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E-shaped Patch Antenna Using L-probe for 4G Communication Systems

[1] Juan Zheng, [1, 2, 3] Guohua Hu, [1] Xueyou Hu, [1] Juanjuan Gu

[1] Department of Electronics & Electrical Engineering, Hefei University, Hefei, Anhui 230601, China
[2] Intelligent Perception Technology Institute, Hefei University, Hefei, Anhui 230601, China
[3] Intelligence Computing & Signal Processing of Ministry of Education Anhui University, Hefei 230039, China
[1] Tel.: +86-551-62158565, fax: +86-551-62158561
E-mail: zhj013062@hfuu.edu.cn, guohua_hu@hfuu.edu.cn

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Abstract: To satisfy requirements of 4G communication systems, an E-shaped microstrip antenna with L-probe is presented. In this design, E-shaped patch is introduced to expand the bandwidth by changing the current distribution, L-probe is introduced to increase the bandwidth by counteracting the inductance of the probe. The electrical property of the antenna is analysised using commercially available Finite Element Software, High Frequency Structure Simulator (HFSS), of Ansoft. Results show that the antenna proposed in this paper has an impedance bandwidth (S11<-10dB) of 33.2 %, which can address the need of bandwidth for 4G communication systems. In addition, the effects on the impedance bandwidth made by the parameters are concluded. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: 4G, Broadband antenna, E-shaped microstrip antenna, L-shaped probe.

1. Introduction

China's Ministry of Industry and Information Technology (MIIT) issued 4G licenses to three Chinese Telecom Operators on 4 December 2013, marking the arrival of a new era in China's high-speed mobile network. The government has allocated 210 MHz of 4G spectrum to the country's three operators for the provision of TD-LTE service. China Mobile got access to 130 MHz of spectrum (1880-1900 MHz, 2320-2370 MHz, 2575-2635 MHz), China Unicom will get 40 MHz (2300-2320 MHz, 2555-2575 MHz) and China Telecom will also have 40 MHz (2370-2390 MHz, 2635-2655 MHz). Owing to the increased bandwidth, the most obvious advantage of the 4G communication systems is its amazing speed. The data rate is up to 100 Mbit/s for high mobility and 1 Gbits/s for low mobility. A 4G communication system is proposed to become a platform capable of providing more interoperability across multiple communication protocols, and user friendly, innovative, and secure applications [1-2].

The increasing requirements for 4G systems call for application of wideband antennas at transmitter and receiver. As one of the most interesting and promising areas of 4G communications, wideband antenna techniques can significantly increase system capacity, improve link quality, and extend cell coverage [2].

The microstrip antenna has received considerable attention due to its advantages such as light weight, low profile, compatibility integration with other circuits and subsystems and easy of fabrication.

However, the standard microstirp antenna has the drawback of narrow band [3]. In order to overcome this serious drawback, some techniques have been proposed to enhance the bandwidth. These include using thicker substrate with low permittivity constant, introducing parasitic element either in coplanar or stack configuration, and modifying the geometry of common radiator patch by incorporating slots [4]. In particular, the last method is most attractive because it can maintain a single radiating structure and give excellent bandwidth improvement [5-8]. In [5], an E-shaped patch antenna is described for the first time, the authors demonstrated that its bandwidth could exceed 30 %, and it could maintain the simplicity of the patch antenna. However, because of feeding by coaxial probe, this patch would limit the bandwidth. As the coaxial probe would introduce inductance, to compensate probe inductance, the L-probe feeding technique has been proposed [9-10]. This feeding technique would introduce capacitance to compensate portion of the inductance introduced by the coaxial probe, and its impedance bandwidth is usually over 30 %.

In this paper, an E-shaped patch antenna fed by L-shaped probe is presented. The design utilizes E-shaped patch techniques and L-probe feeding to enhance the impedance bandwidth. In order to improve the efficiency of the analysis, the electrical property of the antenna is computed using commercially available Finite Element Software, High Frequency Structure Simulator (HFSS), rather than measurement of fabricated antenna. But this does not affect the validity of the design.

The outline of this paper is as follows. In Section 2, the configuration of our proposed antenna will be described. Section 3 will discuss the effects of the parameters to impedance bandwidth. Section 4 will provide the simulated S-parameters, gains and radiation patterns of the proposed antenna. In Section 5, conclusion will be drawn.

