Study of multi-band property of rectangular microstrip patch antenna having different numbers of wide slots

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Abstract: The property of multi-band operation has been studied and investigated analytically through the design of a rectangular patch microstrip antenna having different numbers of wide slots arranged at both the radiating edges. The analyses were carried out using the method of moments simulation software. It is shown that a patch with three slots has a multi-band feature with four resonant frequencies at 1.6, 1.8, 2.65, and 4.83 GHz and adequate values of return loss and gain. It is also shown that a patch with two pairs of wide slots arranged at both the radiating edges has the dual band feature with resonant frequencies at 1.64 and 1.8 GHz and good values of return loss and gain.

Key words: microstrip patch antenna; multi-band property; broadband antenna

There has been considerable interest in investigating the electromagnetic properties of microstrip antennas due to their useful properties such as light weight, conformability, low costs, and the fact that they are simple to manufacture. However, one of the serious limitations of these antennas has been their narrow bandwidth characteristics. The impedance bandwidth of a typical microstrip patch antenna is less than 1% and several percents for thick substrates, satisfying the criteria $h/\lambda_o < 0.023$ for $\varepsilon_r \approx 10$ to $h/\lambda_o < 0.07$ for $\varepsilon_r \approx 2.3$[1]. This is in contrast to 15% to 50% bandwidth of commonly used antenna elements such as dipole, slots and waveguide horns. It is concluded from Ref. [1] that the increase in h and decrease in ε_r will enhance the impedance bandwidth of the microstrip patch antenna. However, this approach is effective up to $h/\lambda_o < 0.02$ only. There are quite a lot of disadvantages to using thick and high dielectric constant substrates including the poor radiation efficiency due to surface wave generation, the spurious radiation from microstrip step-in-width and discontinuities, and the generation of higher order modes along the thickness.

With the rapid development of wireless communications, single-patch single-layer wide band or multi-band antennas have attracted many researchers' attention[2-10]. In this paper, simulation investigation of the multi-band property has been presented for a rectangular patch microstrip antenna. The analytic method is based on the method of moments[11] with the aid of the electromagnetic software "Ensemble SV", which is a planar electromagnetic field simulator for RF and wireless design. The analytic technique actually introduces a number of wide slots in one or both the radiating edges of the patch. In section 1, a rectangular patch is designed and its performance is studied. The introduction of several slots in the patch and the prediction of the resulted performances have been presented in section 2.

1 Design and Analysis of Rectangular Microstrip Patch Antenna

The first step in the design of the rectangular microstrip patch antenna shown in Fig.1 is to choose a

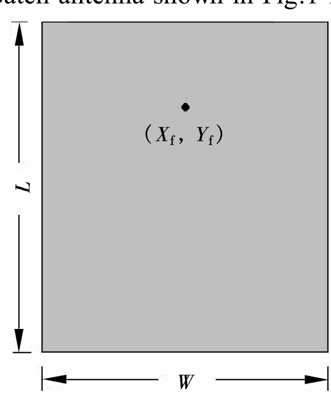

Fig.1 Rectangular microstrip patch antenna

suitable dielectric substrate of appropriate thickness h and loss tangent. A thicker substrate, in addition to being mechanically strong, will increase the radiated power, reduce conductor loss, and improve bandwidth. However, it will also increase the weight, dielectric loss, surface wave loss, and extraneous radiations from the probe feed. It is chosen to be equal to 8 mm, which is smaller than $0.1\lambda_o$, a value that is necessary for the patch resonance[12]. A low value of dielectric

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substrate constant ε_r will increase the fringing field at the patch periphery, and thus the radiated power. The substrate chosen is "cuclad" with $\varepsilon_r = 2.59$ and loss tangent of 0.002 2.

The patch width (W = 56.6 mm) has a major effect on the resonant frequency and radiation pattern of the antenna. It has a large influence on the input resistance and bandwidth. A larger patch width increases the power radiated and thus gives decreased resonant resistance, increased bandwidth, and increased radiation efficiency. The patch length L determines the resonant frequency, and it is a critical parameter in the design because of the inherent narrow bandwidth of the patch. The patch length L for the TM_{10} mode is given by[13]:

$$L = \frac{C}{2f_r\sqrt{\varepsilon_{re}}} - 2\Delta L \tag{1}$$

or

$$f_r = \frac{C}{2(L + 2\Delta L)\sqrt{\varepsilon_{re}}} \tag{2}$$

where C is the velocity of light, ε_{re} is the effective dielectric constant given by

