array uses the slot line as the feed circuit. The monopoles are printed on both sides of the dielectric plate according to a certain rule, and then the dielectric plate having the monopole is placed between the groove lines. These sheet metal pieces are monopole oscillators and have a trapezoidal distribution. These novel complementary monopoles form a novel monopole log-periodic antenna array. In the design of the monopole log- periodic antenna array, the monopole oscillator is in the form of a substrate plane, which avoids the processing error in a small distance and causes the coincidence of the adjacent monopole to affect the performance of the antenna array. At the same time, the radiation area of the antenna array is expanded. 2GHz-6GHz monopole log-periodic antenna unit and 6GHz-18GHz antenna unit 30° evenly placed in a wedge-shaped groove of a metal cylinder. The measured results show that the 2GHz-18GHz end-fire antenna array are available and have good end-fire radiation.

II. ANTENNA DESIGN AND ANALYSIS

The end-fire monopole antenna array is shown in Fig. 1. The relationship between the parameters of the monopole log-periodic antenna array is as follows:

$$tg\theta = \frac{H_1}{R_1} = \frac{H_2}{R_2}, \tag{1}$$

$$\sqrt{\tau} = \frac{H_n}{H_{n-1}}, \tag{2}$$

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$$\mathrm{h} = \sqrt{\tau}/(\Delta\tau)^2 \times H_n, \quad (3)$$

where τ is the scale factor, Δτ is the introduced parameter and θ is the opening angle of the unipolar log periodic antenna array.

As can be seen from Fig. 1, H_1 is the height of the monopole with the lowest frequency. The dielectric plate printed with the monopole is placed on the two sides of the slot line, so that, the feed phase of the adjacent monopole is opposite. The substrate with monopole drivers is Rogers RO4350 substrate with dielectric constant of 3.66, loss tangent of 0.004 and its thickness is 0.5mm. The substrate with feeding network is Rogers RO 3210 with dielectric constant of 10.2, loss tangent of 0.003 and its thickness is 1mm.

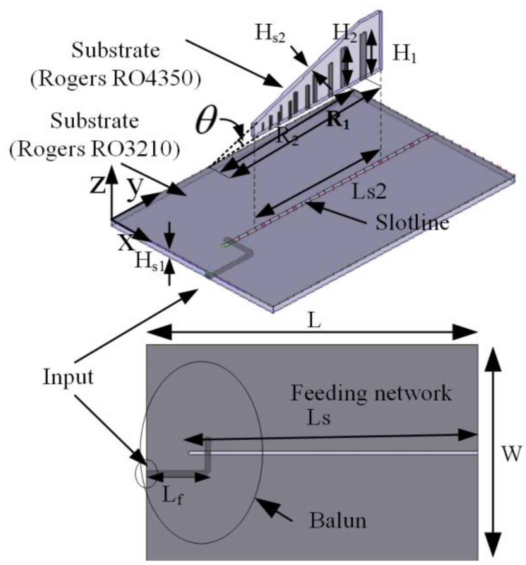

Fig. 1 Overall view of the monopole log-periodic end-fire antenna array with parameter definitions.

The feeding network is microstrip-to-slotline transition, which can provide the balance input for monopoles. The slotline has a characteristic impedance of 80Ω. The microstrip-to-slotline transition has a characteristic impedance of 50Ω. In the design of the feeding network, a microstrip stub and slot stub are inserted to inprove the impedance matching. The equivalent circuit of the microstrip-to-slotline transition is shown in Fig. 2. The open-circuit microstrip stub and the short-circuit slotline are represented as follows:

$$Z_{oc} = -jZ_{mso}\cot(\phi_{mso}), \quad (4)$$

and

$$Z_{sc} = +jZ_{sls}\tan(\phi_{sls}). \quad (5)$$

The proposed monopole log-periodic antenna array consists of microstrip-to-slotline transition as the feeding part and twelve monopoles oriented vertically over ground whose lengths and spacing are decided by log-periodic design principles (formula 1,2,3).

