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DESIGN ANALYSIS OF HIGH GAIN WIDEBAND L-PROBE FED MICROSTRIP PATCH ANTENNA

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Abstract—A new high gain wideband L-probe fed inverted EE-H shaped slotted (LEE-H) microstrip patch antenna is presented in this paper. The design adopts contemporary techniques; L-probe feeding, inverted patch structure with air-filled dielectric, and EE-H shaped patch. The integration of these techniques leads to a new patch antenna with a low profile as well as useful operational features, as the broadband and high gain. The measured result showed satisfactory performance with achievable impedance bandwidth of 21.15% at 10 dB return loss (VSWR ≤ 2) and a maximum gain of 9.5 dBi. The antenna exhibits stable radiation pattern in the entire operating band.

1. INTRODUCTION

In virtue of the explosive growth of wireless system and booming demand for a variety of new wireless application, it is important to design broadband and high gain antennas to cover a wide frequency range. The design of an efficient wide band small size antenna, for recent wireless applications, is a major challenge. Microstrip patch antennas have found extensive application in wireless communication system owing to their advantages such as low-profile, conformability, low-cost fabrication and ease of integration with feed-networks [1]. However, conventional microstrip patch antenna suffers from very

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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]. There are numerous and well-known methods to increase the bandwidth of antennas, including increase of the substrate thickness, the use of a low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonator, 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.

Recently, several techniques have been proposed to enhance the bandwidth for various communication systems. A single layer wide-band E-shape rectangular patch antenna with achievable good impedance bandwidth has been demonstrated [7–9]. The patch substrates of these antennas are non inverted. Utilizing the shorting pins or shorting walls on the unequal arms of a U-shaped patch, U-slot patch, L-strip patch or L-probe feed patch, H-shaped stacked patch antennas, wideband and dual-band impedance bandwidth have been achieved with electrically small size in [10–15]. However the achievable gains of these antennas are below 8.5 dBi.

In this paper, a new LEE-H shape patch is investigated for enhancing the impedance bandwidth and gain. A better gain of 9.5 dBi is achieved compared to the design reported in [4–15].

2. ANTENNA DESIGN

Figure 1 depicts the geometry of the LEE-H patch antenna. The inverted rectangular patch, with width W and length L is supported by a low dielectric superstrate with dielectric permittivity ε_{r1} and thickness h_1. An air-filled substrate with dielectric permittivity ε_0 and thickness h_0 is sandwiched between the superstrate and a ground plane. The proposed patch has a compact dimension of 79 mm × 38 mm. The proposed patch integrates both the EE- and H-shaped patch on the same radiating element. For the inner E-shaped, the slots are embedded in parallel on the radiating edge of the patch symmetrically with respect to the centerline (x-axis) of the patch and it is incorporated with another outer E-shaped slot on the same radiating edge of opposite side. For the H-shaped, the slots are embedded in series on the non-radiating edge of the patch. The EE and H-shaped 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 as shown in Figure 1(b). Table

