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DUAL LINEAR/CIRCULAR POLARIZED PLANNAR ANTENNA WITH LOW PROFILE DOUBLE-LAYER POLARIZER OF 45° TILTED METALLIC STRIPS FOR WIMAX APPLICATIONS

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Abstract—A low profile double-layer polarizer structure is presented for planar patch antennas to obtain circular polarization in 3.5 GHz WiMAX band (3.4–3.6 GHz $\approx$ 5.7% bandwidth). Each polarizer layer is composed of 45° tilted metallic strips on a printed circuit. A bandwidth widening is obtained due to a significant reduction of the distance between polarizer and patches. The associated effects from the interaction of the two structures have been studied. A 2×2 array prototype has been implemented and measured, with a 8% average bandwidth in reflection and dual linear/circular polarization.

1. INTRODUCTION

Circularly polarized antennas are an interesting option for wireless communication systems [1–4]. The effect of multi-path reflection caused by walls and ground surfaces is avoided. The polarization losses are limited to 3 dB. The principle of circular polarization is based on the contribution of two linear and orthogonal polarizations with the same feed amplitude, and 90 degree phase difference. Two linearly polarized crossed elements connected to an external network to obtain the appropriated feeding amplitude and phase (3 dB branch-line coupler [5], two transmission lines with a physical length difference of a quarter wavelength [6]), generate circular polarization. Microstrip patches [7] have been widely used as radiating elements in circular polarization antennas by a truncation of the patch shape [8], although a narrowband response is achieved. On the other hand, a single

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patch with a double feed external network originates a wideband behavior, although some space limitation problems appear in big array configurations. An interesting alternative can be the inclusion of an external structure (polarizer) to convert a linearly into a circularly polarized antenna. The polarizer with metallic strips was introduced by Pakan [9], and developed by Lerner [10]. In this case, the incidence of a plane wave over the polarizer sheets is required. Therefore, the distance between radiating elements and polarizer must be large enough. Likewise, the strips' behavior is resonant, so a multilayer sheet configuration for a wideband operation is also recommended.

In this paper, a broadband circularly polarized patch antenna with external low profile polarizer is proposed. The antenna operates in 3.5 GHz WiMAX band. Therefore, no electronic switch components are included in the radiating elements [11–13], which reduces the complexity of the antenna. The presented antenna is also able to operate in linear polarization mode, by simply removing the polarizer. Therefore, the same radiating elements and feeding network (in an array configuration) are implemented for a linear or a circular polarization antenna, which represents a considerable cost reduction in a mass production process. The possibility of polarization choice, gives the antenna an added value in terms of diversity for the global gain of the process in the WiMAX communication [14]. A 2×2 array prototype has been manufactured and measured, with good broadband results in both linear and circular polarization operation mode.

2. BROADBAND POLARIZER

2.1. Operating Principle

Based on [10], authors presented a monopole antenna in millimeter band with a cylindrical double layer polarizer of metallic strips in diagonal orientation [15]. On that occasion, a narrow band polarization was achieved with a high profile structure. In this paper, a similar polarizer configuration is applied to a patch antenna. In addition, a broadband polarization behavior is obtained, with a thickness reduction of the antenna profile. The operation band is 3.4–3.6 GHz (WiMAX system).

As Fig. 1 shows, a double layer structure is placed over a probe fed linearly polarized double stacked patch [16]. This polarizing structure is composed of two sheets of 45° tilted metallic strips, separated by an intermediate foam layer ($\varepsilon_r = 1$) of approximately $\lambda_0/4$ thickness. Each strip sheet is printed on a thin 0.4 mm FR4 substrate, therefore the polarizer thickness is $0.3\lambda_0$. The horizontal separation between two adjacent strips is $0.7\lambda_0$ in the same sheet, and $\lambda_0/4$ for different layers.

The linearly polarized field E_i from the radiating patch can be divided into two orthogonal and linear electric field components with equal amplitude and phase ($E_{//}$ and $E_{\perp}$). The 45° tilted strip sheets act as a shunt inductance for the E-field component with the same strip orientation ($E_{//}$) [17]. Therefore, in every wave interaction with a polarizer sheet, a phase change is applied to $E_{//}$, while the perpendicular field component ($E_{\perp}$) remains inalterable. A 90° phase difference is obtained between both field components after the polarizer ($E'_{//}$, $E'_{\perp}$). Likewise, the $E_{//}$ component interaction with each strip sheet originates an alteration in the transmitted wave amplitude, as well as, a small reverse reflection wave. The first fact becomes almost insignificant in terms of circular polarization generation. Nevertheless, in order to minimize the reflection effect the separation between the two strip sheets was fixed approximately to $\lambda_0/4$. Under these conditions, the total reflection of the polarizer is almost cancelled.