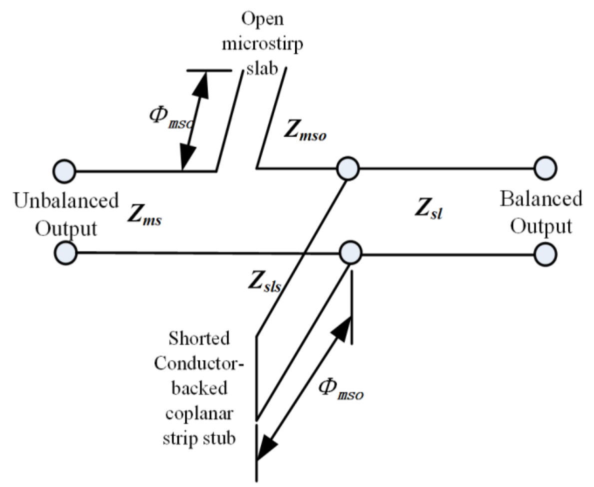

Fig. 2. Equivalent circuit of microstrip-to-slotline transition.

Each of these monopoles attached to both sides of the slotline serves as a driver for the antenna. Also, attached to this slotline are horizontal microstrip lines with their images, and form open-circuited transmission lines. The lengths of these monopoles are related with their first resonance occurs at a frequency which is related to the resonant frequencies of adjacent monopoles by the square root of the design ratio τ. If the longest monopole has a resonant frequency f_0, the monopole immediately in front of it will have a higher resonant frequency $f_0/\sqrt{\tau}$. The entire array is fed at one point by placing a generator on the slotline. The open-circuited monopoles present an impedance to transmission line.

To experimentally verify the proposed end-fire monopole log-periodic antenna, two types of antennas based on the previously design principle is fabricated and assembled. The design of antennas are optimized by using ANSYS Electronics Desktop v16.1. An Agilent N5230A network analyzer and microwave anechoic chamber were used for measurements.

A. Design of 2GHz-6GHz monopole log-periodic antenna

According to the design principle, the 2GHz-6GHz monopole log-periodic antenna is fabricated and assembled in Fig. 3. The dimensions of 2GHz-6GHz monopole log-periodic antenna are revealed in Table 1.

ANYSYS Electronic Desktop v16.1, based on the finite-element method (FEM), was used for the simulations of the 2GHz-6GHz end-fire monopole log-periodic antenna. An Agilent N5230A network was used for the measurement of the prototype. As shown in Fig. 4, the measured and simulated reflection coefficients of the optimized antenna were found to be in closed agreement. The measured bandwidth for the -10dB reflection coefficient covers 2GHz-6GHz.

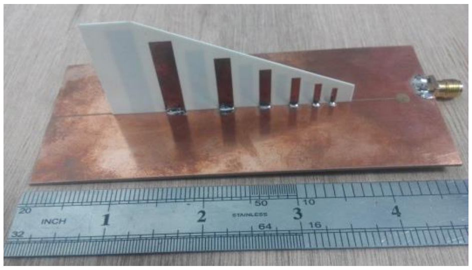

Fig. 3. Fabricated 2GHz-6GHz end-fire monopole log-periodic antenna

Table 1: Dimensions of 2GHz-6GHz end-fire monopole log-periodic antenna (mm)

H_1	H_2	H_{s1}	H_{s2}	W
30.6	26.5	1	0.5	50
L	θ	L_s	L_{s2}	L_f
120	16.2º	107.8	74.5	15

