Wide-Band E-Shaped Patch Antennas for Wireless Communications

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***Abstract*—This paper presents a novel single-patch wide-band microstrip antenna: the E-shaped patch antenna. Two parallel slots are incorporated into the patch of a microstrip antenna to expand it bandwidth. The wide-band mechanism is explored by investigating the behavior of the currents on the patch. The slot length, width, and position are optimized to achieve a wide bandwidth. The validity of the design concept is demonstrated by two examples with 21.2% and 32.3% bandwidths. Finally, a 30.3% E-shaped patch antenna, resonating at wireless communication frequencies of 1.9 and 2.4 GHz, is designed, fabricated, and measured. The radiation pattern and directivity are also presented.**

***Index Terms*—Dual parallel slots, E-shaped, patch antenna, wide band, wireless communications.**

I. INTRODUCTION

MICROSTRIP patch antennas are widely used because of their many advantages, such as the low profile, light weight, and conformity. However, patch antennas have a main disadvantage: narrow bandwidth. Researchers have made many efforts to overcome this problem and many configurations have been presented to extend the bandwidth. The conventional method to increase the bandwidth is using parasitic patches. In [1], the authors presented a multiple resonator wide-band microstrip antenna. The parasitic patches are located on the same layer with the main patch. In [2], an aperture-coupled microstrip antenna is described with parasitic patches stacked on the top of the main patch. However, these methods typically enlarge the antenna size, either in the antenna plane or in the antenna height. With the rapid development of wireless communications, single-patch wide-band antennas have attracted many researchers' attention [3]–[5]. In [6], the authors presented a U-slot microstrip antenna and demonstrated that its bandwidth could exceed 30%.

In this paper, we present a novel single-patch wide-band microstrip antenna: the E-shaped patch antenna. When two parallel slots are incorporated into the antenna patch, the bandwidth increases above 30%. Compared to the U-slot microstrip patch antenna, the E-shaped patch antenna is simpler in construction. By only adjusting the length, width, and position of the slots, one can obtain satisfactory performances. Some experimental results prove the validity of this design. The method of moments [7] with the vector triangular basis function [8] is used for analysis, as well as HP-HFSS software. The electric currents on the E-shaped patch are calculated and graphically presented to explain the wide-band mechanism. Subsequently, a wide-band E-shaped patch antenna with 30.3% bandwidth is designed to cover both 1.9 and 2.4 GHz. These ranges of frequencies are very desirable in modern wireless communications. Radiation patterns are also measured and compared with the numerical data.

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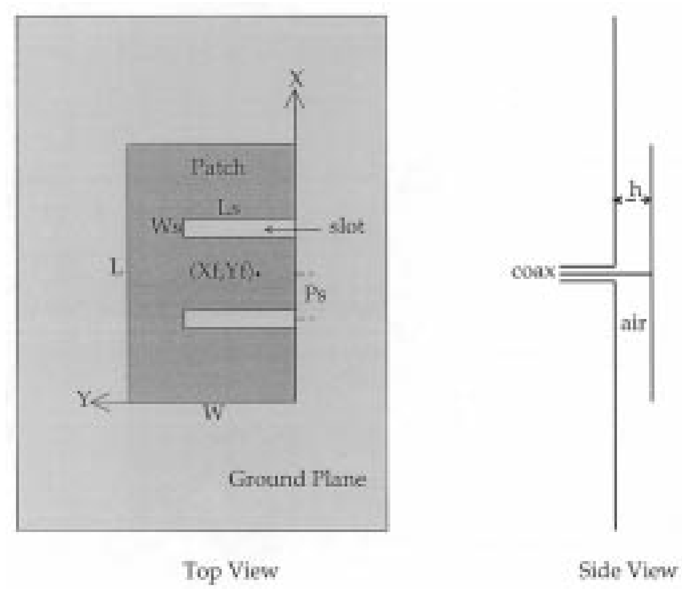
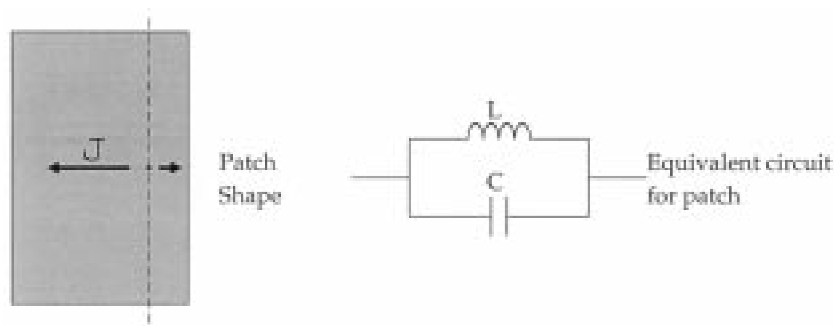


Fig. 1. Geometry of a wide-band E-shaped patch antenna consisting of two parallel slots in the patch.

