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MULTI-SLOTTED MICROSTRIP PATCH ANTENNA FOR WIRELESS COMMUNICATION

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Abstract—A new design technique of microstrip patch antenna is presented in this paper. The proposed antenna design consists of inverted patch structure with air-filled dielectric, direct coaxial probe feed technique and the novel slotted shaped patch. The composite effect of integrating these techniques and by introducing the new multi-slotted patch, offer a low profile, high gain, broadband, and compact antenna element. A wide impedance bandwidth of 27.62% at -10 dB return loss is achieved. The maximum achievable gain is 9.41 dBi. The achievable experimental 3-dB beamwidth (HPBW) in the azimuth and elevation are 60.88° and 39° respectively at centre frequency.

1. INTRODUCTION

With the wide spread proliferation of wireless communication technology in recent years, the demand for compact, low profile and broadband antennas has increased significantly. To meet the requirement, the microstrip patch antenna has been proposed because of its low profile, light weight and low cost [1]. However, conventional microstrip patch antenna suffers from very narrow bandwidth, typically about 5% bandwidth with respect to the center frequency. This poses a design challenge for the microstrip antenna designer to meet the broadband techniques [2, 3].

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There are several well-known methods to increase the bandwidth of patch antennas, such as the use of thick substrate, cutting a resonant slot inside the patch, the use of a low dielectric substrate, multi-resonator stack configurations, the use of various impedance matching and feeding techniques, and the use of slot antenna geometry [4–6]. However, the bandwidth and the size of an antenna are generally mutually conflicting properties, that is, improvement of one of the characteristics normally results in degradation of the other.

Several techniques have been proposed to enhance the bandwidth in the state-of-the art antenna research. A novel single layer wide-band rectangular patch antenna with achievable impedance bandwidth of 20% has been demonstrated [7]. By using the shorting pins or shorting walls on U-shaped patch, U-slot patch, or L-probe feed patch antennas, wideband and dual band antenna with electrically small in size have been reported in [8, 9]. Other techniques involves employing multilayer structures with parasitic patches of various geometries such as E, V and H shapes, which excites multiple resonant modes. These antennas are generally fabricated on thicker substrates [10].

Recently, an E-shaped patch antenna [11] and U-slotted patch antenna [12] have been designed for wireless communications. However, both of these patch substrate are non inverted and achievable gains of both antennas are below 8.5 dBi. In this paper, a new inverted multi-slotted shape patch antenna is investigated for the gain and bandwidth enhancement. The design employs contemporary techniques namely, the coaxial probe feeding, inverted patch, and multi-slotted patch techniques to meet the design requirement. A wider impedance bandwidth is achieved compared to the design reported in [13] and a better gain of 9.41 dBi is achieved compare to design [8, 11–13].

2. ANTENNA DESIGN

Figure 1 depicts the layout of a coaxial probe-fed multi-slotted patch antenna. The structure incorporates an antenna element, air substrate and a vertical probe connected to the patch. The inverted rectangular patch, with dimension of $0.549\lambda_0 \times 0.368\lambda_0$ (where λ_0 corresponding to center frequency) is supported by a low dielectric superstrate with dielectric permittivity ε_1 (2.2) and thickness h_1 (1.574 mm). An air-filled dielectric substrate with dielectric substrate with thickness h_o (12.5 mm) is sandwiched between the superstrate and a ground plane. The slots on the patch are shown in Figure 1(a), where, l and w are the length and width of the slots. The patch is fed by a coaxial probe along the centerline (x-axis) at a distance f_P from the edge of the patch as shown in Figure 1(b).

Table 1 shows the optimized design parameters obtained for the proposed patch antenna. An aluminum plate with dimensions of $1.39\lambda_0 \times 1.25\lambda_0$ and thickness of 1 mm is used as the ground plane. The use of probe feeding technique, slots on the patch with thick air-filled substrates provide bandwidth enhancement while the application of superstrate with inverted radiating patch and the use of parallel slots

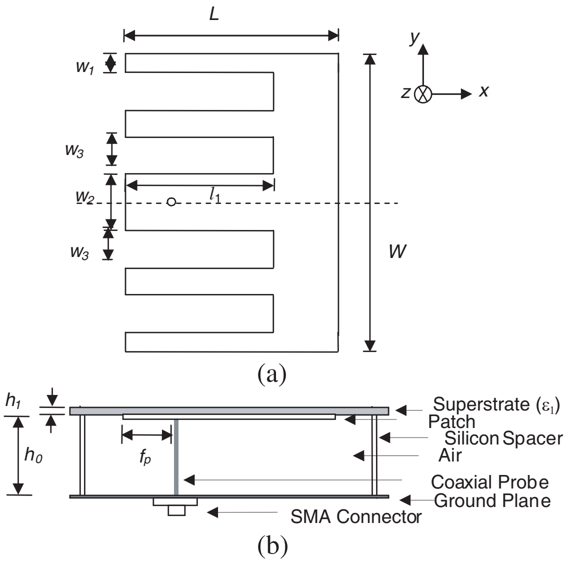


Figure 1. Geometry of proposed patch antenna. (a) Top view, (b) side view.

