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RESEARCH PAPER

Novel SRR-loaded CPW-fed UWB antenna with wide band-notched characteristics

HAIJUN PENG[1], CHUNHUA WANG[1], LV ZHAO[1] AND JUN LIU[2]

This paper presents the design of a split-ring resonators (SRR) loaded coplanar waveguide-fed ultra-wide band (UWB) antenna. As using the electromagnetic coupling SRR connected by open-ended microstrip lines, this UWB antenna achieves wide band-notched characteristics. The frequency of the proposed antenna operates from 2.37 to 10.93 GHz with a broad notch band covers from 4.96 to 6.15 GHz (IEEE 802.11.ac), the relative stopped bandwidth of the notch band achieves 20.42%. Besides, theoretical analysis and experimental results are proposed to illustrate and validate this proposed antenna.

Keywords: UWB antenna, Wide band-notched, Split-ring resonators, Open-ended microstrip

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I. INTRODUCTION

As the Federal Communication Commission (FCC) allocated 3.1–10.6 GHz for ultra-wide band (UWB) applications in 2002 [1], an era of high-speed and short-distance communication was coming. However, the bandwidth of the UWB system covers about 7 GHz, and there are many other communication systems in this frequency range. Therefore, UWB antennas with band-notched characteristics are required to filter out interference signals generated by other coexisting communication systems. A lot of UWB antennas, which are designed with different band-notched properties, have been reported in recent research papers [2–10].

In [2], a technique with multiple etched slots on the patch and split ring resonators (SRR) coupled to feed line was proposed to obtain an UWB antenna with triple notch bands. An UWB antenna realized triple notch bands by embedding an Omega-shaped slot on the radiating patch in [3]. A compact triple notch bands UWB antenna with complementary co-directional split-ring resonator (CSRR) arranged in the middle of the radiating patch close to the feeding strip was presented in [4]. Similarly, dual notch bands UWB antenna with modified complementary CSRR etched on the patch was fabricated in [5]. Some other UWB antennas realized dual notch bands by using quasi-complementary SRR in [6], and by using two nested C-shaped slots in [7]. Moreover, single notch band UWB antenna realized by stub-loaded SRR was proposed in [8]. In [9], an UWB antenna was configured by utilizing a mushroom-type electromagnetic-bandgap structure to achieve single notch band. Another single notch band UWB antenna consisting of a patch with arc-shaped edge and a partially modified ground plane was presented in [10].

All the antennas mentioned above can achieve their band-notch characteristics as expected. Nevertheless, some techniques they adopted are complicated, which may be unsuitable to be applied in low-cost UWB antenna applications. Furthermore, in some single notch band UWB antennas, the notch bands are not wide enough, so they cannot reject unwanted signals in a wide range. The notch band of the UWB antenna in [8] nearly ranges from 6.21 to 6.57 GHz, and the notch bandwidth is 0.36 GHz. In [9], the notch band has a bandwidth of 0.69 GHz and ranges from 5.62 to 6.31 GHz. The antenna in [10] has a rejection frequency band of 5.11 to 5.98 GHz (notch bandwidth is 0.87 GHz). In fact, most of the unwanted narrow band signals from other communication systems are actually scattered in a wide range, then an UWB antenna with wide band-notched characteristics is required. Hence, inspired by the SRR structure in [11], this paper presents a novel coplanar waveguide (CPW) fed UWB antenna with modified SRR to get wide band-notched characteristics. A circular patch with CPW is fabricated on the front surface of the antenna, and the SRR connected by open-ended microstrip lines are fabricated on the back side. This UWB antenna operates from 2.37 to 10.93 GHz, and the notch band is ranging from 4.96 to 6.15 GHz with bandwidth of 1.19 GHz. The relative stopped bandwidth (RSB) of the notch band is 20.42%, and all the frequency bands of the IEEE 802.11.ac are covered in this notch band of the proposed UWB antenna.

