

DESIGN AND FABRICATION OF ONE NOVEL MULTI-POLARIZED MULTI-LAYER WIDEBAND PLANAR ANTENNA

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Abstract—A new multi-layer planar array architecture to achieve multi-polarized radiation is developed in this paper. The design concept is based on embedding U-shaped coupling slots in the ground plane to extend the bandwidth. The proposed antennas have two feed ports, by adjusting the feeding properly, the antennas can transmit arbitrary elliptic polarized signal theoretically. Return loss and radiation patterns are measured for the 1-element, 2-element, 4-element, 16-element antenna arrays at 12.5 GHz. Radiation patterns of the antenna arrays show close agreement to the predicted ones in the shape of the main beam. By further incorporating properly designed feed networks, the -20 dB return-loss bandwidth of the proposed antenna arrays can cover the 12.5 GHz frequency band (12.25–12.75 GHz). Design details and experimental results are presented and discussed.

1. INTRODUCTION

Conventional microstrip antennas have the attractive features of low profile, light weight, easy fabrication, and conformability to mounting hosts. Microstrip antennas inherently have a narrow bandwidth, but in practical applications, enhancement of bandwidth is usually demanded [1, 2]. Studies to achieve compact and broadband operations of microstrip antennas have increased greatly. Significant advances in the design of compact microstrip antennas with broadband, dual-frequency, dual-polarized, circularly polarized, and gain-enhanced operations have been reported over the past years [3, 4, 14, 15]. By embedding the U-shaped coupling slots in the ground plane, the planar antenna shows good impedance matching in a wide band. Patch antennas capable of multi-polarized operations are very suitable for

applications in modern communication system, and a variety of multi-polarized patch antennas have been reported recently [5, 6]. In this paper, we propose a new wideband multi-polarized patch antenna that works in 12.5 GHz band. The proposed antennas have two feed ports, and with the electromagnetic energy fed from a single port, the antennas transmit linearly polarized signals, while fed from both of the two feed ports properly, the antennas can transmit left hand circular polarized (LHCP) or right hand circular polarized (RHCP) wave. The 1-element, 2-element, 4-element, and 16-element antenna arrays are constructed and measured, results show good agreement to simulation.

2. DESIGN CONCEPTS

Figure 1 is the configuration of the multi-layer planar antenna proposed in this paper [7–10]. It has three substrate layers and four metal layers. The radiating square patch is printed in the top metal layer, and the square side has a length of L which is somewhat shorter than a half of λ_g (wavelength in the medium at the operation frequency). The U-shaped coupling slots are embedded in the second metal layer and aligned with the center arms parallel to the patch's radiating edges, respectively. The embedded slot has a width of $slot_w$ and a length of $slot_L + tip_L$, where $slot_L$ and tip_L are, respectively, the center arm length and the side arm length of the U-shaped coupling slot. The distance from the fed point to the square radiating patch center is marked as fed_poi . The feed line is printed in the third metal layer, and the bottom metal layer is the ground plane of the feed network.

The radiating patch is square and uses two U-shaped coupling slots

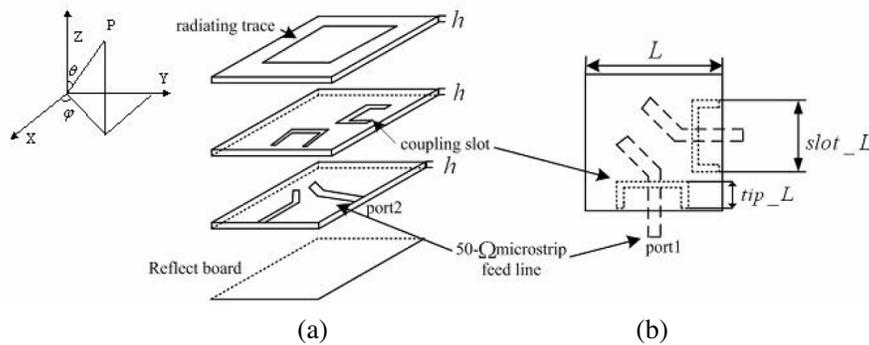


Figure 1. Structure of the antenna element, (a) exploded view, (b) top view.

for obtaining dual linear polarizations [11, 12]. The center arms of the two U-shaped slots are parallel to the x and y axes (see Figure 1). When the electromagnetic energy is fed by both of the two feed ports (port 1 and port 2 in Figure 1) with $\pm 90^\circ$ phase difference, the antenna radiates circular polarized wave. Figure 2 shows the simulated radiation patterns of the constructed prototype when the antenna transmits horizontal polarized (HP) and LHCP signals.

