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BROADBAND E-H SHAPED MICROSTRIP PATCH ANTENNA FOR WIRELESS SYSTEMS

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Abstract—A broadband inverted E-H shaped microstrip patch antenna is proposed and experimentally investigated. The antenna employs novel E-H shaped patch with L-probe feed technique. Prototype of the proposed antenna has been fabricated and measured for electromagnetic analysis including the impedance bandwidth, radiation pattern, and antenna gain. The designed antenna has a dimension of 80 mm by 50 mm, leading to broad bandwidths covering 1.76 GHz to 2.38 GHz. Stable radiation patterns across the operating bandwidth are observed. In addition, a parametric study is conducted to facilitate the design and optimization process.

1. INTRODUCTION

Because of the booming demand in wireless communication system applications, microstrip patch antennas have attracted much interest due to their low profile, light weight, ease of fabrication and compatibility with printed circuits. However, they also have some drawbacks, ranging from narrow bandwidth to low gain [1]. To overcome their inherent limitation of narrow impedance bandwidth and low gain, many techniques have been proposed and investigated, e.g., for probe fed stacked antenna, microstrip patch antennas on electrically thick substrate, slotted patch antenna and stacked shorted patches,

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the use of various impedance matching and feeding techniques, the use of multiple resonators [2–16]. However, bandwidth enhancement and size reduction are becoming major design considerations for practical applications of microstrip antennas due to the improvement of one of the characteristics, which normally results in degradation of the other.

In recent years, many techniques have been reported to achieve wideband patch antenna for modern wireless communication devices. A single layer wideband E-shape rectangular patch antenna with achievable good impedance bandwidth has been demonstrated [17–19]. The patch substrates of these antennas are non-inverted. To reduce the size of antennas with achieving dual band or wide bandwidth, shorting pins or shorting walls on the unequal arms of a U-shaped patch, L-strip patch, U-slot patch, L-probe feed patch, H-shaped stacked patch antennas have been illustrated in [20–27]. However, the achievable gains of these antennas are below 8.5 dBi. More recently, a bidirectional antenna with maximum gain of 8.9 dBi is achieved with limited bandwidth [28]. Again, single layer slotted antenna is investigated for enhancement of bandwidth up to 27.62% [29]. Another L-probe feed high gain antenna is examined in [30]. However, the bandwidth of that antenna drops to 21.15%.

This paper presents a new E-H shaped patch antenna that is investigated for enhancing the impedance bandwidth and gain. The design employs contemporary techniques namely, the L-probe feeding, inverted patch, and E-H shaped patch techniques to meet the design requirement. By extending the edge of E-shaped slots, a wider impedance bandwidth of 30% compared to the design reported in [25–30] and a gain of 9.37 dBi compared to the design reported in [11–28] are achieved in this design. Details of the proposed antenna are described in the paper, and results are presented and discussed.

2. ANTENNA CONFIGURATION

The configuration of the proposed inverted E-H patch antenna is illustrated in Figure 1. The proposed patch with dimension of $80\,\text{mm} \times 50\,\text{mm}$ integrates both the E- and H-shaped slots on the same radiating element. For the E-shaped patch, the slots are embedded in parallel to the radiating edge of the patch symmetrically with respect to the centerline (x-axis) of the patch, and for the H-shaped patch, the slots are embedded in series on the non-radiating edge of the patch. The E- and H-shaped 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 an L-shaped probe with height h_P and horizontal length L_P along the centerline (x-axis) at a distance f_P from the edge of the patch

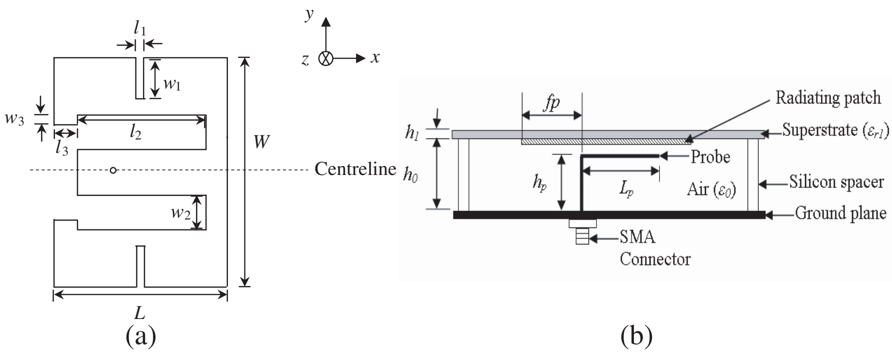

Figure 1. Configuration of the proposed patch antenna. (a) Top view. (b) Side view.