[1]College of Computer Science and Electronic Engineering, Hunan University, Changsha 410082, People's Republic of China
[2]State Grid Hunan Electric Power Company, Changsha 410012, People's Republic of China
Corresponding author:
C. Wang
Email: wch1227164@hnu.edu.cn

II. ANTENNA DESIGN CONSIDERATION

Figure 1(a) shows the structure of a traditional UWB antenna using a circular patch fed by CPW. A modified structure of an

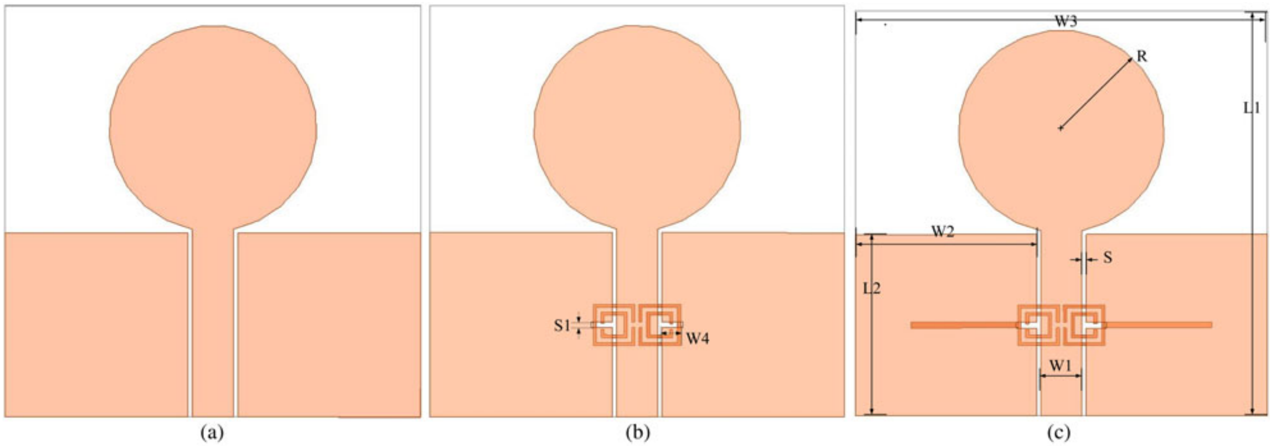

Fig. 1. Schematics of different UWB antennas.

UWB antenna, which incorporates etched stubs and loaded SRR in the middle of the CPW, is illustrated in Fig. 1(b). The structure of the UWB antenna proposed in this paper is charted in Fig. 1(c); a pair of microstrip lines is added and connected to the SRR in this work. Figure 2 displays the enlarged view of the SRR and the microstrip line.

The fabricated prototype of the proposed UWB antenna is demonstrated in Fig. 3. On the top side of this UWB antenna in Fig. 3(a), the circular monopole has a radius R of 12.5 mm and is fed with the CPW having ground plane area of $W_3 \times L_2$, the width W_3 is 50 mm and the length L_2 is 22.4 mm. As a result of the current distributes along the ground plane width and the ground plane acts as an impedance matching circuit, the antenna performance is vitally influenced by the ground plane [12]. A pair of SRR connected by microstrip lines is printed on the back side of the antenna, which is illustrated in Fig. 3(b). When the EM signal spreads along the CPW, it induces an electromotive force on the SRR, and then induces current oscillating between the two rings of the SRR. These oscillating currents between the two rings generate a resonance, which blocks signal propagation at a specific frequency. The calculation of the specific resonance frequency will be discussed in later section. All parameters of the proposed UWB antenna have been listed in Table 1. This proposed UWB antenna was fabricated on a Taconic substrate with $h = 1.575$ mm, dielectric constant ε_r of 2.33 and a loss tangent of 0.0009 to verify its performance.

Figure 4 shows the simulated return losses of the traditional, the modified and the proposed UWB antennas. From the simulated results, the traditional UWB antenna has two transmission poles in the UWB frequency, and the modified UWB antenna with band-notched characteristics has three poles.

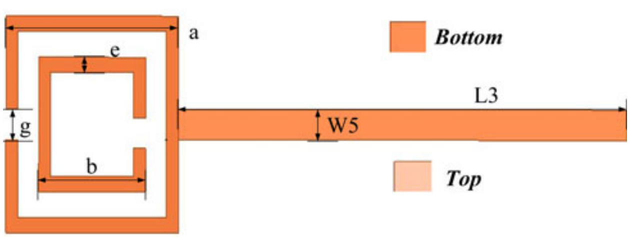

Fig. 2. The enlarged view of the SRR and the microstrip line.

Table 1. Design parameters of the proposed antenna.