Figure 3 shows the arrangement of the coupling slots and the feed network of the 4-element antenna array. The arrangement chosen as Figure 3 makes the antenna array obtain low cross polarization. As

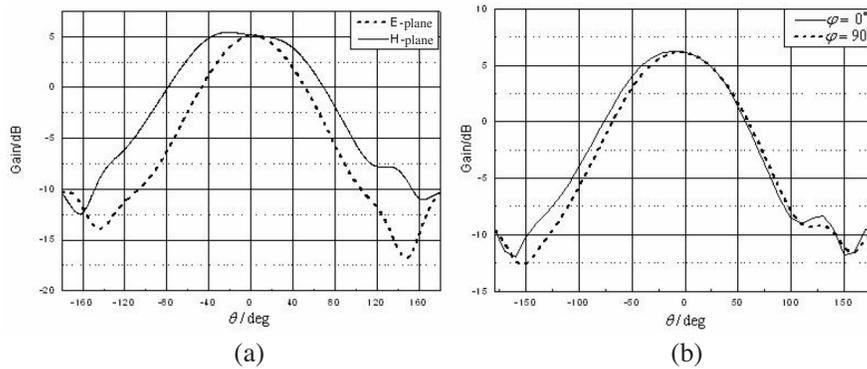


Figure 2. Radiation patterns when antenna transmits, (a) HL polarization, (b) LHCP signals.

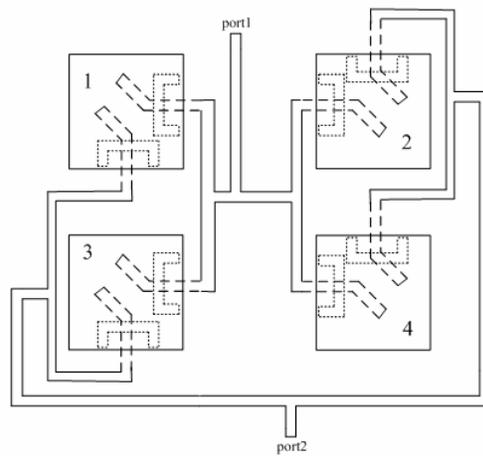


Figure 3. Top view of four-element antenna array.

shown in Figure 3, in order to obtain main beam in $\theta = 0^\circ$ direction when electromagnetic energy is fed from port 1, the feed line lengths of element 2 and element 4 should be $\lambda_g/2$ longer than those of element 1 and element 3, respectively. Figure 4 shows the configuration of 256-element antenna array.

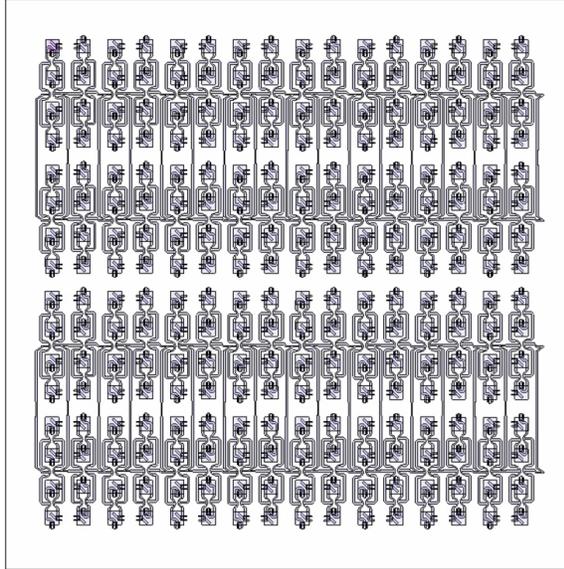


Figure 4. Top view of 256-element antenna array.