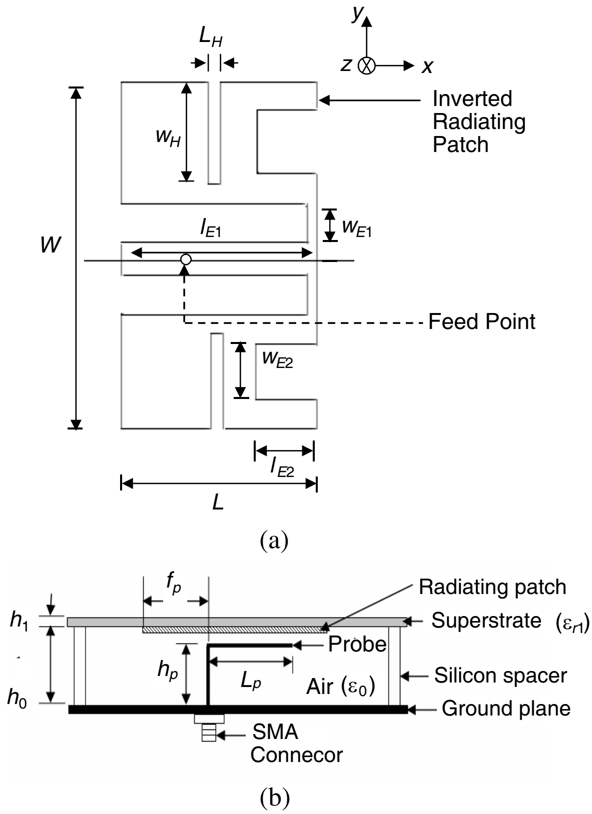

Figure 1. Geometry of proposed patch antenna. (a) Top view. (b) Side view.

1 shows the optimized design parameters obtained for the proposed patch antenna. A Rogers RT 5880 Duroid$^{\text{TM}}$ dielectric substrate with dielectric permittivity, ε_{r1} of 2.2 and thickness, h_1 of 1.5748 mm has been used in this paper. The thickness of the air-filled substrate, h_0 is 16.5 mm. An aluminum plate with dimensions of 200 mm $\times$ 180 mm and thickness of 1 mm is used as the ground plane. The proposed antenna is designed to operate at 1.86 GHz to 2.30 GHz region. The use of L-probe feeding technique with a thick air-filled substrate provides the bandwidth enhancement, while the application of superstrate with inverted radiating patch offers a gain enhancement, and the use of parallel slots reduces the cross polarization level. The use slots also reduce the size of the patch and broadening the bandwidth. 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 the excitation probe and defining a capacitive load for compensating an inductance of the excitation probe antenna so as to obtain wideband operating frequency. The photograph of the proposed patch is shown in Figure 2.

Table 1. The proposed patch antenna design parameters.

Parameter	Value [mm]
W	79
L	38
w_H	2
l_H	18
w_{E1}	4
l_{E1}	37
w_{E2}	11
l_{E2}	12
h_0	16.5
h_1	1.5748
h_p	14
L_p	27
f_p	7

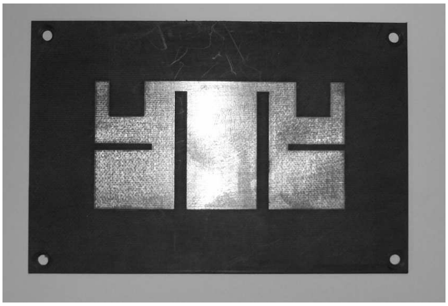

Figure 2. Photograph of the proposed patch.

3. RESULTS AND DISCUSSION

The resonant properties of the proposed antenna have been predicted and optimized using a frequency domain three-dimensional full wave electromagnetic field solver HFSS^{TM} v11. It is measured by an Agilent 8753ES network analyzer and the dimension anechoic chamber is 5 m × 5 m × 5 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 1.98 GHz and 2.18 GHz as shown in the figure gives the measure of the wideband characteristic of the patch antenna. The measured impedance bandwidth of 21.15% (1.86–2.30 GHz) is achieved at 10 dB return loss (VSWR $\leq$ 2) while the simulated patch gives an impedance bandwidth of 21.79% (1.84–2.29 GHz).

Figure 4 shows the measured radiation patterns of the yz-plane and xz-plane, respectively. The radiation patterns are measured at resonant frequencies of 1.98 GHz and 2.18 GHz and at the center frequency of 2.08 GHz. As shown in figure, the designed antenna displays good broadband radiation patterns in the yz-plane and xz-plane. It can be seen that 3-dB beamwidth in the yz-plane and xz-plane are 66.18° and 48.57° at 2.08 GHz, respectively. The beam squinting is 15°–25° degrees from the boresight as shows in the figure. However, the squinted beam is conducive to the indoor applications where the antenna is installed such that the ground plane of the antenna is parallel to the base station. The measured cross-polarization level of the proposed antenna at 2.08 GHz is shown in Figure 5. The