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}} \tag{3}$$

and ΔL is the line extension due to the fringing field given by

$$\Delta L = 0.412h\frac{(\varepsilon_{re} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{re} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

The patch length L is solved to be 50.6 mm corresponding to the TM_{10} mode of 1.7 GHz. The feed is chosen to be at $X_f = 28.3$ mm, $Y_f = 44.75$ mm, this location will help introducing extra modes besides TM_{10} mode. Fig. 2 shows the simulated return loss against frequency for this antenna. It can be found that it is a multi-resonant antenna with resonant frequencies at 1.7, 3.12, 4.13, and 4.88 GHz. The return loss at the first two resonant frequencies is about −7 dB, which is acceptable in some communication applications. And at the other two resonant frequencies, it is sufficiently below −10 dB.

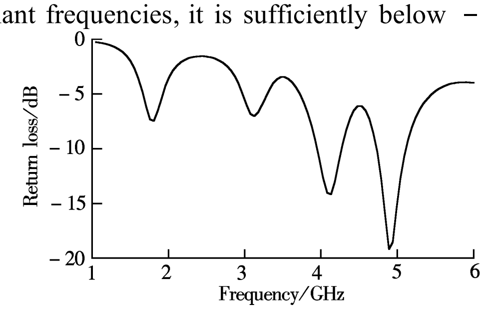

Fig.2 Simulated return loss of rectangular patch

The simulated gain is plotted with respect to frequency in Fig.3, showing a reasonable gain value of 6.75 dB at the first resonant frequency. However, the gain values at the other three frequencies are too low and it can be concluded that this antenna acts as single-band one at 1.7 GHz. The H-plane and E-plane radiation patterns at 1.7 GHz are shown in Fig.4.

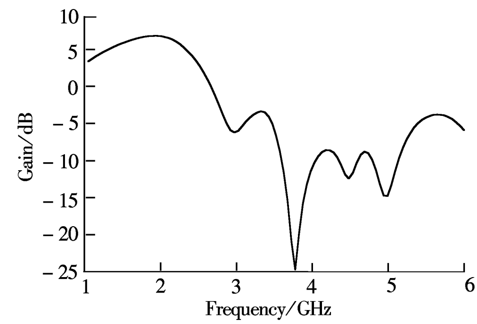

Fig.3 Simulated gain of rectangular patch

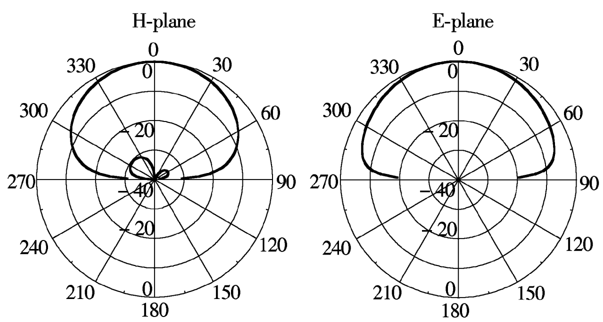

Fig.4 Radiation patterns of rectangular patch at 1.7 GHz

2 Slotted Rectangular Microstrip Patch Antenna

Recently, it has been shown that, by embedding a U-shaped slot in the rectangular patch, an impedance bandwidth greater than 20% can be easily achieved for a microstrip antenna with a probe feed[14, 15]. Introducing a rectangular slot in the radiating edge of the patch is simpler in construction than introducing a U-slot. By only adjusting the length, width, and position of the slots, one can obtain satisfactory performances. Fig.5 depicts a patch antenna with one slot of dimensions W_{s1} = 10.8 mm, L_{s1} = 24 mm. As shown in Fig.6, there are four resonant frequencies at 1.8, 2.82, 3.87, and 4.78 GHz. The return loss values at the first two resonant frequencies are greater than −10 dB, while the other three resonant frequencies have return loss values less than −10 dB. The gain value as shown in Fig. 7 for the first frequency is about 5.9 dB, but it is very small for the other three. This does not imply a multi-band behaviour but rather single band at 1.8 GHz. The H-plane and E-plane radiation patterns at 1.8 GHz are shown in Fig.8.