3. ANTENNA ARRAYS AND TEST RESULTS

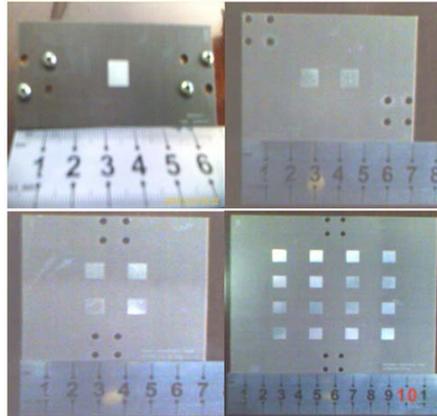
The 1-element, 2-element, 4-element, and 16-element antenna arrays were constructed and measured at frequency of 12.5 GHz. The top patch substrate [13] has relative permittivity $\varepsilon_1 = 2.2$ and thickness $h_1 = 0.5$ mm. Both of the central and bottom patch substrate have relative permittivity $\varepsilon_2 = \varepsilon_3 = 2.65$ and thickness $h_2 = h_3 = 0.8$ mm. The HFSS simulation software was helpful in obtaining proper parameters of the proposed antennas. The characteristic impedance of all the microstrip-line sections in the feed network is chosen to be 50Ω . In order to obtain good matching to eliminate feed-line reflections that could cause pattern degradation, optimized parameters in Figure 1 are given in Table 1.

Table 1. Values of the main antenna structure parameters.

Parameters	Slot width	$slot_L$	Feed line width	fed_poi	L	tip_L	$term_L$
values	0.4 mm	2.8 mm	1.15 mm	2 mm	6.4 mm	3.9 mm	3.6 mm

3.1. Fabrication of the Proposed Antenna

Figure 5 shows the fabricated 1-element, 2-element, 4-element, and 16-element antenna arrays. The electromagnetic energy is fed by the probe through the dielectric substrate and then coupled from the U-shaped slots to the radiating patches. The element spacing is chosen to be about 0.67λ (λ : wavelength in the vacuum). The advantages of this spacing are that it is large enough (a) to enable the feed network to be accommodated within the area below and between the patches, and (b) to ensure that mutual coupling between the patches is relatively weak. It is also not so large as to allow grating lobes to appear in the radiation pattern and thereby reduce the antenna directivity. The substrate dimension can be a little larger in order to decrease the coupling from the side of the patch substrate.

**Figure 5.** Photographs of the fabricated antenna arrays.

3.2. Measured Results

The radiation patterns of the linearly polarized antenna element are plotted in Figure 6(a), and both the measured and the simulated return

loss data of the antenna element are shown in Figure 6(b). It is observed that the antenna element has a wider main beam in E -plane. The gain of the antenna element is 5.5 dB and the 3 dB beam-width is about 90° .

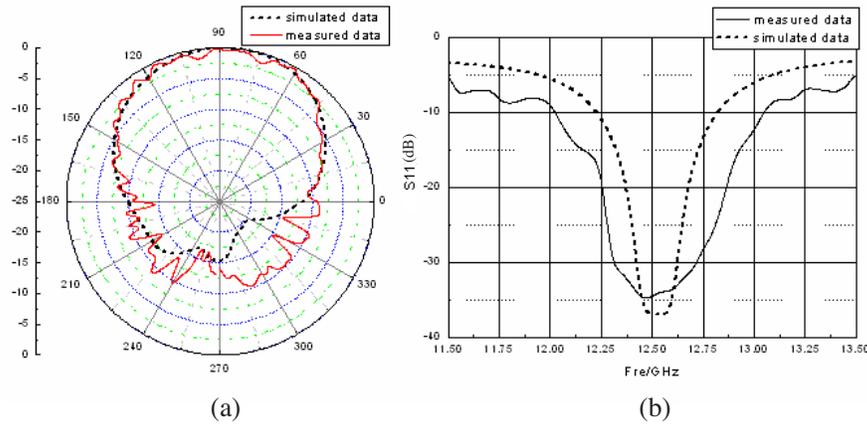


Figure 6. (a) E -plane radiation pattern, (b) S_{11} of antenna element.