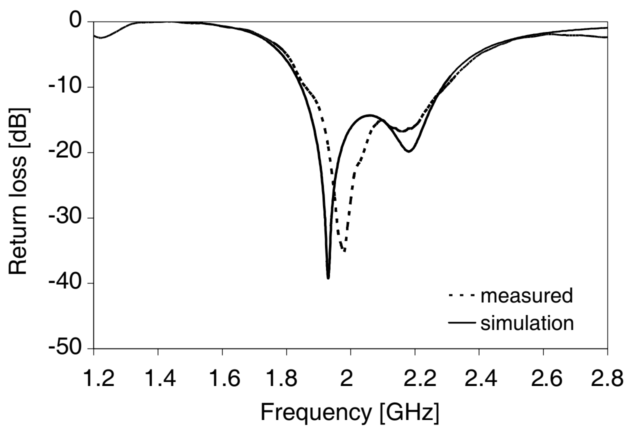

Figure 3. Return loss of the proposed patch.

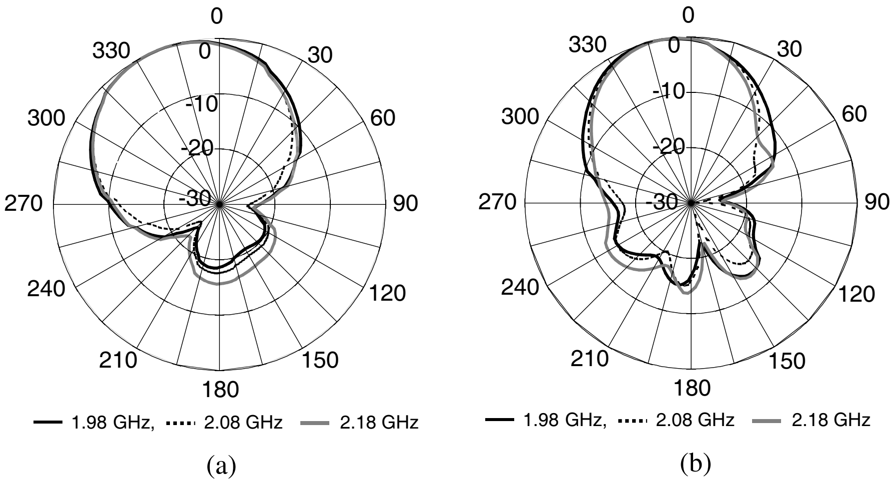

Figure 4. Measured radiation pattern of the antenna. (a) yz-plane. (b) xz-plane.

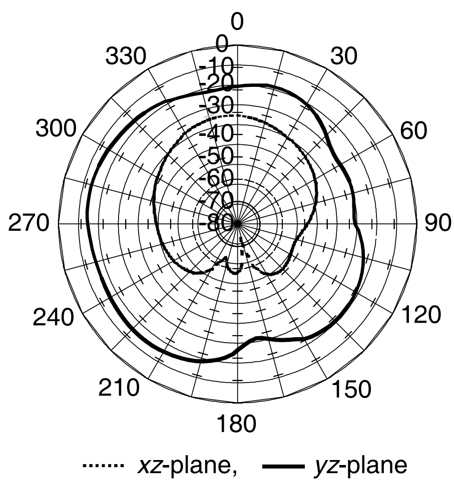

Figure 5. Measured cross-polarization of the proposed antenna.

peak cross-polarization level of the antenna is observed to be about $-31\,\text{dB}$ and $-12\,\text{dB}$ below the copolarization level of the main lobe at xz-plane and yz-plane at the frequency of 2.08 GHz. It is notable that the radiation characteristics of the proposed patch antenna are better to those of the conventional patch antenna due to good cross polarization level of $-31\,\text{dB}$ at xz-plane is achieved over the impedance bandwidth.