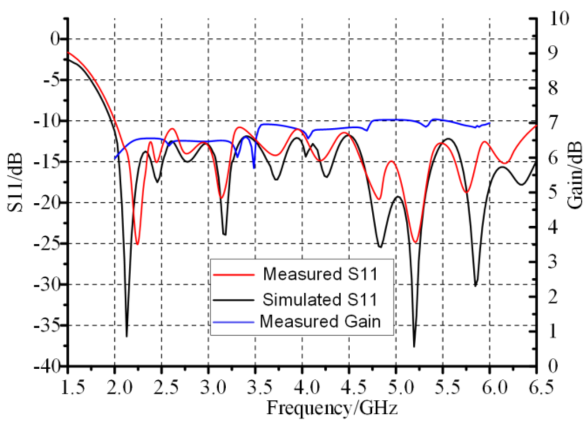

Fig. 4. Refection coefficient and measured gain in the end-fire direction of the 2GHz-6GHz monopole log-periodic antenna.

The simulation result closely resembles the measured result at the operating bandwidth validating the design principle of the broadband end-fire monopole log-periodic antenna. The measured gain in the end-fire direction was found to be 6dB-7dB across the operating bandwidth, as shown in Fig. 4. The antenna exhibits high gain throughout the operating band, the antenna is suitable for transmitting and receiving applications in the wideband wireless communication systems.

Figure 5 shows the simulated and measured radiation patterns of the proposed antenna. It can be seen that the measured radiation patterns agree well with the simulated ones. The measured half-power beam width (HPBW) is in the range of 30º-45º in YOZ plane and 45º-65º in XOY plane. And the proposed antenna has a good end-fire radiation pattern.

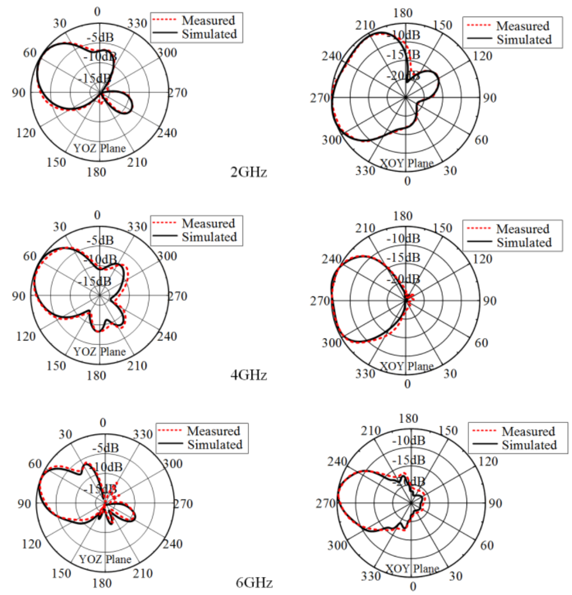

Fig. 5. Simulated and measured normalized radiation pattern of the monopole log-periodic antenna at 2GHz, 4GHz, 6GHz.

B. Design of 6GHz-18GHz monopole log-periodic antenna

According to the design principle, the 6GHz-18GHz monopole log-periodic antenna is fabricated and assembled in Fig. 6. The dimensions of 6GHz-18GHz monopole log-periodic antenna are revealed in Table 2.

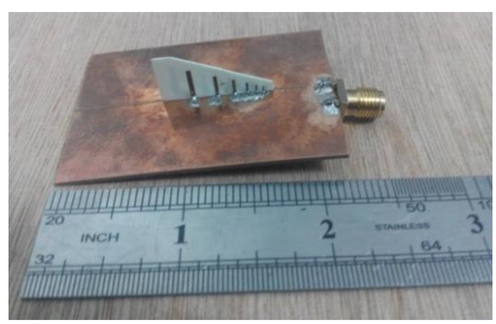

Fig. 6. Fabricated 6GHz-18GHz end-fire monopole log-periodic antenna

Table 2: Dimensions of 6GHz-18GHz end-fire monopole log-periodic antenna (mm)