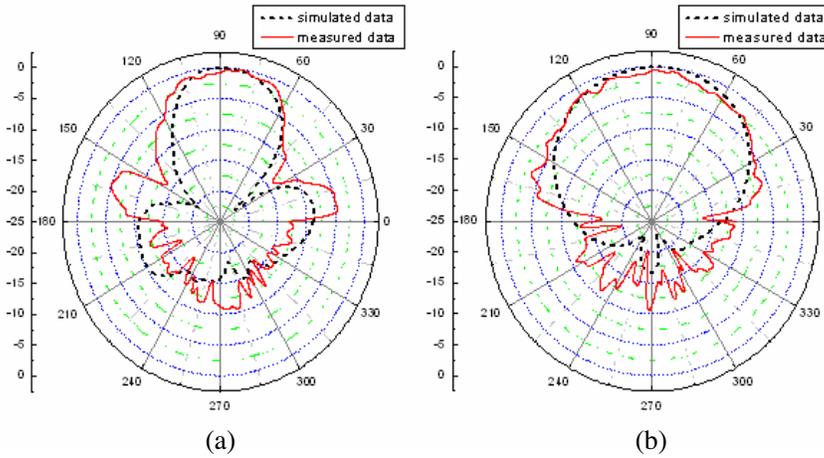


Figure 7. (a) E -plane, (b) H -plane radiation pattern of the 2-element array.

Figure 7 plots the E - and H -plane radiation patterns of the 2-element antenna array. The 2-element antenna array has a narrower beam width and two grating beams in E -plane. The 2-element

antenna array obtains 6.7 dB gain in both E -plane and H -plane. The 3 dB beam-widths are about 50° and 90° in the E - and H -plane, respectively. The return loss of the 2-element antenna array is shown in Figure 8, and the measured result agrees well to simulation.

The E -plane radiation patterns of 4-element and 16-element linearly polarized antenna arrays are measured and plotted in Figure 9 and Figure 11, respectively. The 3 dB beam-widths are about 35° and 20° of the 4-element and 16-element antenna array, respectively. The antenna gains are 8.86 dB and 13.88 dB of the 4-element and 16-element

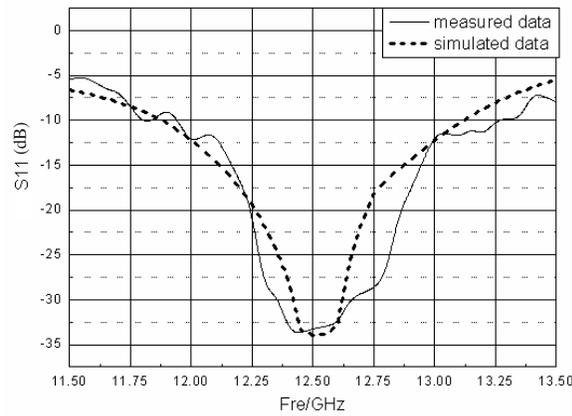


Figure 8. S11 of 2-element antenna array.

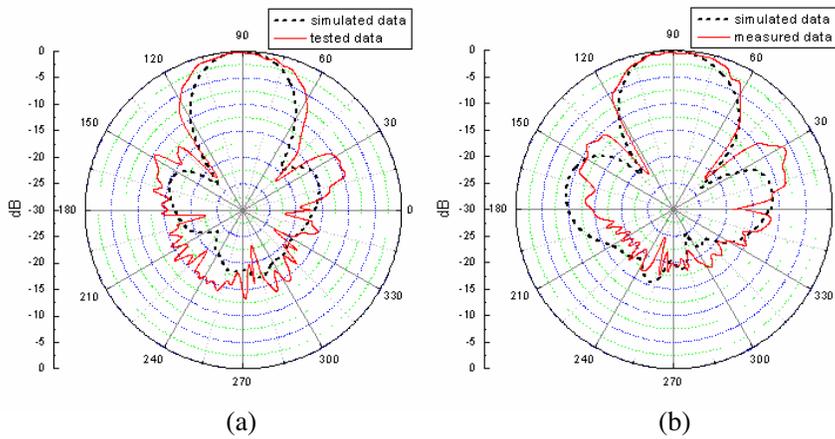


Figure 9. (a) E -plane, (b) H -plane radiation pattern of 4-element array.

antenna array, respectively. Figure 10 and Figure 12 show the return losses of the 4-element and 16-element antenna array when the arrays are single port excited, respectively. The 3 dB return-loss bandwidths are wider than those simulated.