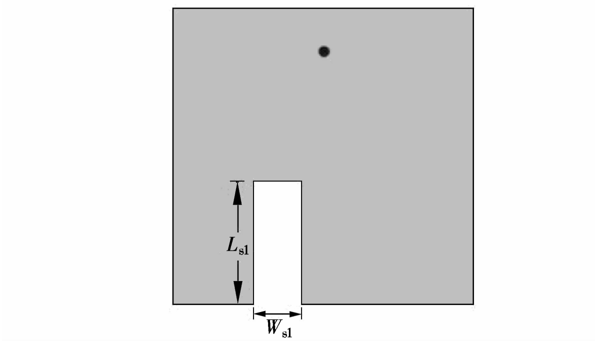

Fig.5 Rectangular one-slot patch

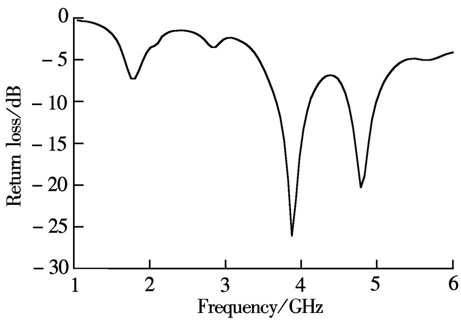

Fig.6 Simulated return loss of one-slot patch

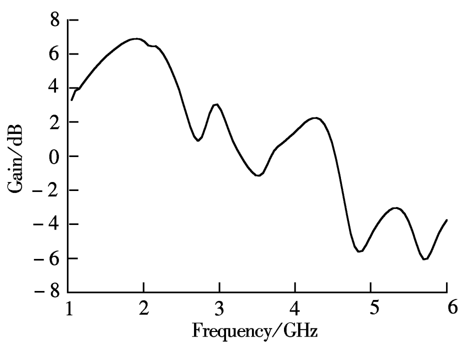

Fig.7 Simulated gain of one-slot patch

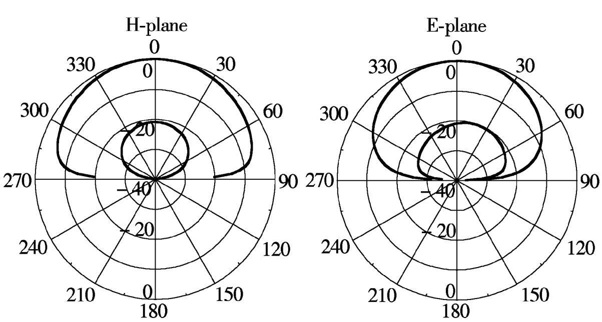

Fig.8 Radiation patterns of one-slot patch at 1.8 GHz

Fig.9 shows the introduction of a second slot at the same radiating edge with the same dimension. The return loss of this antenna is shown in Fig.10, and again there are four resonant frequencies at 1.6, 1.8, 3.77, and 4.84 GHz with return loss values of −5.9, −6.94, −24.8, and −26.35 dB, respectively. The gain values as depicted in Fig.11 are 5 and 6.8 dB for the first two frequencies, and very small for the other two. Therefore, this antenna is a dual-band one at 1.6 and 1.8 GHz. Fig.12 shows the H-plane and E-plane radiation patterns at 1.6 and 1.8 GHz.