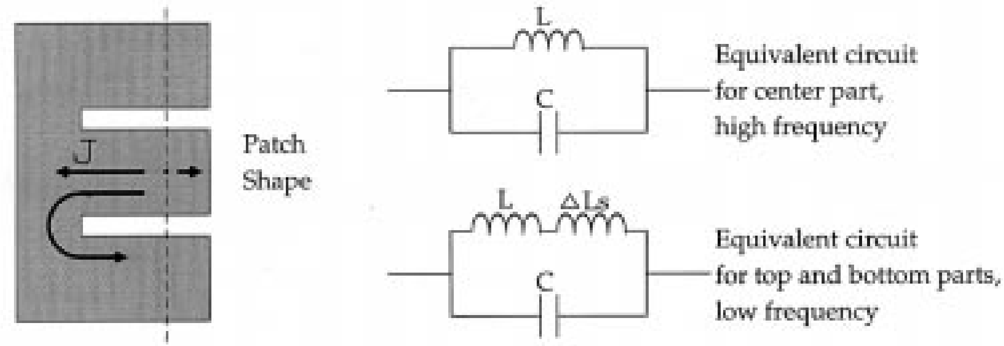
II. PERFORMANCE FEATURES OF E-SHAPED PATCH ANTENNAS

The antenna geometry is shown in Fig. 1. The antenna has only one patch, which is simpler than traditional wide-band microstrip antennas. The patch size is characterized by (L, W, h) and it is fed by a coaxial probe at position (X_f, Y_f). To expand the antenna bandwidth, two parallel slots are incorporated into this patch and positioned symmetrically with respect to the feed point. The topological shape of the patch resembles the letter "E," hence the name E-shaped patch antenna. The slot length (Ls), width (Ws), and position (Ps) are important parameters in controlling the achievable bandwidth.

Fig. 2 demonstrates the basic idea of the wide-band mechanism of the E-shaped patch antenna. The ordinary microstrip patch antenna can be modeled as a simple LC resonant circuit [Fig. 2(a)] [9]. Currents flow from the feeding point to the



(a)



(b)

Fig. 2. Dual resonance: the wide-band mechanism of E-shaped patch antennas. (a) The ordinary microstrip patch antenna. (b) The E-shaped patch antenna.

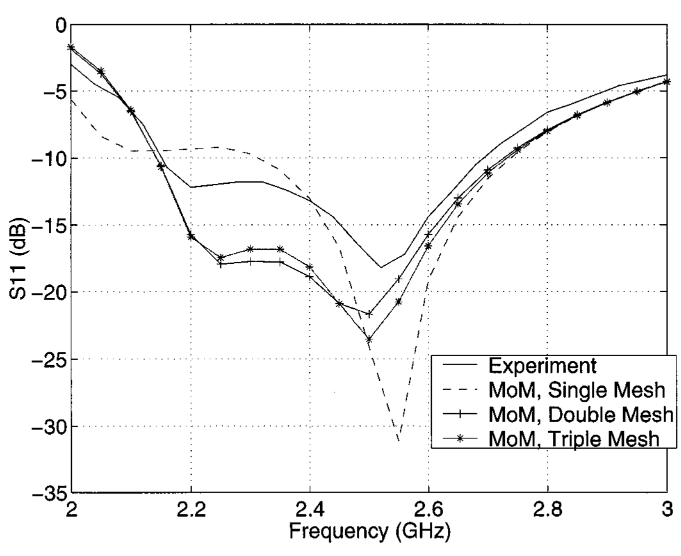


Fig. 3. Measured and calculated S_{11} of a 21.2% bandwidth E-shaped patch antenna.