The measured peak gain of the proposed patch antenna at various frequencies is shown in Figure 6. As shown in the figure, the maximum achievable peak gain is 9.5 dBi at the frequency of 2.06 GHz and the gain is better compare to design reported in [5–15]. In addition, the design in [10] is based on foam substrate that is more complex than our design which is based on air substrate. Figure 7 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 80%.

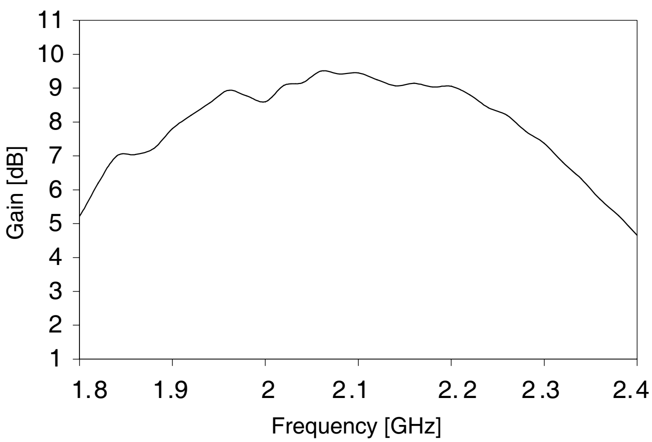

Figure 6. Measured gain of the antenna at different frequency.

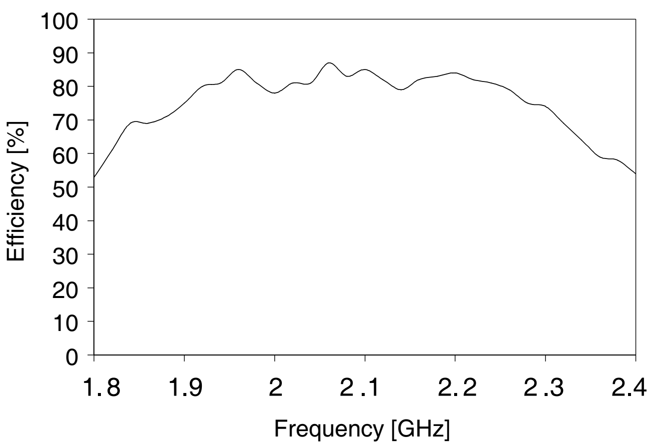

Figure 7. Measured efficiency of the antenna.

The simulated current distribution on the patch is illustrated in Figure 8. Due to identical manner of current flow in both resonant frequencies on the antenna, only current distribution on the first second resonant frequency is depicted in the figure. Arrows show the direction of the current distribution. It can be observed that the electric current intensely flows at the edge of the inner E shaped slots especially near the feeding probe of the patch. This suggests that the inner slots have a significant effect on the antenna performance. The current flow on outer E shaped slots restricts the current flow, helps reducing crosspolarization level. However, the current is uniformly distributed elsewhere.

Figure 9 shows the variation on the return loss with different widths of the slots (w_{E1}) on the patch. It can also be observed that the first resonant frequency shifted upwards with the increasing of slot width. Again, with decreasing the slot width, second resonant frequency exhibits better resonant at the expense of reducing the upper edge frequency resulting in a bandwidth reduction. Thus, the slot width, w_{E1} equals 4 mm is used as the optimized value.

Figure 10 shows the variation on the return loss with different heights of the slots air gap (h_0) on the antenna. It can be observed that