Parameters	a	b	e	g	L_1	L_2	L_3	W_1
Length (mm)	5	3.1	0.35	0.7	50	22.4	13	5
Parameters	W_2	W_3	W_4	W_5	S	S_1	R	h
Length (mm)	22	50	6	0.7	0.5	0.7	12.5	1.575

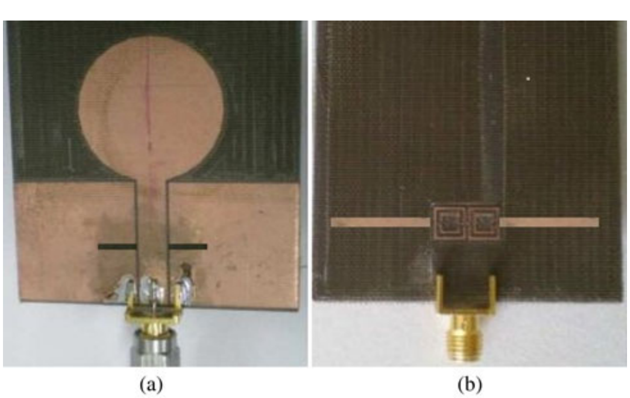

Fig. 3. Fabricated prototype of the proposed UWB antenna.

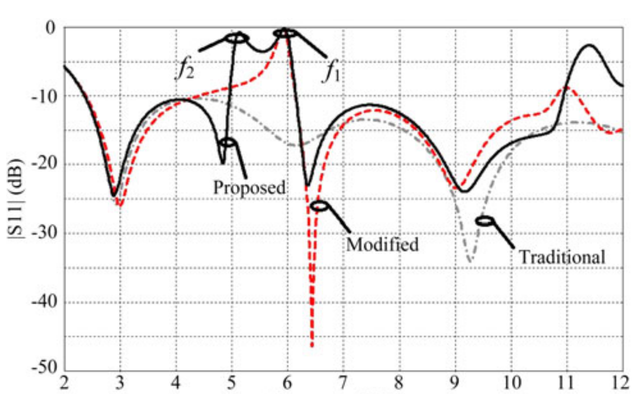

Fig. 4. The simulated return losses of the traditional, modified and proposed UWB antennas.

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Contrastively, the proposed UWB antenna possesses four poles, and the band-notched behavior is obtained from 4.95 to 6.15 GHz ($|S_{11}|$ is bigger than −10 dB). Moreover, the notch band of this proposed UWB antenna has two transmission zeros (f_1 and f_2).

III. RESONANCE FREQUENCY ANALYSIS

According to [13], the resonance frequency f_1 of the SRR is given as:

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{1}{L_r C_r}}, \qquad (1)$$

where the C_r is the total equivalent capacitance of the SRR and can be evaluated as:

$$C_r = \left(2a_{avg} - \frac{g}{2}\right)C_{pul} + \frac{\varepsilon_0 e t_m}{2g}, \qquad (2)$$

where the e and t_m are the width and thickness of the metallic rings, respectively. The ε_0 is the free space permittivity and the average ring dimension a_{avg} can be calculated as:

$$a_{avg} = \frac{a}{2} - e - \frac{a-b}{4}. \qquad (3)$$

The capacitance of C_{pul} is analyzed in [14] and it can be given as follow:

$$C_{pul} = \frac{\sqrt{\varepsilon_e}}{c_0 Z_0}, \qquad (4)$$

where $c_0 = 3 \times 10^8$ m/s and Z_0 is the intrinsic impedance of the transmission line. The ε_e is the effective permittivity of the medium and can be expressed as:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2}. \qquad (5)$$

Based on the analysis in [15], the total equivalent inductance L_r of the SRR can be evaluated as:

$$L_r = 0.0002l\left(2.303\log_{10}\frac{4l}{e} - \gamma\right), \qquad (6)$$

where the constant $\gamma = 2.853$ and the wire length $l = 4a–g$. Thus, the resonance frequency f_1 of the SRR can be evaluated by using (1)–(6). Moreover, as charted in Fig. 1(c), a pair of microstrip lines connecting to the SRR is designed in this work. Hence, equations (7)–(9) are used to evaluate the resonance frequency f_2 of the microstrip lines:

$$f_2 = \frac{c_0}{2 \times W_5}\sqrt{\frac{2}{\varepsilon_r + 1}}, \qquad (7)$$

$$f_2 = \frac{1}{(L_3 + 2\Delta L)\sqrt{\varepsilon_e}\sqrt{\varepsilon_0 \mu_0}}, \qquad (8)$$