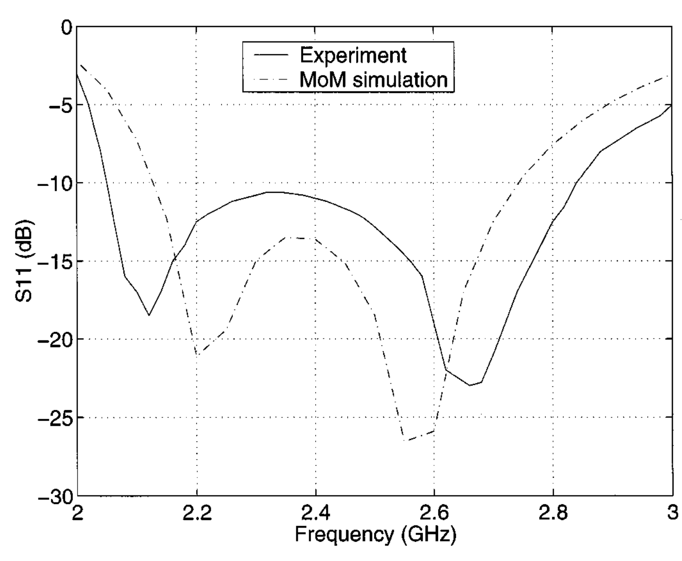
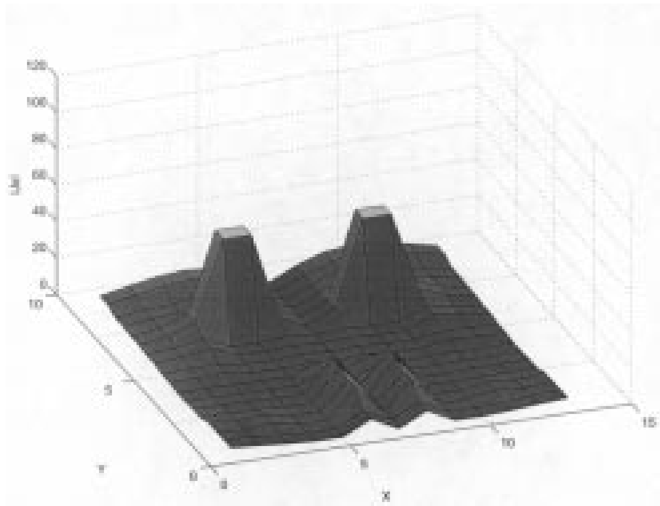


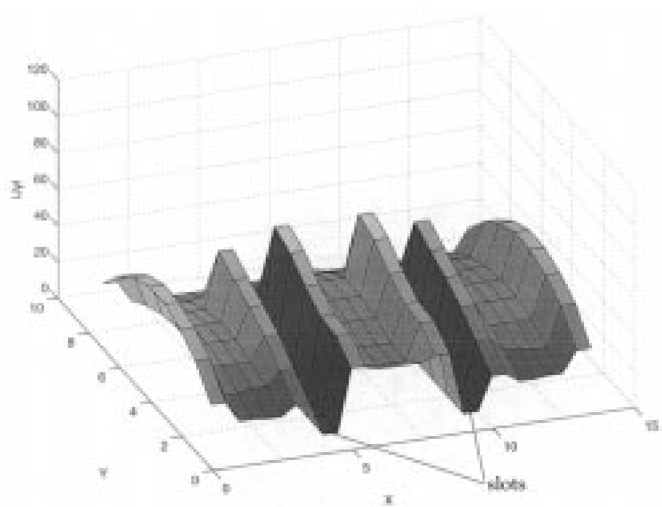
Fig. 4. Measured and calculated S_{11} of a 32.3% bandwidth E-shaped patch antenna.

top and bottom edges. L and C values are determined by these currents path length. When two slots are incorporated into the patch, the resonant feature changes, as shown in Fig. 2(b). In the middle part of the patch, the current flows like normal patch. It represents the initial LC circuit and resonates at the initial frequency. However, at the edge part of the patch, the current has to flow around the slots and the length of the current path is increased. This effect can be modeled as an additional series inductance ΔLs [10]. So the equivalent circuit of the edge part resonates at a lower frequency. Therefore, the antenna changes from a single LC resonant circuit to a dual resonant circuit. These two resonant circuits couple together and form a wide bandwidth.

Some experiments and calculations were carried out to demonstrate the performance of this wide-band configuration. The method of moments (MoM) was used for analysis and the

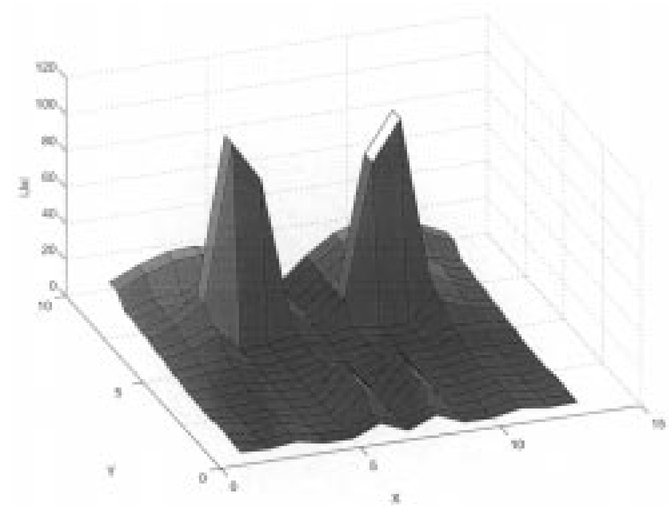


(a)