2. Antenna Configuration

The proposed antenna configuration is illustrated in Fig. 1. This antenna is composed of E-shaped patch and L-probe feed. The E-shaped patch with dimensions of W × L is supported by air substrate. The thickness of substrate is h. For the E-shaped patch, two slots are inserted into radiating edge of the patch symmetrically with regard to the x-axis of the patch. The dimension of the slots is Ws × Ls. This patch is supported by L-shaped probe. For the L-probe, it is made of metal. The height of the L-probe is h_p. The length of the L-probe is L_p.

The use of E-shaped patch and L-probe provides the bandwidth enhancement. The principle of the E-shaped patch has been elaborated in [5]. With incorporation of two parallel slots into the microstrip patch, the E-shaped antenna produces two resonances. Therefore the wider impedance bandwidth can be achieved. As shown in [5], the variations of Ls, Ws can significantly affect the bandwidth. Adjusting the Ls can control the two resonances. Adjusting the Ws can control the match.

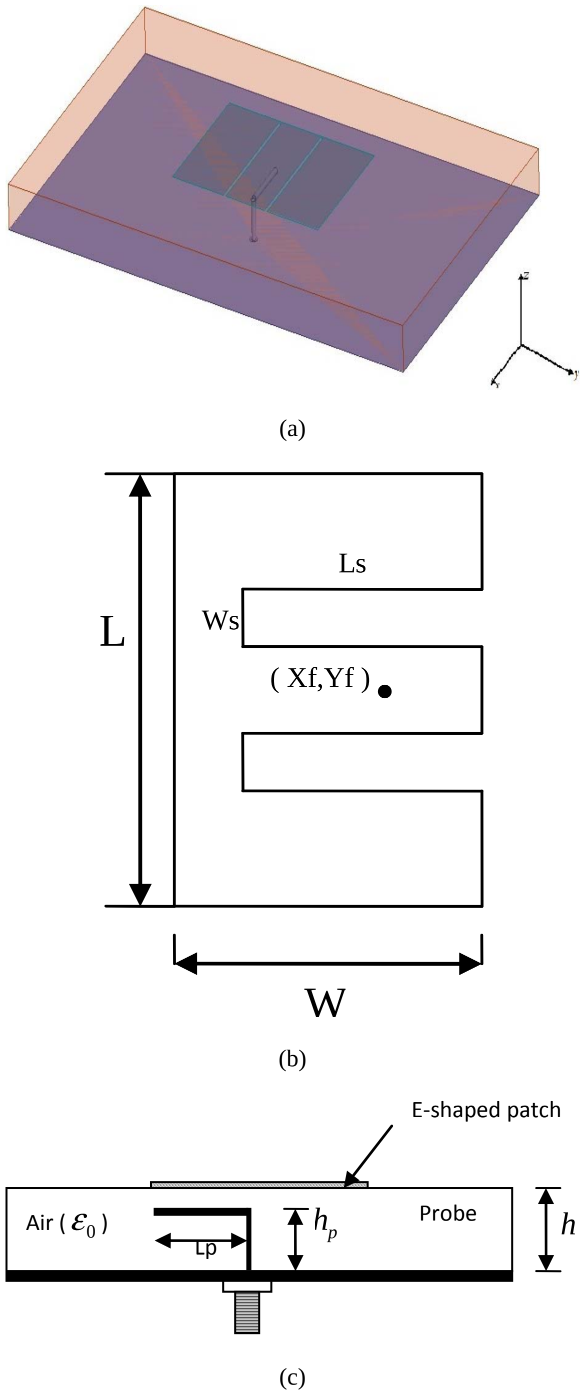


Fig. 1. Configuration of the proposed antenna (a) Three-dimensional view, (b) Top view, (c) Side view.

The principle of L-probe has been elaborated in [9]. For traditional microstrip antenna, increasing the thickness of the substrate can enhance the bandwidth. But for coaxial probe, the bandwidth is limited by the inductance. To overcome this problem, the L-probe is introduced. Using L-probe, the introduced inductance of probe can be easily decreased. The reason for this is that L-probe will introduce capacitance that can counteract or reduce the probe inductance. With the use of a rectangular patch fed by the L-probe, the bandwidth can be significantly enhanced.

For a rectangle patch antenna, the length and the width are calculated as below [3].

$$W=\frac{c}{2f\sqrt{(\varepsilon_r+1)/2}}, \quad (1)$$

$$L=L_e-2\Delta L=\lambda_0/\sqrt{\varepsilon_e}-2\Delta L=\frac{c}{2f_0}\frac{1}{\sqrt{\varepsilon_e}}-2\Delta L, \quad (2)$$

where
c is the velocity of light;
ε_r is the dielectric constant of substrate;
f_0 is the antenna working frequency;
W is the patch non resonant width;
L is the patch actual length.