H_1	H_2	H_{s1}	H_{s2}	W
8	6.8	1	0.5	30
L	θ	L_s	L_{s2}	L_f
45	16°	39	23.6	8

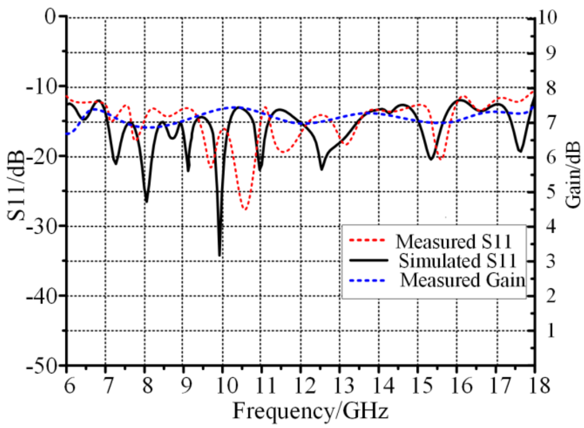

Fig. 7. Refection coefficient and measured gain in the end-fire direction of the 6GHz-18GHz monopole log-periodic antenna.

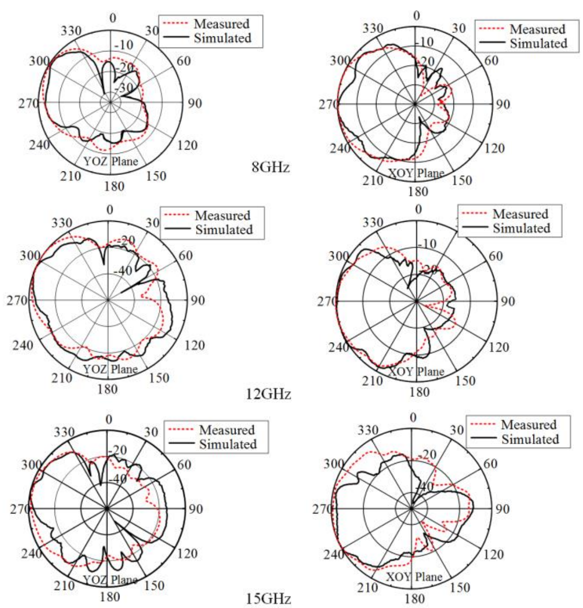

Fig. 8. Simulated and measured normalized radiation pattern of the monopole log-periodic antenna at 8GHz, 12GHz, 15GHz.

ANYSYS Electronic Desktop v16.1, based on the finite-element method (FEM), was used for the simulations of the 6GHz-18GHz end-fire monopole log-periodic antenna. An Agilent N5230A network was used for the measurement of the prototype. As shown in Fig. 7, the measured and simulated reflection coefficients of the optimized antenna were found to be in closed agreement.

As shown in Fig. 7, the measured bandwidth for -10dB reflection coefficient covers 6GHz-18GHz. The simulation result closely resembles the measured result at the operating bandwidth validating the design principle of the broadband end-fire monopole log-periodic antenna. The measured gain in the end-fire direction was found to be 6.5dB-7.5dB across the operating bandwidth. The antenna exhibits high gain throughout the operating band, the antenna is suitable for transmitting and receiving applications in the wideband wireless communication systems.

Figure 8 shows the simulated and measured radiation patterns of the proposed antenna. It can be seen that the measured radiation patterns agree well with the simulated ones. And the antenna has good end-fire radiation pattern.

III. MONOPOLE LOG-PERIODIC ANTENNA ARRAY RADIATION PATTERN ON METAL CYLINDER

The 2G-18GHz conformal monopole log-periodic antenna array consists of a metal cylinder, a fixed antenna metal inverted cone, and twelve monopole log-periodic antenna arrays. Two types of monopole log-period antenna arrays conforming to a metal cylinder consisting of a 2GHz-6GHz monopole log-periodic antenna unit and a 6GHz-18GHz antenna unit 30° evenly placed in a wedge-shaped groove of a metal cylinder as shown in Fig. 9 (a). The composition is shown in Fig. 9. To verify the performance of the new unipolar log-periodic antenna array, we tested conformal monopole log-periodic antenna array as shown in Fig. 10.