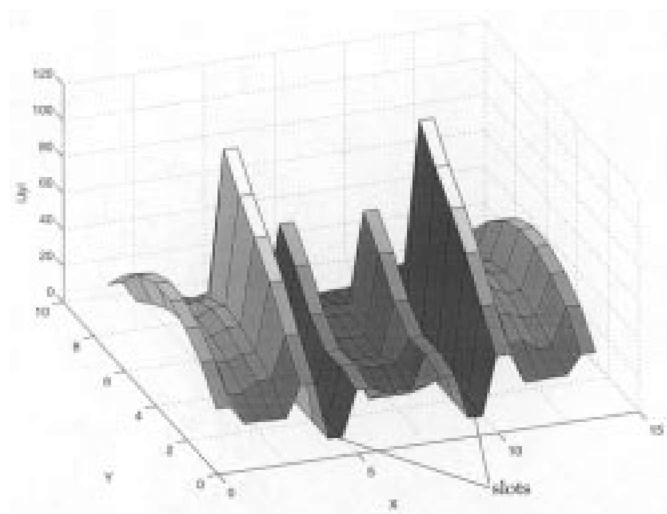


(b)

Fig. 5. The currents on the patch at high resonant frequency (a) Jx and (b) Jy. X, Y denote the number of the cell in MoM, while each cell is 5 mm $\times$ 5 mm. The unit for current is amperes/square meter while the excitation voltage is 1 V.



(a)



(b)

Fig. 6. The currents on the patch at low resonant frequency (a) Jx and (b) Jy. X, Y denote the number of the cell in MoM, while each cell is 5 mm $\times$ 5 mm. The unit for current is amperes/square meter while the excitation voltage is 1 V.

vector triangular function was chosen as the basis function. Fig. 3 gives the return loss of a 21.2% bandwidth (at -10 dB) for an E-shaped patch antenna example. The antenna parameters are listed below (in millimeters):

$$(L, W, h) = (70, 45, 10), \quad (Xf, Yf) = (35, 10)$$
$$Ls = 30, \quad Ws = 5, \quad Ps = 12.5.$$

The S_{11} is measured on an HP-8510 network analyzer. From the figure, it can be observed that the antenna has clearly two resonant frequencies: 2.2 and 2.52 GHz. It agrees well with the explanation given above. The antenna frequency band with -10–dB return loss covers the frequency range of 2.15–2.66 GHz. It has a bandwidth of 21.2% with the center frequency 2.4 GHz. Fig. 3 also shows the MoM simulation with different mesh densities. The patch was divided into nine subsections along the y direction (Ny), which is about 20 cells per wavelength at the high-frequency end, 3 GHz. The initial number of subsections along the x direction (Nx) was 14 so that the subsection size

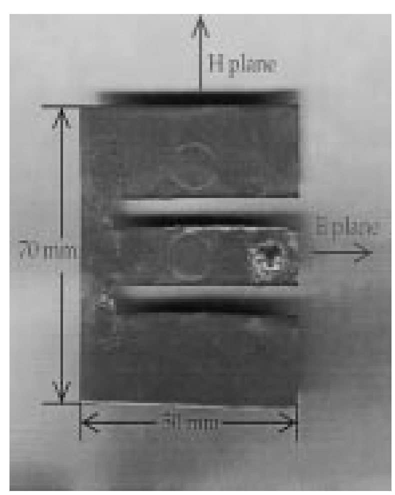


Fig. 7. A photo of an E-shaped patch antenna resonating at wireless communication frequencies of 1.9 and 2.4 GHz.