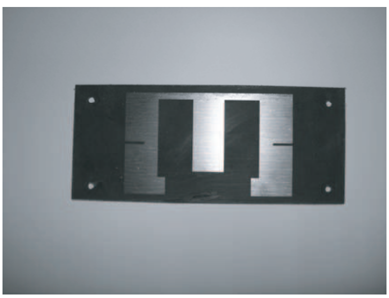

Figure 2. Photograph of the proposed patch.

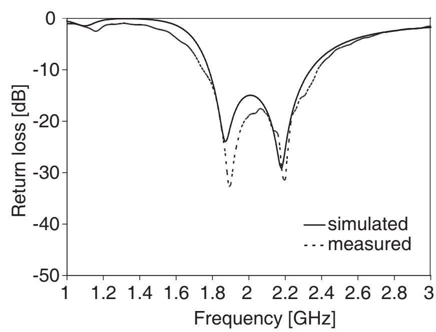

Figure 3. Measured and simulated return loss of the proposed patch.

as shown in Figure 1(b). With the aid of simulation by HFSS$^{\text{TM}}$ v11, which is frequency domain three-dimensional full wave electromagnetic field solver, the antenna is optimized and then prototyped. The photograph of the proposed patch is shown in Figure 2. Table 1 shows the optimized design parameters obtained for the proposed patch antenna. A dielectric substrate with dielectric permittivity ε_{r1} of 2.2 and thickness h_1 of 1.5748 mm has been used in this design. The thickness of the air-filled substrate h_o is 16.0 mm. An aluminum plate with dimensions of 200 mm × 180 mm and thickness of 1 mm is used as the ground plane. The proposed antenna is designed to operate at 1.76 GHz to 2.38 GHz region. The use of L-probe feeding technique with a thick air-filled substrate provides the bandwidth enhancement,

Table 1. The proposed patch antenna design parameters.

Parameter	Value [mm]	Parameter	Value [mm]
W	80	l_3	7
L	50	h_0	16
w_1	10	h_1	1.5748
l_1	1	h_p	14
w_2	6	L_p	24
l_2	40	f_p	8
w_3	6		

while the application of superstrate with inverted radiating patch offers a gain enhancement, and the use of parallel (E-shaped) and series slots (H-shaped) reduce the size of the patch. The H-shaped slots also help to reduce the cross-polarization level. The use of superstrate on the other hand would also provide the necessary protections for the patch from the environmental effects. By incorporating amended E-shaped slot (means slightly extending the edge of E-shaped slot) in radiating edges, the bandwidth has been improved. In addition, the antenna has wider impedance bandwidth in comparison with the antenna described in [25–30]. The proposed radiating patch encompasses slots symmetrically adjacent to the excitation probe and defining a capacitive load for compensating an inductance of the excitation probe antenna so as to obtain wideband operating frequency.

3. RESULTS AND DISCUSSION

The antenna has been measured in an anechoic chamber using satimo hybrid stargate 64 near field antenna measurement system and Agilent E8362C vector network analyzer [31]. To achieve unlimited near-field sampling using a probe array, the spherical scanning system was utilized for this near-field antenna measurement system. Using standard spherical wave expansion techniques, the antenna radiation can be fully defined by a set of modal coefficients. These modal coefficients are fed to a software employing a ray propagation technique. Probe array technologies are now accepted as an efficient and accurate tool for antenna measurements. Figure 3 shows the simulated and measured return loss results of the proposed patch antenna. There is good agreement between the measured and simulated results. The two closely excited resonant frequencies at 1.91 GHz and 2.21 GHz as shown in the figure give the measure of

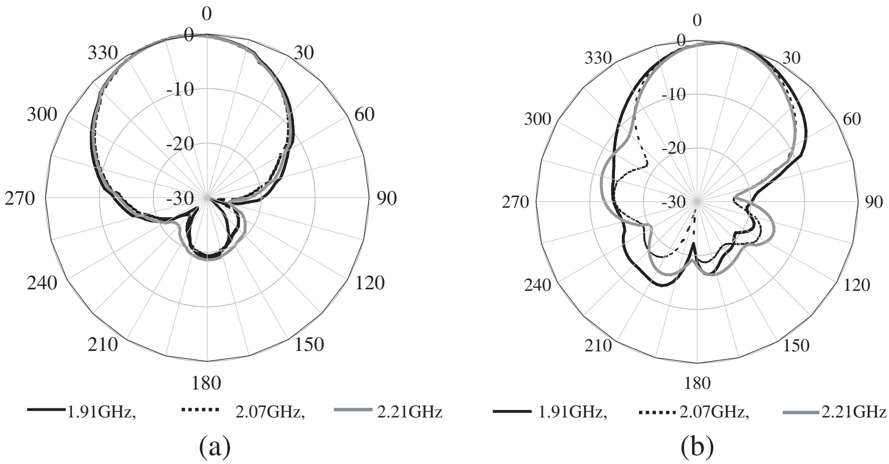

Figure 4. Measured radiation pattern of the antenna. (a) Azimuth, and (b) Elevation.

the wideband characteristic of the patch antenna. The measured impedance bandwidth of 30% (1.76–2.38 GHz) is achieved at -10 dB return loss (VSWR $\leq$ 2) while the simulated patch gives a slightly lower impedance bandwidth of about 27% (1.78–2.34 GHz).