The effective dielectric constant is ε_e given as

$$\varepsilon_e=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}(1+12\frac{h}{W})^{-\frac{1}{2}} \quad (3)$$

The extension length is Δl given as

$$\frac{\Delta l}{h}=0.412\frac{(\varepsilon_{eff}+0.300)(\frac{W}{h}+0.262)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.813)} \quad (4)$$

Based on the Formula (1-4), the dimensions of the proposed antenna are shown in Table 1. Several key parameters that help to achieve an optimal design are described in Section 3.

Table 1. Dimensions of proposed antenna (units in mm).

Parameters	Values
W	50
W_s	1.2
L	70
L_s	49
L_p	19
h	15
h_p	12.8
feed point	(18,0)

3. Discussion on Key Parameters

In this section, the effects of some key parameters on the impedance bandwidth are studied. The numerical optimization is performed using HFSS^{TM} v13. Fig. 2 shows the variation of the slot length (Ls). Observe that as the slot length Ls increases, the surface current path increases and consequently the two resonant frequencies shift downwards. In brief, Ls plays an important role to control the two resonant frequencies. Thus, the optimized value of Ls for the proposed antenna is 49 mm.

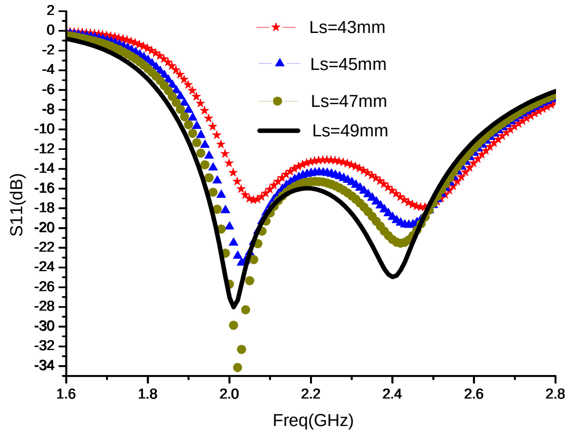


Fig. 2. Simulated reflection coefficients for different lengths of slot.

Fig. 3 shows the reflection coefficients for different width of slot (Ws). The slot width is varied from 1mm to 7 mm. It can be observed that with the increasing of the slot width, the S_{11} at higher frequency doesn't match well. When the Ws becomes even larger, the antenna does not perform as a wide-band one. Again, with the deceasing of the Ws, the two resonant frequencies become distinct and a wide-band match is obtained. In brief, Ws is an important parameter to control the wide-band. Thus, the optimized value of Ws for the proposed antenna is 1 mm.

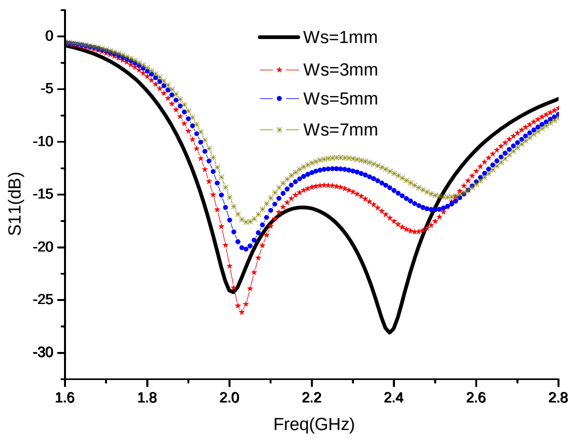


Fig. 3. Simulated reflection coefficients for different widths of slot.

Fig. 4 and Fig. 5 show the variations of the probe length (Lp) and probe height (h_p). Observe that with the length Lp increasing, the first and second resonances shift downwards and that is due to the fact that the probe feed's inductance increases. When the Lp increases to an optimized value, the capacitive effects disappear, which results in better impedance bandwidth. When the Lp continues to increase, the capacitive effects dominate, the lower frequency disappears. Thus, the optimum value of Lp is 19 mm for broadening the impendance bandwidth. As seen from Fig. 5, it can be found that the height of L-probe affects the higher frequency. When the h_p is small, the S_{11} doesn't match well. With the h_p increasing, the higher resonant frequency appears. In brief, h_p is an important parameter to control the higher frequency. Thus, the optimized value of h_p is 13 mm.