In previous author's paper [15], as well as in other publications [10], the air distance T from the radiating element to the polarizer is set to at least λ_0, in order to achieve an incident plane wave at the polarizer position. A narrow band response was obtained in [15] ($T = 5.5\lambda_0$) with a two layer polarizer as the one shown in Fig. 1. In this paper, the T separation is significantly reduced ($T = 0.07\lambda_0$). The interaction between the incident field E_i and the polarizer occurs at the near field region. Therefore, the linear polarization of the incident wave is not purely generated yet. As a consequence, the resonant behavior of the phase change applied to the involved field components [10]

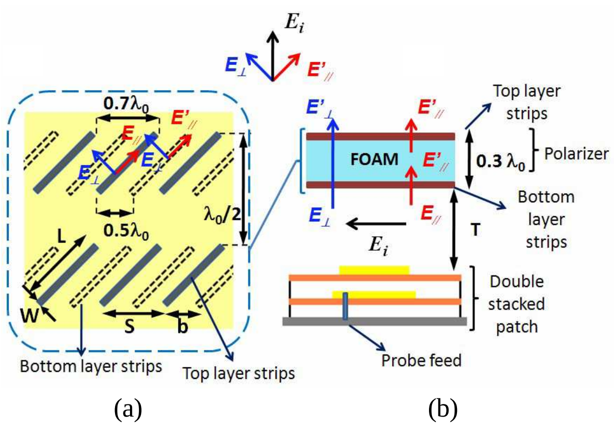


Figure 1. Broadband and low profile polarizer structure over double stacked patch: (a) Polarizer top view, (b) patch and polarizer side view.

is outstandingly modified, and a bandwidth extension of the generated circular polarization is achieved.

2.2. Simulations

For high values of T distance, the polarizer and radiating element design can be developed in a separate process. Nevertheless, in present design this aspect must be taken into account. The polarizer parameters are summarized in Table 1.

Figure 2 shows the simulated axial ratio of a single patch at the main beam direction according to different T distances. The optimum separation between patch and polarizer with $T = 6$ mm. In previous authors' paper [13], the obtained axial ratio with a high profile polarizer over a monopole antenna was 1% (3 dB criteria) at millimeter band. The optimum $T = 6$ mm case in Fig. 2 presents a 8.7% bandwidth.

The reflection coefficient evolution is showed in Fig. 3. The selected T separation also presents the optimum reflection response. A 10% bandwidth for −15 dB criteria is obtained, covering WiMAX band, even when the polarizer is removed (linear polarization). As Fig. 4 demonstrates, no radiation pattern asymmetries or losses are introduced by the polarizer strips in such a close distance from the patch. According to the Fig. 1 strip orientation, a Right Hand Circular Polarization (RHCP) is generated in the antenna. By turning strip layers down the Left Hand (LHCP) component could be radiated.

Table 1. Broadband polarizer parameters.

	λ_0	W	L	T	S	b
Polarizer	85.7	5.3	47	6	42.8	21
	(mm)					

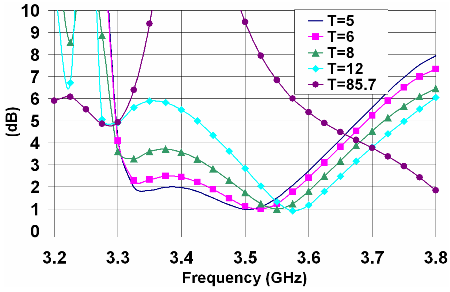


Figure 2. Simulated axial ratio evolution for single element with broadband polarizer.

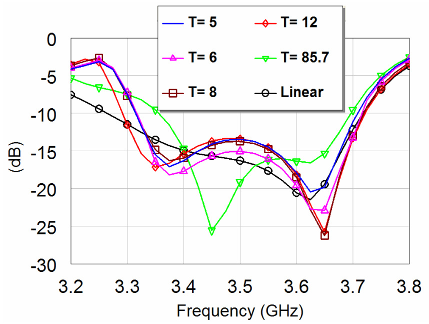


Figure 3. Simulated reflection coefficient evolution for single element with and without broadband polarizer.

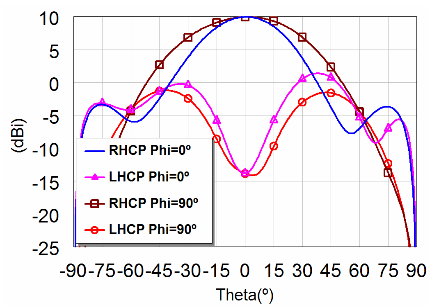


Figure 4. Simulated gain radiation pattern for single element with broadband polarizer for RHCP desired polarization at 3.5 GHz. $T = 6$ mm.