Table 1. The proposed patch antenna design parameters.

Parameter	Value [mm]
W	79
L	53
l_1	37
w_1	5
w_2	15
w_3	10
h_0	12.5
h_1	1.5748
f_p	10

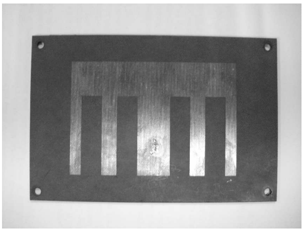


Figure 2. Photograph of the proposed patch.

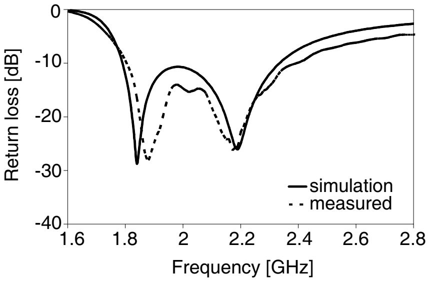


Figure 3. Return loss of the proposed patch.

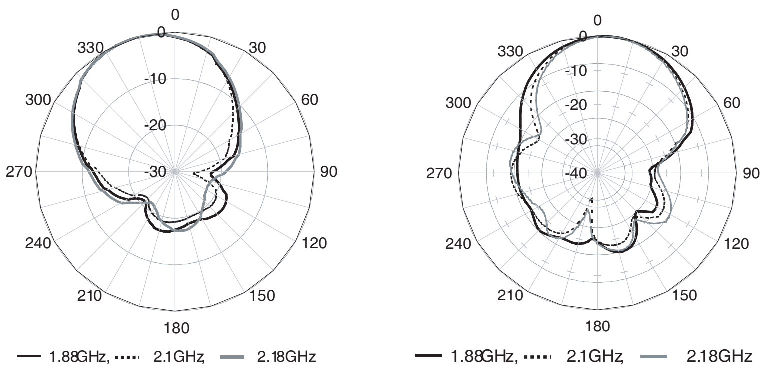
offers a gain enhancement. The use of superstrate on the other hand would also provide the necessary protections for the patch from the environmental effects. The proposed radiating patch comprises slots symmetrically surrounding near the excitation probe and defining a capacitive load for compensating an inductance of the excitation probe pin so as to obtain good impedance bandwidth. Adding two more slots symmetrically surrounding the probe on the patch eventually improve the overall impedance bandwidth and better impedance matching. The presences of multi-slots restrict the patch currents, at its resonance frequencies that provide lower return loss. In design [14], the slotted antenna achieved bandwidth of 26.92%, however that paper presented only the simulated results while the proposed multi-slotted antenna in this paper shows measured results, tested in anechoic chamber that achieved a bandwidth of 27.62%. In addition, the multi-slots on the patch reduce the size of the proposed patch in this paper and shows better return loss at resonant frequencies (about -28 dB) compare to the simulated design reported in [14]. The photograph of the proposed patch is shown in Figure 2.

3. RESULTS AND DISCUSSION

The resonant properties of the proposed antenna have been predicted and optimized using of a commercial software package HFSS$^{\text{TM}}$ v11. It is measured by an Agilent 8753ES network analyzer and the dimension of the anechoic chamber is $5\,\text{m} \times 5\,\text{m} \times 5\,\text{m}$. Figure 3 shows the simulated and measured results of the return loss of the proposed patch antenna which are in good agreement. The two closely excited resonant frequencies at 1.88 GHz and at 2.18 GHz as shown in the figure gives the measure of the wideband characteristic of the patch antenna. The measured impedance bandwidth of 27.62% (1.81–2.39 GHz) is achieved at 10 dB return loss (VSWR ≤ 2) while the simulated patch gives an impedance bandwidth of 26.63% (1.79–2.34 GHz).

Figure 4 shows the measured radiation patterns of the azimuth and the elevation, respectively. The radiation patterns are measured at resonant frequencies of 1.88 GHz and 2.18 GHz and at the center frequency of 2.1 GHz. As shown in figure, the designed antenna displays good broadband radiation patterns in the azimuth and elevation. It can be seen that 3-dB beamwidth (HPBW) in the azimuth (yz-plane) and elevation (xz-plane) are 60.88° and 39° at 2.1 GHz, respectively.