The top of the monopole dielectric plate of the monopole log-periodic antenna array is flush with the surface of the metal cylinder. Adding a dielectric sleeve outside the antenna keeps the appearance of the metal cylinder smooth, so that the monopole log-periodic antenna array conforms to the metal cylinder without affecting the aerodynamic distribution.

Since the monopole log-periodic antenna array is applied to the direction finding, only one monopole is considered to be fed, and the other monopole are matched with the resistance of 50 ohms. Due to the symmetry of the monopole log-periodic antenna array from 2 GHz to 18 GHz, we tested only two of the new 2 GHz to 18 GHz unipolar log-periodic antenna arrays as shown in Fig. 9 (b). As shown in Fig. 11, the monopole log-periodic antenna array has good end-fire radiation characteristics. The monopole log-periodic antenna array has good end-fire radiation characteristics.

Due to the influence of the metal cylinder and the antenna floor, the monopole log-periodic antenna array has an approximation. It can be seen from Fig. 11, due to the influence of the gap of the feeding circuit, the radiation pattern of the high frequency band of the antenna array is depressed and the side lobes are increased at the high frequency point. However, the radiation patterns of the antenna elements at different angles in the antenna array can cover the axial direction of the metal cylinder, which meets the target of the antenna array radiation, and has a good application prospect on the metal body.

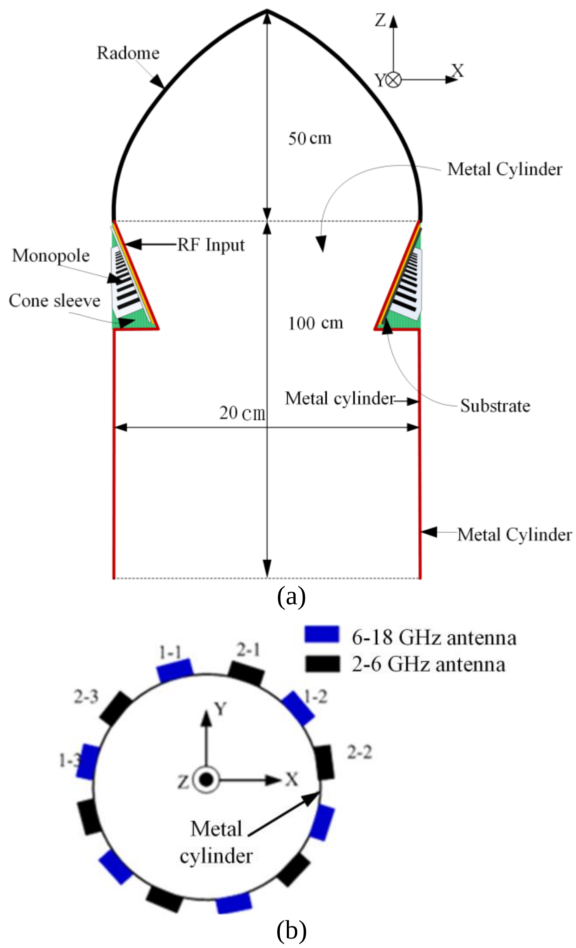

Fig. 9. Conformal monopole log-periodic antenna array on metal cylinder: (a) side view and (b) top view.

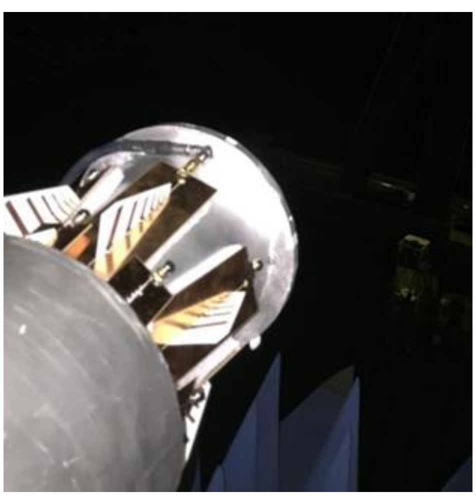

Fig. 10. 2 GHz-18 GHz monopole antenna array test picture.