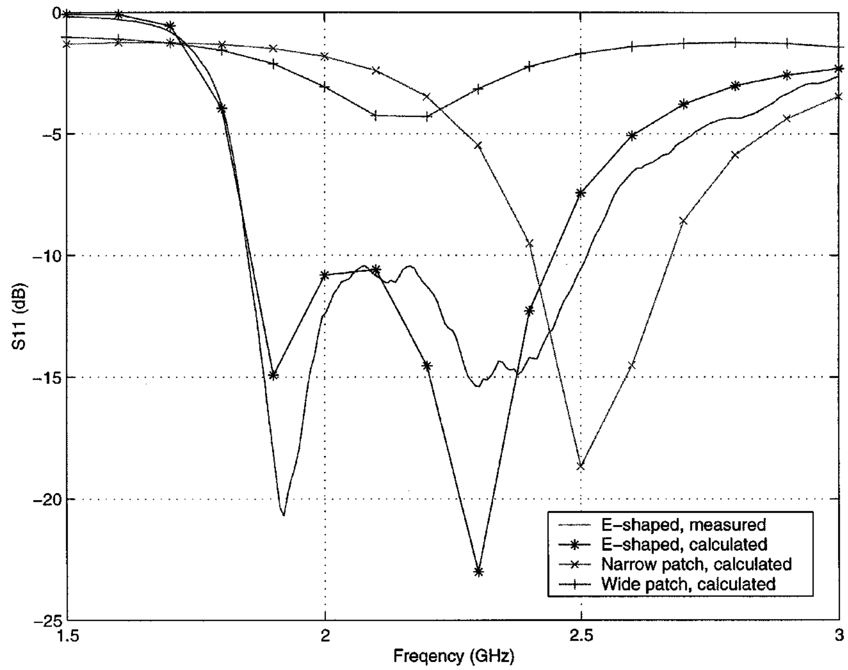


Fig. 8. S_{11} of the E-shaped patch antenna for wireless communications (measured and calculated), compared with simple patch antennas without slots.

was the same in both directions. However, the computation result of this single-density mesh was not good. The subsections number was increased to obtain an accurate result. It was found that the number of subsections along the x direction was not enough while it was sufficient along the y direction. The reason was that the currents had more variations along the x direction due to the two slots. The double-mesh $(Nx = 28, Ny = 9)$ and triple-mesh $(Nx = 42, Ny = 9)$ results are also presented. The converged results agree well with the experimental result.

By properly adjusting the parameters of slots and the position of the feeding point, a 32.3% antenna bandwidth is achieved. An elegant approach for the parameter selection would be the utilization of modern genetic algorithms [11]. Fig. 4 gives the return loss of this 32.3% E-shaped patch antenna. The antenna parameters are listed below (in millimeters):

$$(L, W, h) = (70, 45, 10), \quad (Xf, Yf) = (35, 7)$$
$$Ls = 35, \quad Ws = 4, \quad Ps = 9.$$

This antenna also has two distinct resonant frequencies. One is 2.12 GHz and the other is 2.66 GHz. The antenna frequency band covers the range of 2.05–2.64 GHz and achieves a bandwidth of 32.3%.

To thoroughly comprehend the effect of the slots, Figs. 5 and 6 present the currents at two resonant frequencies. First, one can see that, in both frequencies, currents Jy are greater than Jx. This is reasonable because the basic cavity mode under the patch is in the TM_{01} mode. Second, there are strong currents flowing around the slots. The amplitudes of the Jy currents become larger along the slots. At the ends of the slots, the amplitude of Jy is the largest. Here, Jx with large amplitude also appears. The amplitude of Jx is almost the same as the amplitude of Jy. Thus, it guarantees the continuity of the currents around the slots. Most importantly, the amplitudes of currents around the slots are different at low resonant frequencies and high resonant frequencies. It means that the effects of the slots at these two resonant frequencies are different. This is the key reason why the slots can extend the bandwidth. At the high frequency, the amplitudes of the currents around the slots are almost the same as those at the left and right edges of the patch. The effect of the slots are not significant. The patch works like ordinary patch. Therefore, the high resonant frequency is mainly determined by the patch width W, less affected by the slots. While at the low frequency, the amplitudes of the currents around slots are greater than those at high frequency. The slots congregate the currents and this effect can be modeled as an inductance. Due to this additional inductance effect, it resonates at a low frequency. Thus, this lower resonant frequency is mainly characterized by the slots. This phenomena agrees well with our previous explanation. Now it can be concluded that the antenna width W controls the higher resonant frequency while the slots control the lower resonant frequency. Because of the dual resonant character, this kind of microstrip antenna can achieve a wide bandwidth.

III. E-Shaped Patch Antenna Design for 1.9–2.4 GHz Wireless Communications

In this section, a wide-band E-shaped patch antenna for wireless communications is characterized in detail. A photo of the antenna is shown in Fig. 7. The antenna parameters are listed below (in millimeters):

$$(L, W) = (70, 50), \quad h = 15, \quad (X_f, Y_f) = (35, 6)$$
$$Ls = 40, \quad Ws = 6, \quad Ps = 10.$$

Fig. 8 shows the S_{11} results of this E-shaped patch antenna. The S_{11} is calculated by HP-HFSS software and measured on an HP-8510 network analyzer. From the figure, one can observe that the E-shaped patch antenna resonates at 1.9 and 2.4 GHz. These frequencies are chosen because they are useful frequen-