The radiation characteristics of the proposed antenna are also studied. The measured radiation patterns of the azimuth and elevation are shown in Figure 4. The radiation patterns are measured at resonant frequencies of 1.91 GHz and 2.21 GHz and at the center frequency of 2.07 GHz. The designed antenna displays good broadband radiation patterns in the azimuth and elevation which can be clearly seen in the figure. It can be observed that 3-dB beamwidth in the azimuth (yz-plane) and elevation (xz-plane) are 63.53° and 51.37° respectively at 2.07 GHz. Figure 5 shows the measured cross-polarization level of the proposed antenna at 2.07 GHz. The peak cross-polarization level of the antenna is observed to be about -30 dB and -13 dB below the copolarization level of the main lobe at xz-plane and yz-plane at the frequency of 2.07 GHz. It is notable that the radiation characteristics of the proposed patch antenna are better to those of the conventional patch antenna because good cross-polarization level of -30 dB at xz-plane is achieved over the impedance bandwidth.

The measured peak gain with frequency is shown in Figure 6. As shown in the figure, the maximum measured gain is 9.37 dBi at 2.18 GHz, and the gain variation is 1.81 dBi between the frequency ranges of 1.76 GHz to 2.38 GHz. In addition, the gain in this design

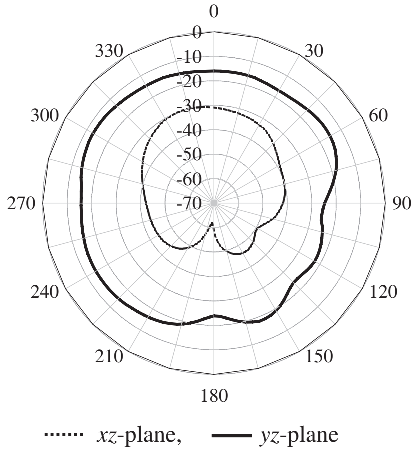

Figure 5. Measured cross-polarization of the proposed antenna.

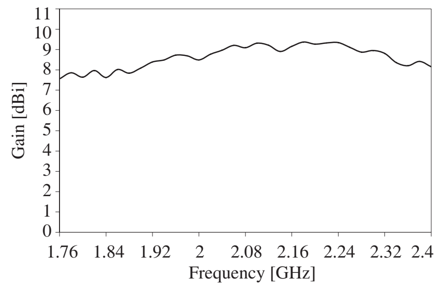

Figure 6. Measured gain of the antenna at different frequency.

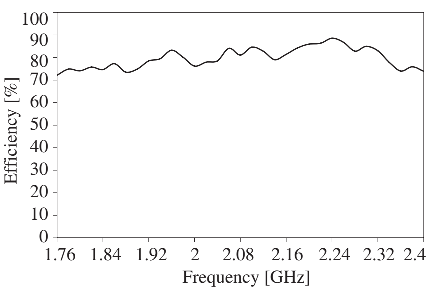

Figure 7. Measured efficiency of the antenna.

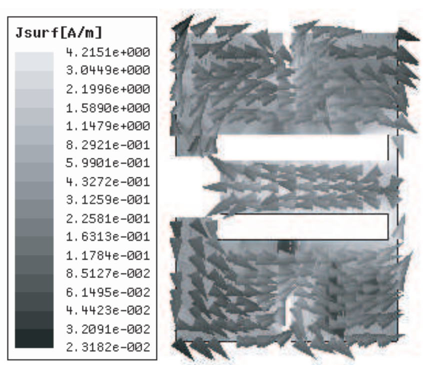

Figure 8. Current distribution at 1.91 GHz.

is better compared to the design reported in [11–28]. Also, the design in [20] is fed by L-probe feed and based on foam substrate that is more complex than our design which is based on air substrate.

Figure 7 shows the total efficiency of the proposed patch antenna at various frequencies where the total efficiency of the antenna is measured in a 3D space. The figure indicates high antenna efficiency over the operational frequency, and it is around an average of 80% while the maximum measured efficiency is 89% at 2.24 GHz.

Figure 8 shows the simulated current distribution on the patch.