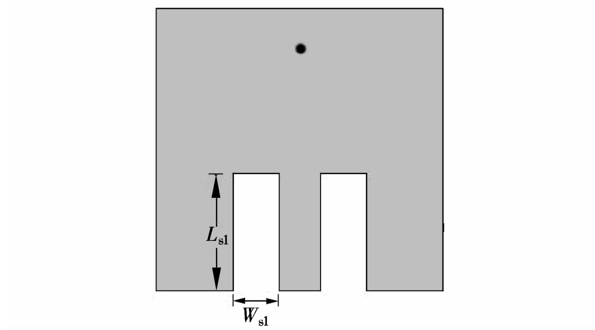

Fig.9 Rectangular two-slots patch

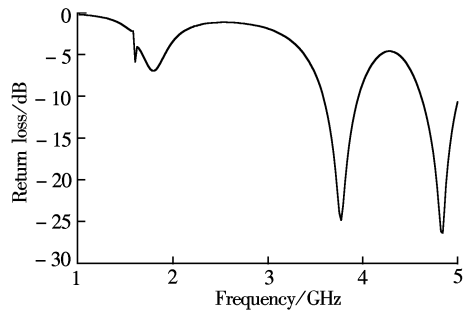

Fig.10 Simulated return loss of two-slots patch

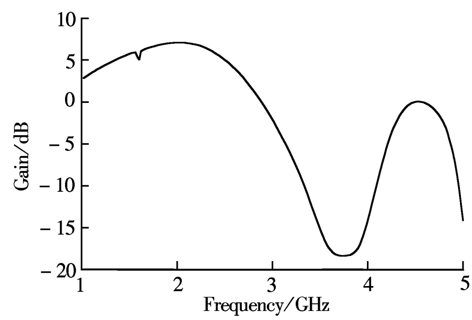

Fig.11 Simulated gain of two-slots patch

Introducing a third slot at the opposite radiating edge of the patch with dimensions W_{s2} = 5.8 mm, L_{s2} = 21.5 mm, as shown in Fig.13, will make the antenna have five resonant frequencies at 1.6, 1.8, 2.65, 3.42, and 4.83 GHz. The return loss values as shown in Fig. 14 are −8.5, −14.36, −8.11, −7.41, and −8 dB, respectively. The gain values as depicted in Fig.15 are 5.13, 6.38 and 4.88 dB for the first three frequencies, 3.34 dB for the fifth one, and too small a value for the fourth one. This antenna constitutes a reasonable multi-band one with four resonant frequencies and adequate return loss and gain values at 1.6, 1.8, 2.65, and 4.83 GHz. The H-plane and E-plane radiation patterns for the above four frequencies are shown in Fig.16.

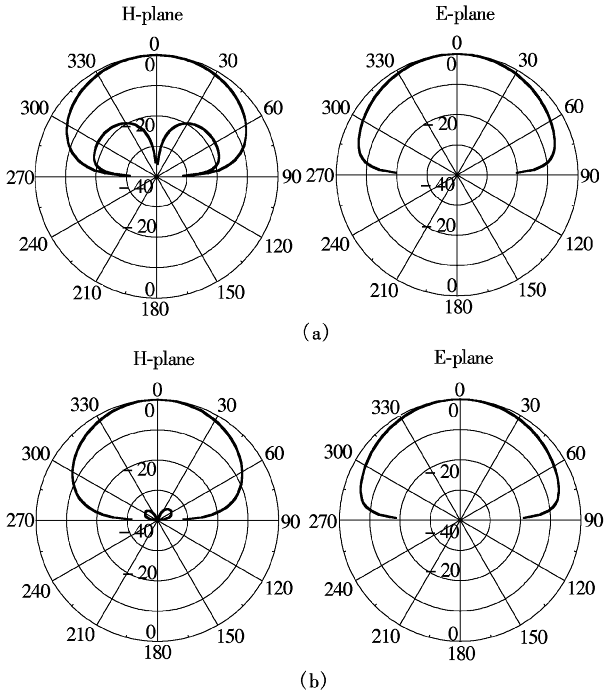

Fig.12 Radiation patterns of two-slots patch.
(a) 1.6 GHz; (b) 1.8 GHz

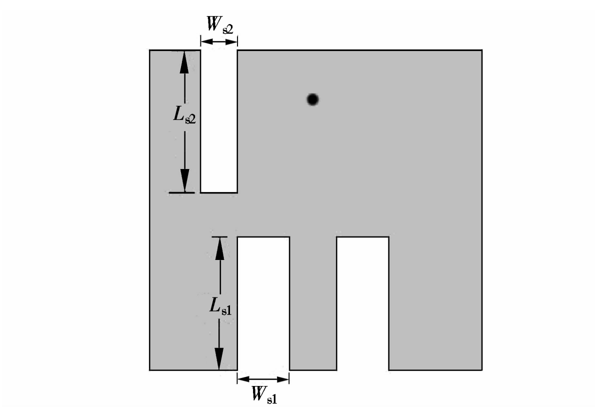

Fig.13 Rectangular three-slots patch

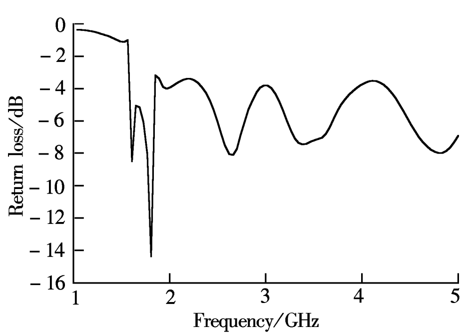

Fig.14 Simulated return loss of three-slots patch

If a forth slot is introduced in the opposite radiating edge with the same dimension as the third slot as shown in Fig. 17, then two distinct resonant frequencies are produced at 1.64 and 1.8 GHz. The return loss values for these two frequencies as shown in Fig.18 are −19.27 and −22.35 dB, respectively,