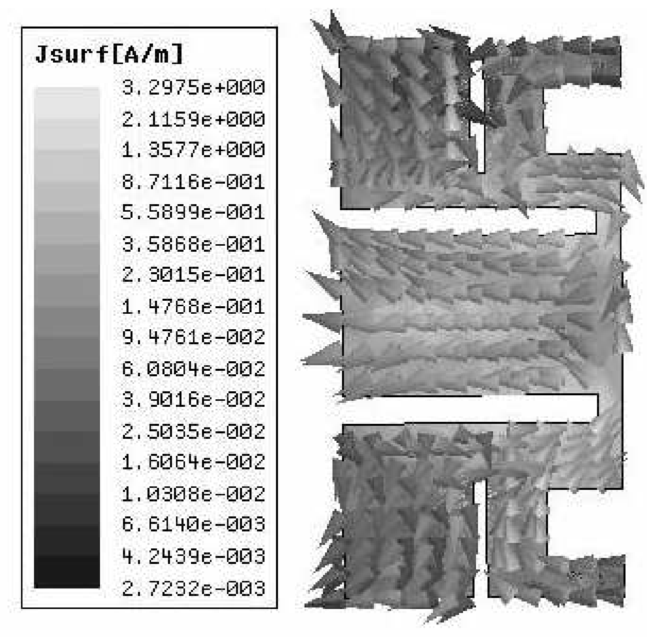

Figure 8. Current distribution at 1.98 GHz.

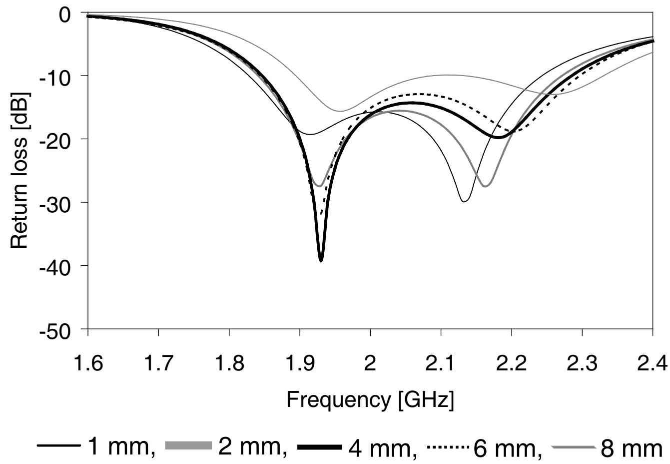

Figure 9. Effects on return loss of different slot width (w_{E1}).

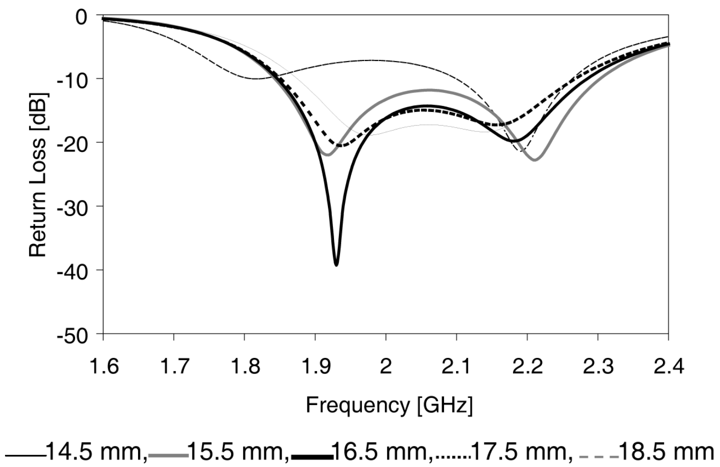

Figure 10. Effects on return loss of different height (h_0) of antenna air gap.

the first resonant is highly affected and shift upward with increasing or decreasing the height of antenna air gap. Hence, an optimal value of $h_0 = 16.5$ was chosen for the antenna design.

4. CONCLUSION

A new technique for enhancing gain and bandwidth of microstrip patch antenna is successfully developed in this paper. The LEE-H microstrip patch antenna achieves an impedance bandwidth of 21.15% (1.86 to 2.3 GHz) at 10 dB return loss. The maximum achievable gain of the antenna is 9.5 dBi. Techniques for microstrip broadbanding, size reduction, and cross-polarization reduction are applied with significant improvement in the design by employing new EE-H shaped patch design, inverted patch, and L-probe feeding. The proposed antenna with enhanced performance is suitable to be deployed on the base station in an indoor environment.

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