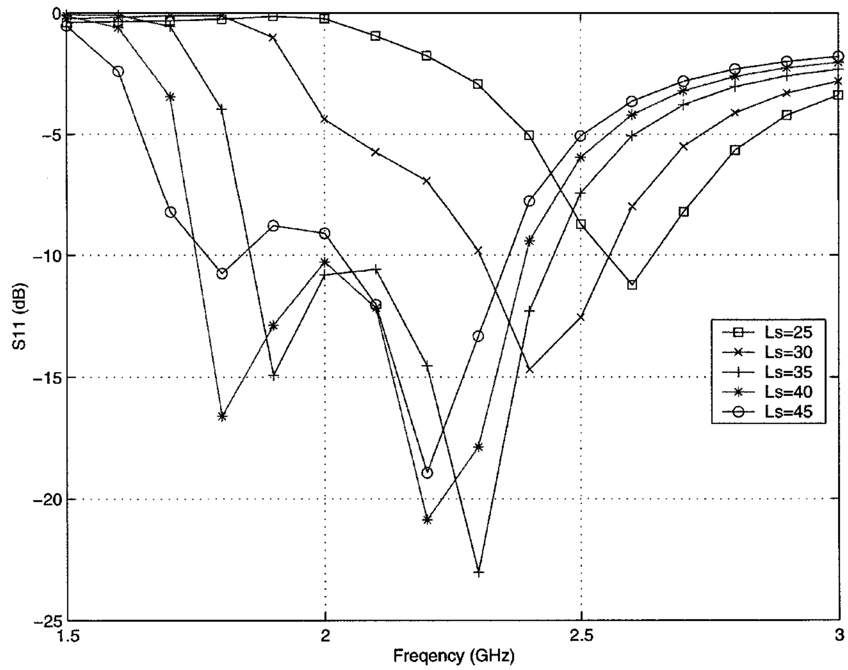


Fig. 9. Calculated S_{11} of E-shaped patch antennas with different slot lengths.

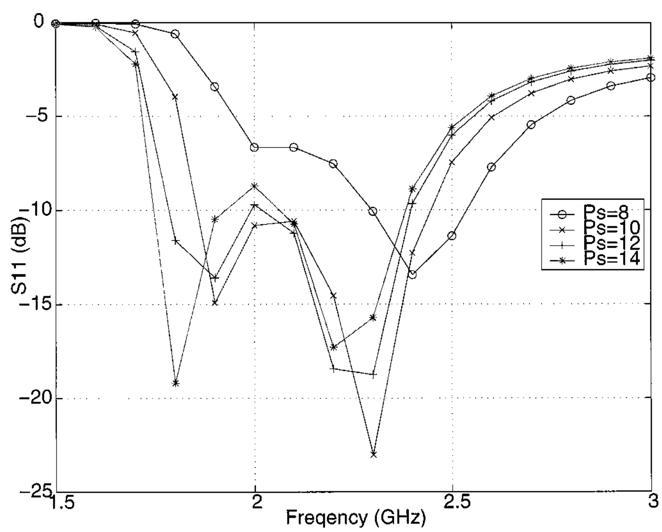


Fig. 10. Calculated S_{11} of E-shaped patch antennas with different slot positions.

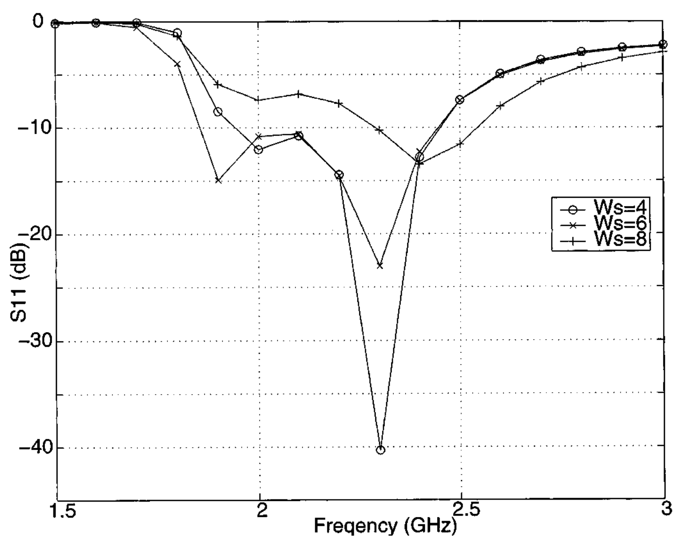


Fig. 11. Calculated S_{11} of E-shaped patch antennas with different slot widths.

cies in modern wireless communications. The E-shaped patch antenna has a wide bandwidth of 30.3%. The simple patch antennas without slots are also simulated for comparison. They have the same height and width as this E-shaped patch antenna. The narrow patch antenna, which has the same length as the middle part of the E-shaped patch antenna, has a bandwidth of 10% while the wide patch antenna with the same length as the E-shaped patch antenna doesn't match to 50 Ω.