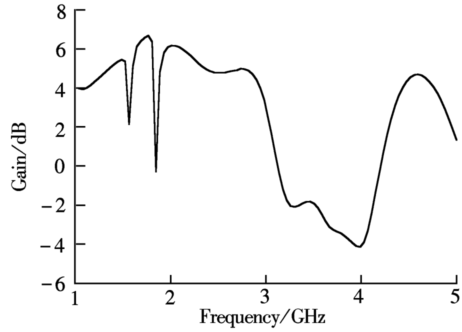

Fig.15 Simulated gain of three-slots patch

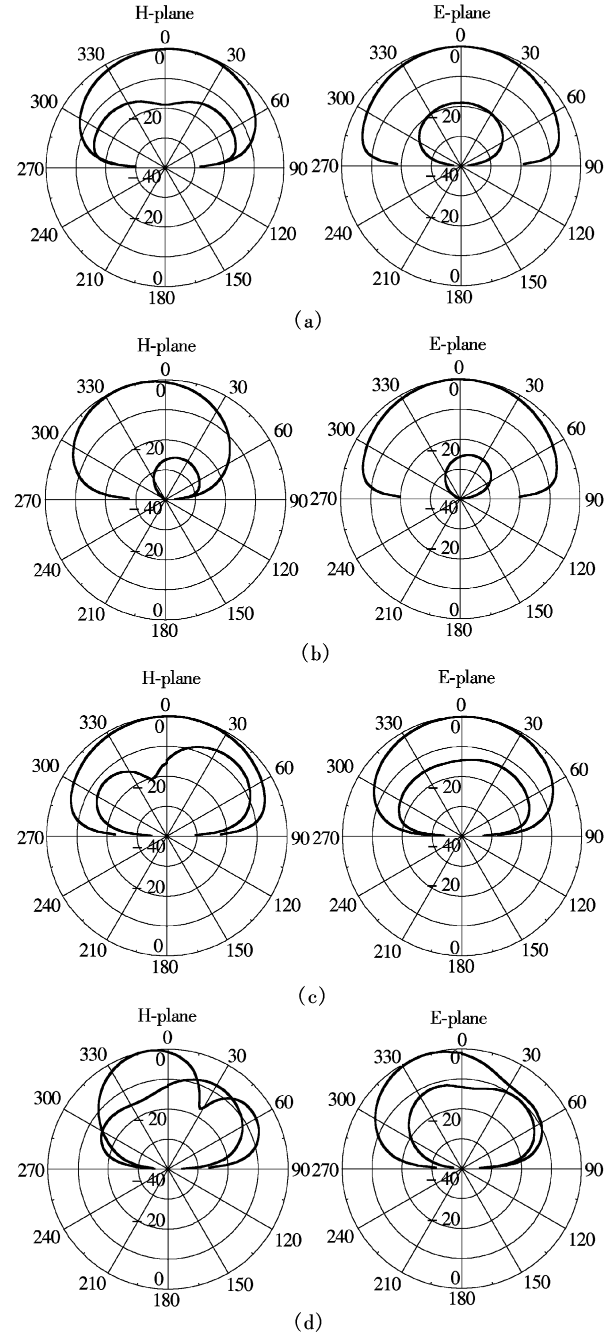

Fig.16 Radiation patterns of three-slots patch.
(a) 1.6 GHz;(b) 1.8 GHz; (c) 2.65 GHz; (d) 4.83 GHz

and their gain values as shown in Fig.19 are 5.8 and 7 dB, respectively. This antenna is a real dual-band one with good values of return loss and gain at the above two frequencies. Fig. 20 shows the H-plane and E-plane radiation patterns at the above two frequencies.