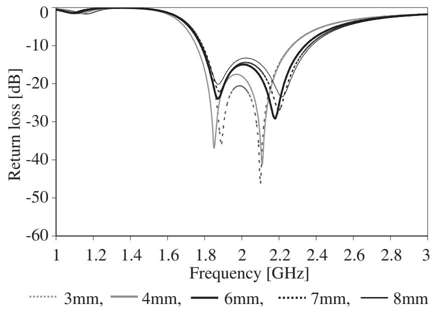

Figure 9. Effects on return loss of different slot width (w_2).

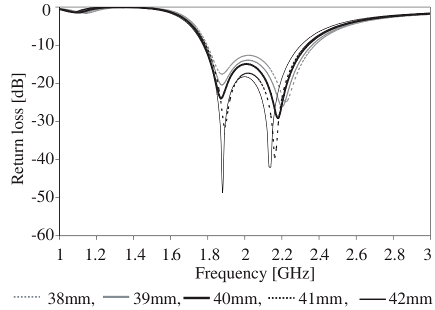

Figure 10. Effects on return loss of different slot length (l_2).

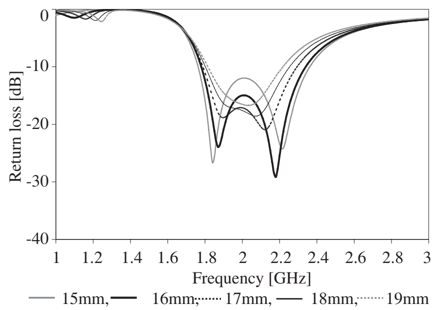

Figure 11. Effects on return loss of different height (h_0) of antenna air gap.

The current distribution on first resonant frequency is depicted in the figure due to identical manner of current flow in both resonant frequencies on the antenna. Arrows indicate the direction of the current distribution. It can be noted that the electric current strongly flows at the edge of the E-shaped slots especially near the feeding probe of the patch. This puts forward that the E-shaped slots govern the antenna performance. The current flow is restricted due to the H-shaped slots which lead reduction of cross-polarization level. However, the current is uniformly distributed to a different place.

The parametric studies are carried out by simulating the antenna with one geometry parameter slightly changed from the reference design while all the other parameters are fixed. Figure 9 shows the variation on the return loss with parameter w_2 (width of the slots on the patch). It can be observed that with increasing the slot width, both resonant frequencies shift upwards. Again, with decreasing the

Table 2. Measured performances of the antennas.

Antenna structure	Total antenna dimension	Maximum gain (dBi)	Bandwidth at −10 dB return loss	Frequency	3-dB beamwidth
Proposed antenna	80 × 50 × 16 mm^3	9.37	30%	1.76–2.38 GHz	*yz*-plane: 63.53° *xz*-plane: 51.37°
[29] Multi-slotted antenna	79 × 53 × 12.5 mm^3	9.41	27.62%	1.81–2.39 GHz	*yz*-plane: 60.88° *xz*-plane: 39°
[30] High gain antenna	79 × 38 × 16.5 mm^3	9.5	21.15%	1.86–2.30 GHz	*yz*-plane: 66.18° *xz*-plane: 48.57°

slot width, both resonant frequencies shift downward and exhibit better resonates at the expense of reducing the upper edge frequency resulting in a bandwidth reduction. Thus, the slot width, w_2, equal to 6 mm is used as the optimized value.

Figure 10 shows the variation on the return loss with parameter l_2 (length of the slots on the patch). It can be observed that both resonant frequencies shift upwards with decreasing the slot length. Again, impedance bandwidth reduces with increasing the slot length. Thus, the slot length, l_2, equal to 40 mm is used as the optimized value.

Figure 11 shows the variation on the return loss with parameter h_0 (height of air gap on the antenna). It can be observed that both resonates are highly affected and shift upward with increasing the height of antenna air gap. Hence, an optimal value of $h_0 = 16$ mm is chosen for the antenna design.

The comparison of the proposed antenna with our previously published antennas is tabulated in Table 2. From the table it can be concluded that the proposed antenna has better bandwidth at -10 dB return loss and 3-dB beamwidth at xz-plane compared to our previously published papers.

4. CONCLUSION

In this paper, a broadband microstrip antenna for gain and bandwidth enhancement is successfully developed. With the use of L-probe feed and E-H microstrip patch, the antenna has achieved 30% impedance bandwidth from 1.76 GHz to 2.38 GHz and a maximum gain of 9.37 dBi. Techniques for microstrip broadbanding, size reduction, high gain and stable radiation pattern are carried out and experimentally verified in this design. Furthermore, the parametric studies have addressed the effects of the width and length of slots of the patch and height of the air gap on the performance of the antenna. The information derived from the study will be helpful for antenna engineers to design and optimize the antennas for indoor wireless applications.

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