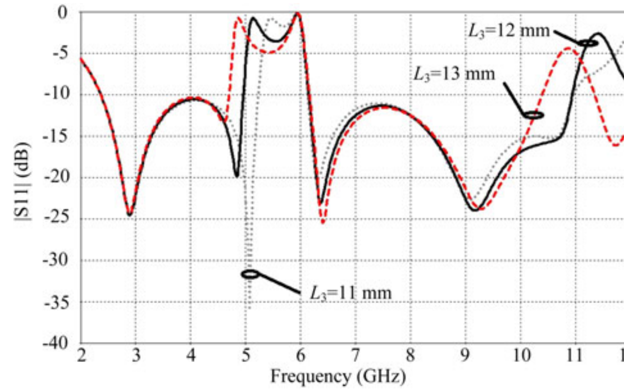

Fig. 5. Simulated return losses versus frequency of the proposed UWB antenna for different L_3.

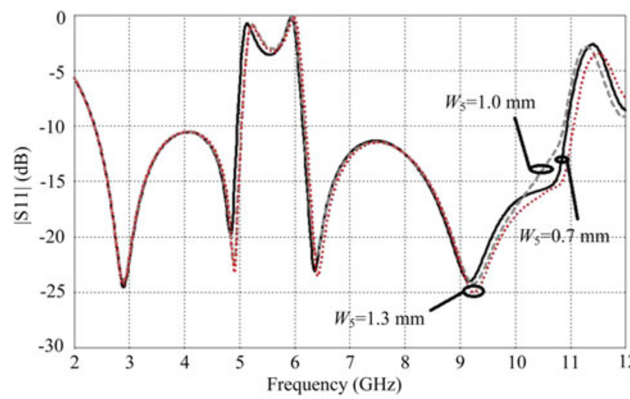

Fig. 6. Simulated return losses versus frequency of the proposed UWB antenna for different W_5.

$$\Delta L = 0.412\frac{(\varepsilon_e + 0.3)((W_5/h) + 0.264)}{(\varepsilon_e - 0.258)((W_5/h) + 0.8)}, \qquad (9)$$

where L_3 is the length of microstrip line, and W_5 is the width of it. It is apparent that the f_2 is separately affected by W_5 in (7) and dominated by L_3 in (8). Simulated results for testifying the influence of W_5 and L_3 on f_2 will be demonstrated in Section IV.

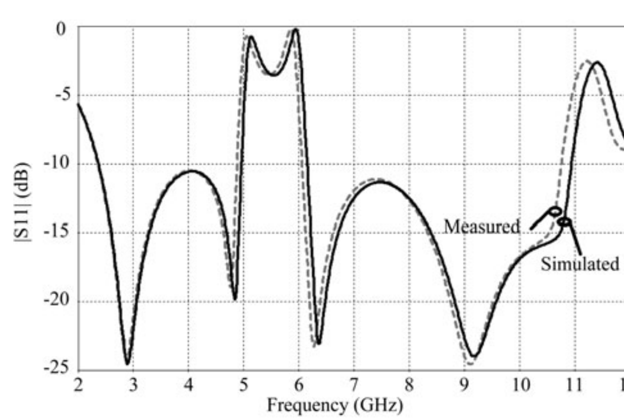

Fig. 7. Simulated and measured return losses versus frequency of the proposed UWB antenna.

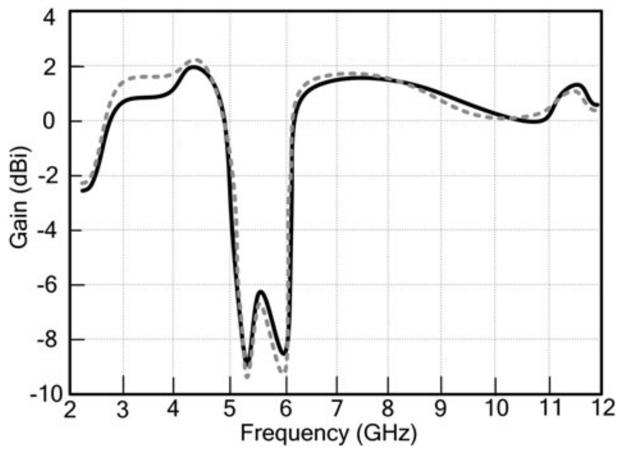

Fig. 8. Simulated (solid line) and measured (dotted line) gain versus frequency of the proposed UWB antenna.