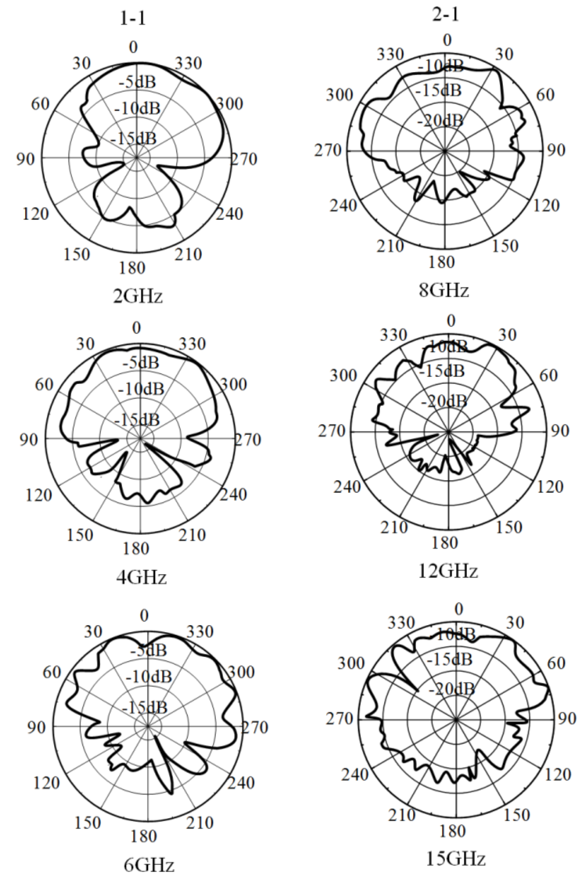

Fig. 11. Radiation pattern of XOZ plane.

IV. CONCLUSIONS

The paper uses two monopole log-periodic antenna arrays (2GHz-6GHz, 6GHz-18GHz monopole log-periodic antenna array) to form an end-fired directional antenna array covering 2GHz-18GHz. Two monopole log-periodic antenna arrays are alternately embedded in an inverted conical metal body. While maintaining the aerodynamic layout, the conformality of metal cylinder is realized. The measurement results show that the proposed antenna array can cover from the 2GHz to 18GHz. The conformal end-fired antenna array has good end-fire radiation characteristics and meets the requirements of the direction finding. According to its advantages, the proposed antenna is a good candidate for ultra wideband wireless communications, phase antenna array systems.

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Chao Chen was born in China, in 1979. He received his M.S degree in Sichuan University in 2005. He is currently an Associate Professor in Chengdu University of Information Technology. His research and industrial experience covers a broad spectrum of electromagnetics, including RF, Microwave, Millimeter wave Integrated Circuits and Systems design for Wireless Communication, Navigation, Identification, Mobile TV applications, RFIC/MMIC/MMMIC device modeling, System on Chip (SoC) and System in Package (SiC) Design.

Jiandan Zhong received his M.S. and Ph.D. degrees in Chengdu University of Information Technology in 2010 and Universtiy of Electronic Science and Technology of China in 2017. He is now Lecturer with College of Communication Engineering, Chengdu University of Information Technology. His current research interests include wideband antennas, patch antennas and wireless communication and signal and information processing.

Yi Tan is now Lecturer with College of Communication Engineering, Chengdu University of Information Technology. His research activities are electromagnetic meta-material and its application in microwave engineering area, FDTD and CAD analysis for the metamaterial model and characteristics.