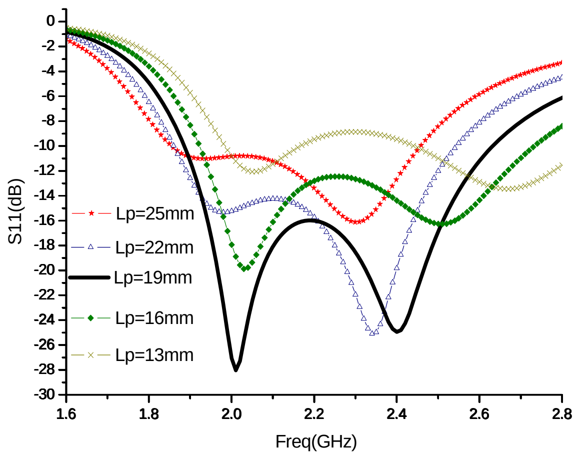


Fig. 4. Simulated reflection coefficients for different lengths of L-probe.

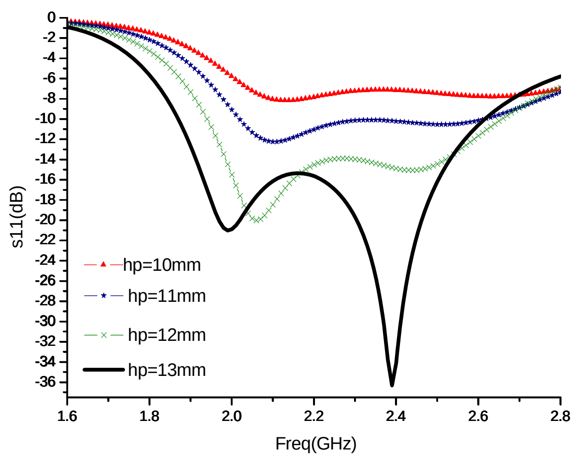


Fig. 5. Simulated reflection coefficients for different heights of L-probe.

4. Simulation Results

Fig. 6 shows the simulated reflection coefficient of the proposed antenna. The frequency covers 1.88 to 2.63 GHz and the fractional bandwidth of S_{11} is 33.3 %. The two resonant frequencies are 2 GHz and 2.4 GHz. From the figure, it can be found that this antenna is suitable for 4G systems. Fig. 7 shows the simulated gain of the proposed antenna. As shown in the figure, the maximum gain of the antenna within the bandwidth is 8.92 dBi at 2.27 GHz, and the gain variation is 1.39 dBi between the frequency ranges of 1.88 GHz to 2.63 GHz. Fig. 8 shows the simulated radiation patterns of the proposed antenna. The radiation patterns are simulated at resonant frequencies of 2 GHz and 2.4 GHz. As shown in the figure, the proposed antenna displays good broadband radiation patterns in the xz-plane (E-plane) and yz-plane (H-plane). Fig. 9 shows the surface current distribution of the proposed antenna at two resonant frequencies. As shown in Fig. 9a, it is note that at the first resonance of 2 GHz, the current distribution is observed with concentration around the slot of the proposed antenna. As shown in Fig. 9b, it is note that at the second resonance of 2.4 GHz, the current distribution is observed with concentration on the edges of the patch.

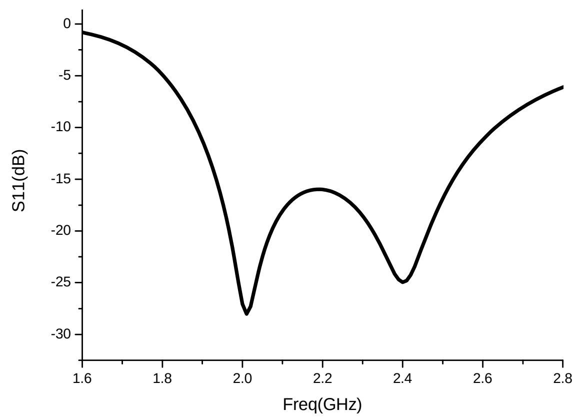


Fig. 6. Simulated reflection coefficients of antenna.