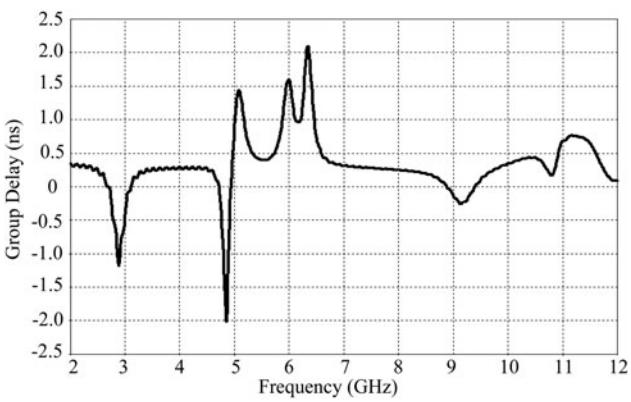

Fig. 9. Measured group delay versus frequency of the proposed UWB antenna.

IV. RESULTS AND DISCUSSIONS

As two different equations of f_2 have been discussed in Section III, different values of W_5 and L_3 are utilized in simulation to testify their effect on f_2. Figure 5 shows the simulated return losses of the proposed UWB antenna for different L_3. It can be figured out from the curves that the resonance frequency f_2 is decreasing as the length of microstrip line L_3 increases, while the resonance frequency f_1 is nearly unchanged. Meanwhile, the bandwidth of the notch band is increasing along with the increasement of L_3. However, the L_3 cannot be lengthened immoderately, as the whole operating frequency of the antenna will be reduced and fails to cover the UWB bandwidth from 3.1 to 10.6 GHz when L_3 increases. Therefore, the $L_3 = 12$ mm is selected as the optimized length in this proposed UWB antenna.

The simulated return losses of the proposed UWB antenna for different W_5 are drawn in Fig. 6. It is denoted in Fig. 6 that the resonance frequency f_1 and f_2 are scarcely changed when the W_5 increases, while the cut-off frequency of the proposed UWB antenna is varied. In accordance with these issues, the width of 0.7 mm is adopted as the optimal option.

In Fig. 7, the simulated and measured return losses versus frequency of the proposed UWB antenna are presented. It is easy to find out that the simulated and measured results are coincided. The proposed UWB antenna operates in the 2.37–10.93 GHz frequency range with notch band from 4.96 to 6.15 GHz, and the RSB of notch band is about 20.42%. The resonance frequency f_1 of SRR is 5.12 GHz and the resonance frequency f_2 of microstrip line is 5.96 GHz, respectively. Figure 8 draws the simulated and measured gain versus frequency of the proposed UWB antenna. At the notch band of 4.96 to 6.15 GHz, the gain reduces sharply (<0 dBi), whereas the gain for the rest of the operating frequency remains acceptable. The return losses and gain performances of the proposed UWB antenna well validate the theoretical analysis in Section III, and indicate that this antenna can efficiently reject unwanted interference signals in the notch band frequency.

Figure 9 shows the measured group delay versus frequency of the proposed UWB antenna. As it can be seen from Fig. 9, the variation of the group delay is relatively stable for the operating frequency, while the variation of the group delay is bigger than 0.5 ns for the notch band. Figure 10 illustrates measured radiation patterns of the *E*- and *H*-planes at three different sample frequencies of 3.0, 7.2, and 10.0 GHz. From Fig. 10, it is obvious that the proposed antenna has acceptable omnidirectional radiation patterns at all three specific frequencies, which indicates that signals can be transmitted efficiently by this UWB antenna in the non-notched band. The group delay and radiation patterns performances denote