Because of some fabrication imperfection, we can find from Figure 6 to Figure 12: 1. The 3 dB return-loss bandwidths were found wider than those simulated. 2. All of the antenna array patterns measured maintain the correct main beam and correct sidelobe positions although the backlobes are higher than those simulated.

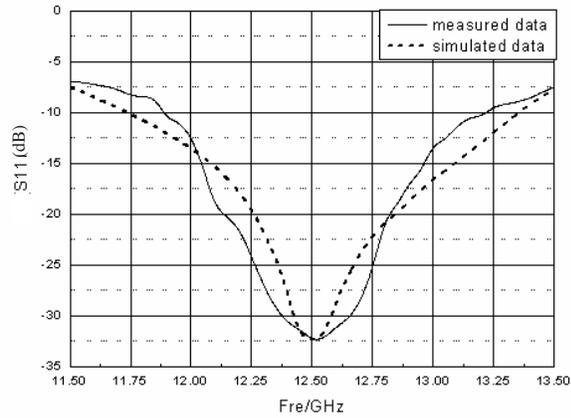


Figure 10. S11 of 4-element antenna array.

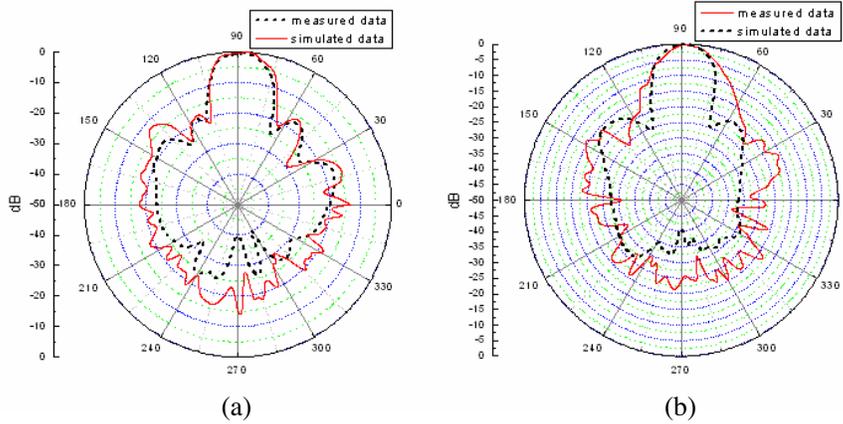


Figure 11. (a) *E*-plane, (b) *H*-plane radiation pattern of 16-element array.

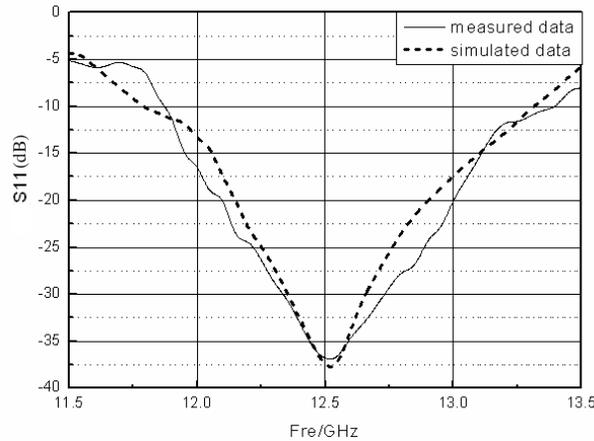


Figure 12. S11 of 16-element antenna array.

4. CONCLUSION

A wideband multi-polarized patch antenna operating in the 12.5 GHz frequency band has been proposed and experimentally studied. To meet the bandwidth requirements, a stacked configuration with U-shaped coupling slots embedded in the ground plane was utilized. The radiation patterns of the constructed antenna arrays show close agreement to those simulated. By incorporating a properly designed feed network, the proposed antenna arrays obtain low return losses in the 12.5 GHz band (S11 less than -20 dB).

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