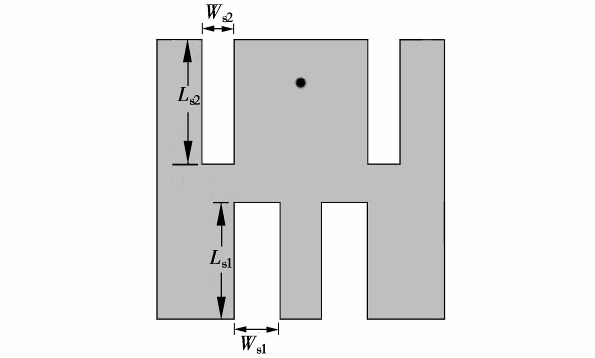

Fig.17 Rectangular four-slots patch

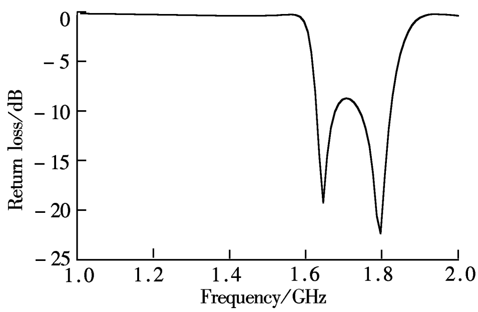

Fig.18 Simulated return loss of four-slots patch

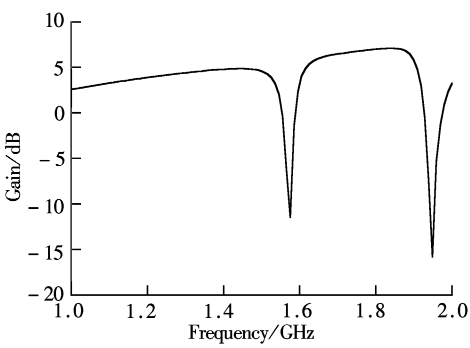

Fig.19 Simulated gain of four-slots patch

3 Conclusion

The property of multi-band has been studied through the design of rectangular microstrip patch antenna having different numbers of wide slots at one or both the two radiating edges. The analysis is based on the method of moments using an electromagnetic field simulator. It is shown that the introduction of four slots at both the edges makes the antenna act like a dual-band antenna with good return loss and gain values at 1.64 and 1.8 GHz. It is also shown that the introduction of only three slots at both edges makes the antenna have a multi-band feature with four resonant frequencies and adequate values of return loss and gain at 1.6, 1.8, 2.65, and 4.83 GHz, a property that is very useful in many wireless communication systems.

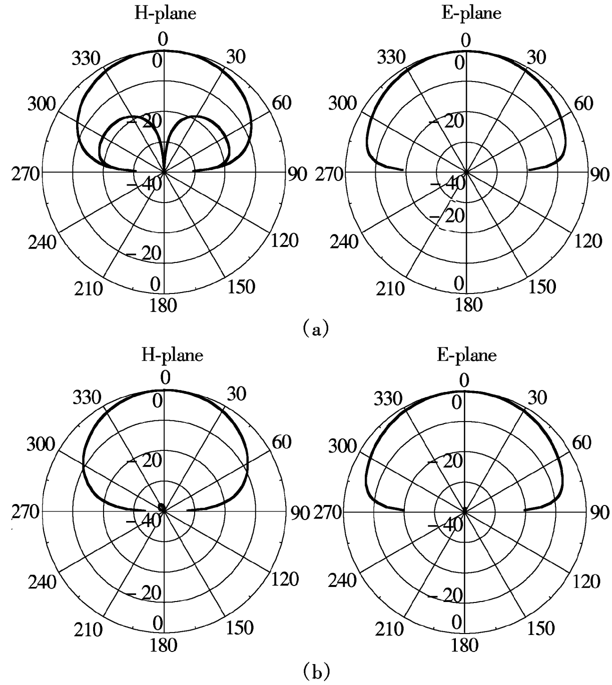

Fig.20 Radiation patterns of four-slots patch.
(a) 1.64 GHz; (b) 1.8 GHz

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具有不同宽槽数的矩形微带贴片天线多带特性研究

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摘要: 主要研究了多带工作的特性,并通过设计矩形贴片微带天线——包含不同数目的并放置在两辐射端的槽, 进行分析.分析基于 MOM 仿真软件包, 结论表明一个贴片上有 3 个槽的天线具有多带特性: 4 个振荡频率分别在 1.6, 1.8, 2.65, 和 4.83 GHz, 并且具有足够的反射损耗和增益值.同时证明了带有 2 对槽的贴片天线(槽分别位于两辐射端)有双带特性, 其振荡频率分别在 1.64 和 1.8 GHz, 而且返回损耗和增益值很好.

关键词: 微带天线; 多带特性; 宽带天线
中图分类号: TN820.1