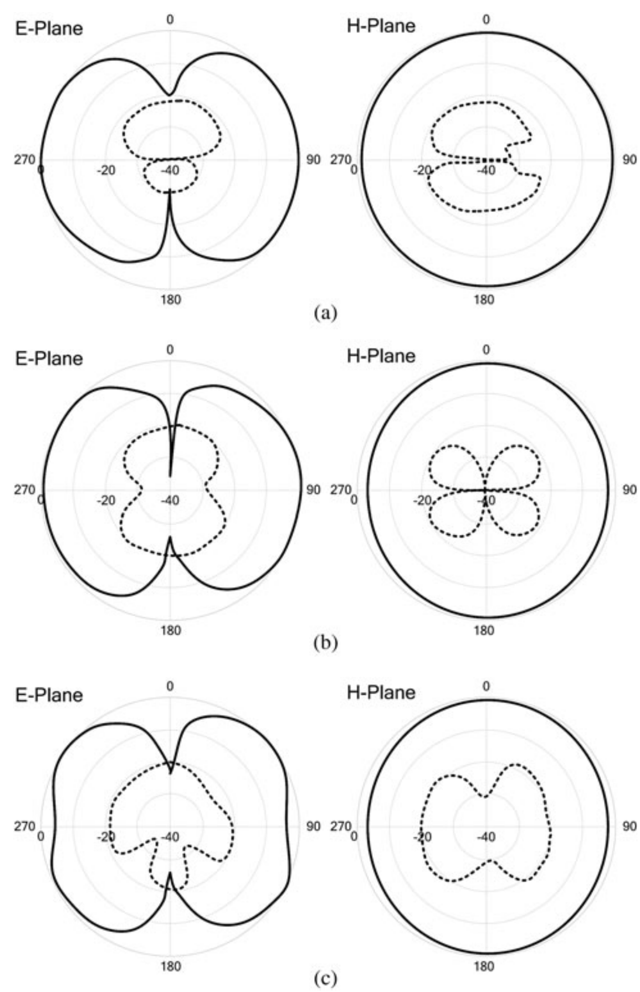

Fig. 10. Measured co-polarization (solid line) and cross-polarization (dotted line) radiation patterns of *E*- and *H*-planes of the proposed UWB antenna at different frequencies: (a) 3.0 GHz, (b) 7.2 GHz, and (c) 10.0 GHz.

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Table 2. Comparison of this work with other UWB antennas.

References	[8]	[9]	[10]	This work
Notch band range (GHz)	6.21–6.57	5.62–6.31	5.11–5.98	**4.96–6.15**
Notch bandwidth (GHz)	0.36	0.69	0.87	**1.19**
RSB (%)	5.63	11.56	15.68	**20.42**

that the proposed UWB antenna is suitable to be applied in most UWB wireless communication systems requiring band-notch characteristics.

The performance comparisons of the proposed antenna with other reported antennas are summarized in Table 2. It is clear that the notch band of the proposed UWB antenna ranges wider than other antennas with larger notch bandwidth of 1.19 GHz. The higher RSB percentage shows that the proposed UWB antenna has wider band-notched characteristics.

V. CONCLUSION

This paper presents a novel SRR-loaded CPW-fed antenna with wide band-notched characteristics for UWB applications. Some designing parameters are optimized by CST and HFSS software. The proposed antenna operates in the range from 2.37 to 10.93 GHz with a wide notch band frequency from 4.96 to 6.15 GHz, and the RSB of notch band is up to 20.42%. Theoretical analysis and experimental results both indicate that this proposed UWB antenna can be utilized in many UWB applications.

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Haijun Peng was born in 1991 in Yongzhou, China. He received the B.S. degree in the major of Information and Communication Engineering from Hunan Institute of Science and Technology, Yueyang, China and his post-graduation is in the field of integrated circuit from the College of Information Science and Engineering, Hunan University, Changsha, China. His research interests are mainly in wireless communication circuit, ultra-low power, and UWB RFIC design.

Chunhua Wang was born in Yongzhou, China, in 1963. He received the B.S. degree from Hengyang Normal College, Hengyang, China, in 1983; the M.S. degree from Physics Department, Zheng Zhou University, Zheng Zhou, China, in 1994; and the Ph.D. degree from the School of Electronic Information and Control Engineering, Beijing University of Technology, Beijing, China, in 2003. He is currently a Professor of College of Information Science and Engineering, Hunan University, Changsha, China. His research interests include current-mode circuit design, filtering, radio frequency circuit, and wireless communications.

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Lv Zhao was born in Xiangtan, China, in 1986. He received the B.S. degree from Hunan University of Science and Technology, Xiangtan, China, in 2008; and the M.S. degree from College of Information Science and Engineering in Guangxi University, in 2012. He is currently studying in Hunan University for the Ph.D. degree. His research interests are focused on RF front-end circuits design and wireless communications.

Jun Liu was born in 1974, received his Ph.D., and was the Professor of Engineering. Currently, he is an engineer at the STATE GRID HUNAN Electric Power Company. His main research interests include optical communications, wireless communications, next-generation networking, and Internet.

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