Slots play an important role to control the wide-band behavior of the E-shaped patch antenna. There are three parameters to characterize the slots, namely slot length, slot position, and slot width. Fig. 9 shows the effect of the slot length (L_s) on the antenna. When the slot length is small, the antenna only has one resonant frequency. When the slot length increases, another lower resonant frequency appears. The longer the slot length, the lower the second resonant frequency. In brief, the slot length is an important parameter to characterize the resonant frequencies of the E-shaped patch antenna. The slot position (Ps) is presented in Fig. 10. When Ps is small, the S_{11} at lower frequencies does not match well. When Ps becomes larger, the two resonant frequencies become distinct and a wide-band match is obtained. However, when Ps becomes even larger, the S_{11} between two resonant frequencies is larger than -10 dB. The antenna does not perform as a wide-band one but rather as a dual-frequency one. Therefore, Ps is a useful parameter to adjust the matching to 50 Ω. Fig. 11 details the importance of the slot width. The two

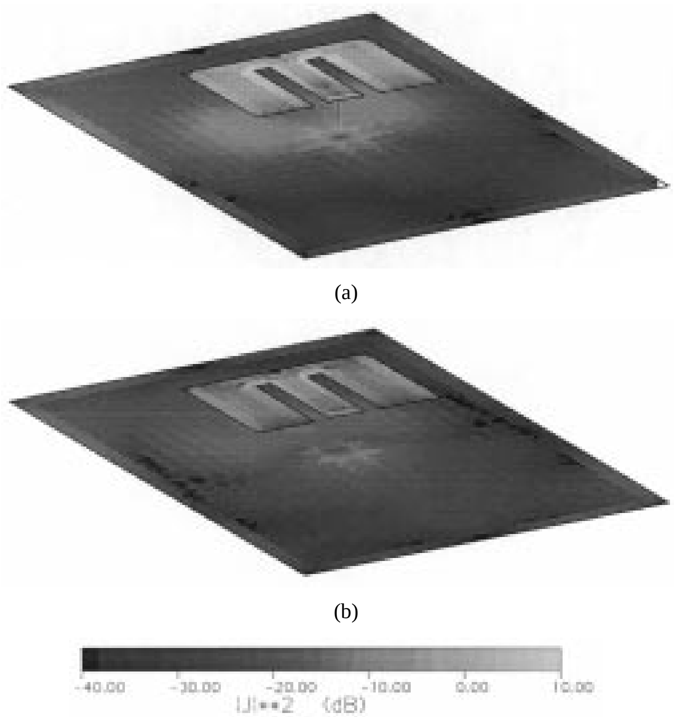


Fig. 12. Currents of the E-shaped patch antenna with finite ground plane at (a) 1.9 GHz and (b) 2.4 GHz.

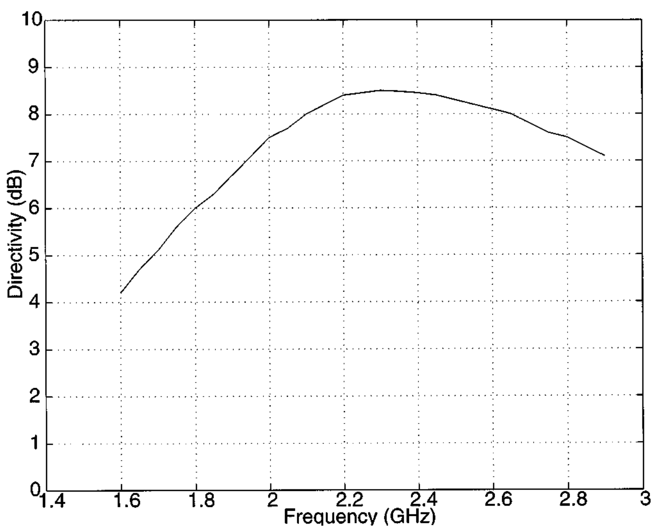


Fig. 13. Calculated directivity of the E-shaped patch antenna versus frequency.

resonant frequencies exist in all three cases, but the best match can be obtained only when $Ps = 6$ mm, which means that slot width is useful to adjust coupling and achieve good match.