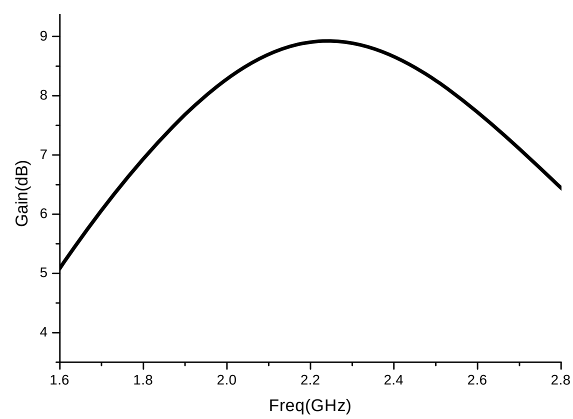
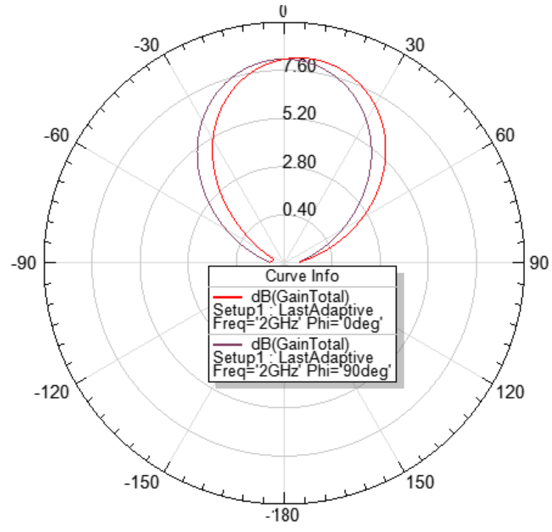
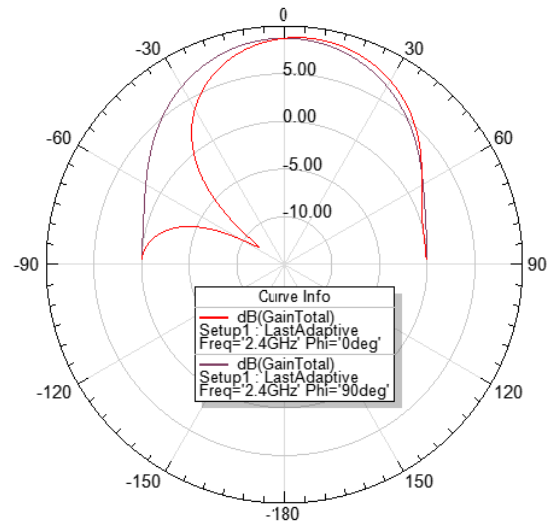


Fig. 7. Simulated gain of antenna.



(a)



(b)

Fig. 8. Simulated radiation patterns of antenna
(a) E-plane and H-plane at 2 GHz,
(b) E-plane and H-plane at 2.4 GHz.

5. Conclusions

In this paper, an E-shaped patch antenna with L-probe feed for 4G communication systems is designed and optimized to achieve a bandwidth of 33.3 % in 1.88-2.63 GHz. The parametric studies have addressed the effects of the length and width of the slots and the length and height of the probe. The information derived from the study will be helpful for antenna engineers to design and optimize the antennas for 4G communication applications.

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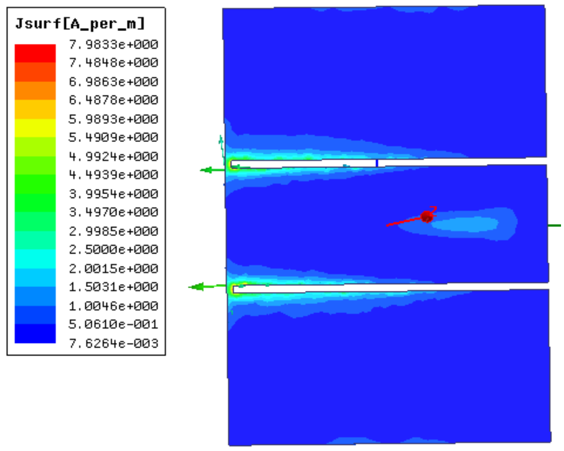
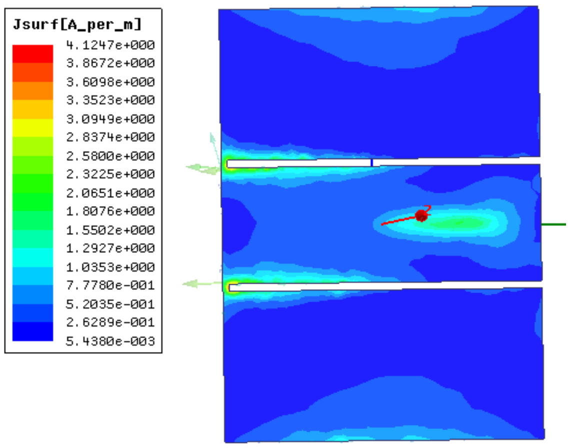


(a)



(b)

Fig. 9. Current distribution of antenna
(a) frequency is 2GHz,
(b) frequency is 2.4GHz.

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