The measured peak gain of the proposed patch antenna at various frequencies is shown in Figure 5. As shown in the figure, the maximum achievable gain is 9.41 dBi at the frequency of 2.1 GHz and the gain is better compare to design reported in [8, 11–13]. In addition, the design in [8] is based on foam substrate that is more complex than our



(a) (b)

Figure 4. Measured radiation pattern of the antenna. (a) Azimuth, (b) elevation.

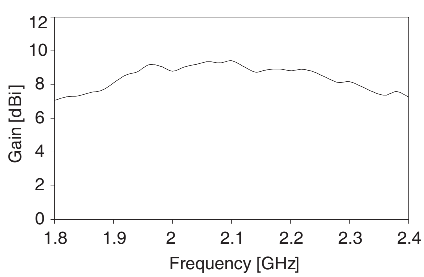


Figure 5. Measured gain of the antenna at different frequency.

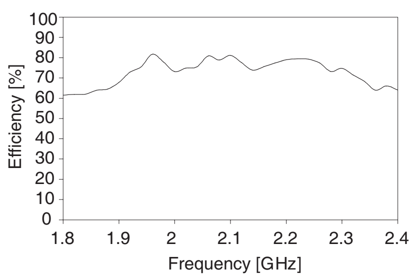


Figure 6. Measured efficiency of the antenna.

design which is based on air substrate. Figure 6 shows the measured total efficiency of the patch antenna. The figure indicates high antenna efficiency over the operational frequency and it is around an average of 72%.

The surface current distribution is illustrated in Figure 7, including the current flow on multi-slotted area of the patch. Due to identical manner of current flow in both resonant frequencies on the antenna, only current distribution on the second resonant frequency is depicted in the figure. Arrows show the direction of the current distribution. It can be observed from the figure that the current intensely flows at the edge of the slots especially near the feeding probe of the patch. However, the current is uniformly distributed elsewhere.

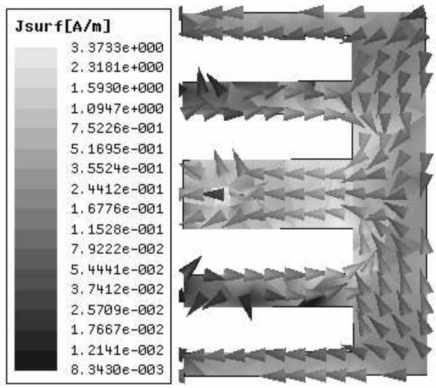


Figure 7. Current distribution at 2.18 GHz.

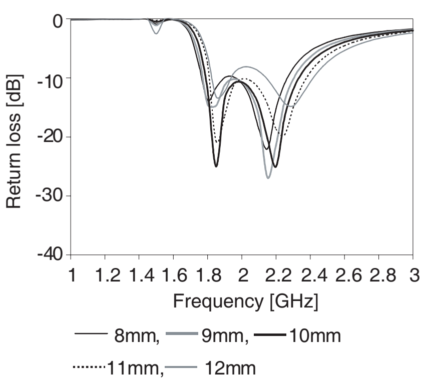


Figure 8. Effects on return loss of different slot width (w_3).

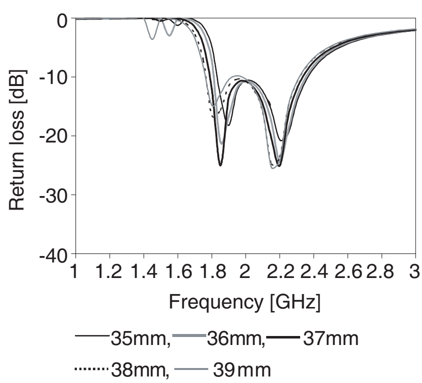


Figure 9. Effects on return loss of different slot length (l_1).

Figure 8 shows the variation on the return loss with different widths of the slots (w_3) on the patch. With decreasing slot width, impedance bandwidth decreases. It can also be observed that the second resonant frequency reduces with the increasing of slot width. Thus, the slot width, w_3 equals 10 mm is used as the optimized value.

Figure 9 shows the variation on the return loss with different lengths of the slots (l_1) on the patch. With increasing the slot lengths, the second resonant frequency remains same, but first resonant frequency decreases. Again, decreasing slot lengths also decreases the first resonant frequency. Thus, the slot length, l_1 equals 37 mm is used as optimized value.

4. CONCLUSION

A new technique for enhancing the gain and bandwidth of a microstrip patch antenna has been developed and implemented successfully. The experimental results demonstrate that it has a wide impedance bandwidth of 27.62% at 10 dB return loss, covering from 1.81 to 2.39 GHz frequency. The maximum achievable gain of the antenna is 9.41 dBi. Techniques for microstrip broadbanding, size reduction, stable radiation pattern and high gain are applied with significant improvement in the design by employing the proposed multi-slotted patch shaped design, inverted patch, and coaxial probe feeding.

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