Usually the ground plane effect is a critical factor in communication applications. A large finite ground plane is analyzed and the currents on the ground plane are calculated to understand which areas are effective for the antenna operation. The ground size is chosen to be 14 cm $\times$ 21 cm which is about 8 times that of the patch size using the technique developed in [12]. Fig. 12 shows the simulated currents of the antenna structure with finite ground plane. One can observe that most currents concentrate under the patch and more areas are needed for low frequency than for high frequency. In other words, the

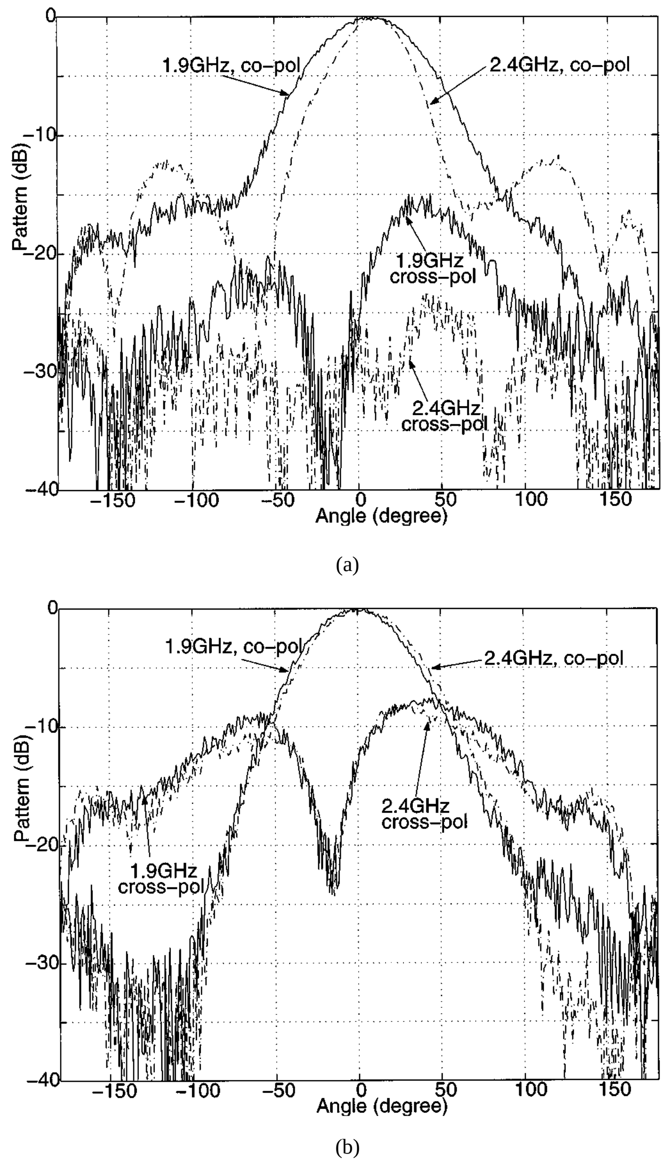


Fig. 14. Measured co-pol and cross-pol radiation patterns at two resonant frequencies of 1.9 GHz and 2.4 GHz. (a) E plane pattern. (b) H plane pattern.

ground plane size is determined by the low frequency. If -20 dB is chosen as the criterion for the relative level of ground plane current amplitude, $1\lambda \times 1\lambda$ (1.9 GHz) ground plane area is sufficient for the proper operation of the antenna.

Fig. 13 presents the calculated directivity of the antenna. It is 8.5 dB at 2.4 GHz and 6.7 dB at 1.9 GHz. The frequency range from 1.9 to 2.4 GHz is inside the 3-dB directivity band. Since the antenna matches well in this frequency range, it should have the similar level of gain. The radiation pattern of the E-shaped patch antenna is measured in the far-field chamber located at the UCLA antenna lab and shown in Fig. 14. They are measured at two resonant frequencies: 1.9 and 2.4 GHz. The experimental results agree well with the numerical results which are not shown here. In the E plane, the 3-dB beamwidth is 42 degrees at 2.4 GHz and 63 degrees at 1.9 GHz. The peak cross-pol at 1.9 GHz is -15 dB, which is higher than -25 dB at 2.4 GHz. This is due to different current distributions at these two frequencies. In the H plane, the radiation pattern is similar at 1.9 GHz and 2.4 GHz. The 3-dB beamwidth is 60 degrees at both frequencies. The peak cross-pol is −7 dB at 50 degrees. This high cross-pol is generated by the leaky radiation of the slots. However, it's still acceptable for some communication applications.

IV. Conclusion

The E-shaped patch antenna with wide bandwidth is presented in this paper. Compared to conventional wide-band microstrip patch antennas, it has the attractive features of simplicity and small size. The electric currents on the patch are determined and the wide-band mechanism is discussed in depth. Finally, a 30.3% bandwidth E-shaped patch antenna, applicable to modern wireless communication frequencies of 1.9 to 2.4 GHz, is designed, measured, and characterized in detail.

Acknowledgment

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