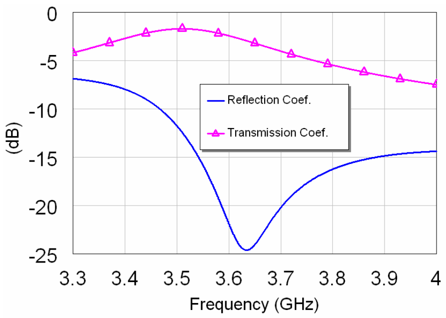
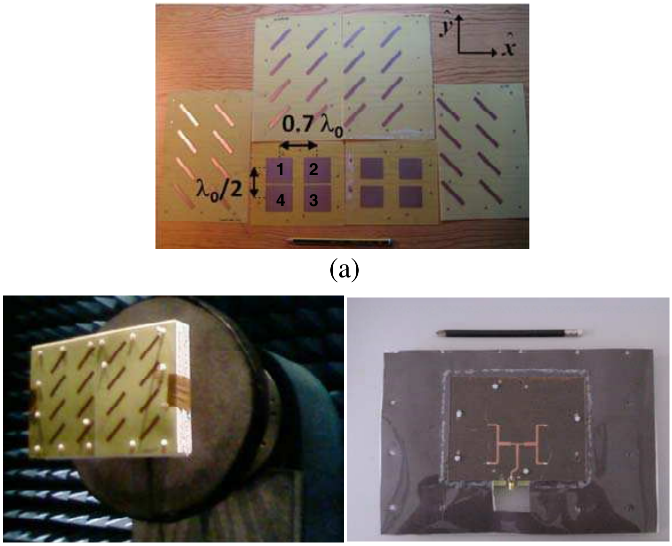


Figure 5. Polarizer reflection and transmission coefficients according to Floquet Theorem.

The polarizer reflection and transmission coefficients have been analyzed applying the Floquet theorem. As Fig. 5 demonstrates, a minimum reflection and maximum transmission behaviour is achieved from 3.5 to 3.7 GHz, which explains the not appreciable influence of the polarizer structure over the radiating patch.

3. DUAL LINEAR/CIRCULAR POLARIZATION 2 × 2 ARRAY

A 2 × 2 array prototype has been manufactured (Fig. 6). A 0.8 mm thickness and $\varepsilon_r = 2.5$ substrate is used to implement the feeding network for maximum directivity. Under these conditions, the antenna reflection coefficient has been measured for RHCP by placing the polarizer as Fig. 6 shows, and for linear polarization without the polarizer. As Fig. 7 demonstrates, linear and circular responses are almost the same. In comparison with the measured single patch



(a) (b) (c)

Figure 6. 2 × 2 array prototype: (a) Patches and polarizer printed circuits, (b) antenna in anechoic chamber, (c) 2 × 2 feeding network.

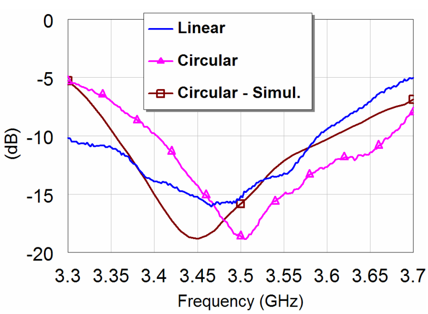


Figure 7. Dual array reflection coefficient. Measured v simulated results.

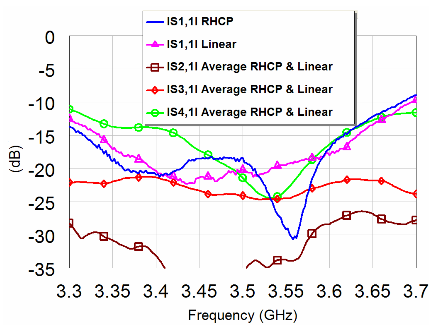


Figure 8. Measured patch reflection and coupling results in 2 × 2 array configuration for dual polarization operation.

reflection (Fig. 8), abrupt reflection deterioration is observed due to high coupling effects [18] in the array configuration (Fig. 8, according to Fig. 6(a) patches' numeration). A 8.4% reflection bandwidth is achieved for the dual array operation (−10 dB criteria in Fig. 7), and 8.7% for the single patch case (−15 dB criteria in Fig. 8).

The measured radiation pattern in Fig. 9 shows, an excellent linear polarization response of the array antenna without the polarizer. Due to the bigger array size in the horizontal plane ($\phi = 0°$), a narrower beam-width is achieved. The peak gain value is 13.1 dBi, which represents a 95% of efficiency. The measured radiation pattern with the broadband polarizer for a desired RHCP polarization is shown in Fig. 10. Good polarization discrimination is observed, with a gain peak value of 12.8 dBi, which represents an efficiency of 89%. Nevertheless, the array high coupling conditions, jointed to the asymmetric disposition of the polarizer strips and the ground plane edge effects, originate a radiation pattern asymmetry of the horizontal plane, as well as a beam narrowing. In fact, while a 43.5° beam-width is measured in vertical plane for both linear and circular polarization, 36° for linear and 30° for circular behavior are obtained in the horizontal plane.

The axial ratio evolution of the array antenna in the horizontal and vertical cut planes is summarized in Fig. 11. The optimum frequency response is obtained at 3.6 GHz, where 20° (horizontal plane) and 30° (vertical plane) angle coverage is achieved for a 3 dB axial ratio criteria. Likewise, the previously indicated horizontal plane asymmetry is observed.

The polarization analysis is completed with the measured axial ratio versus frequency response at the main beam direction. As Fig. 12

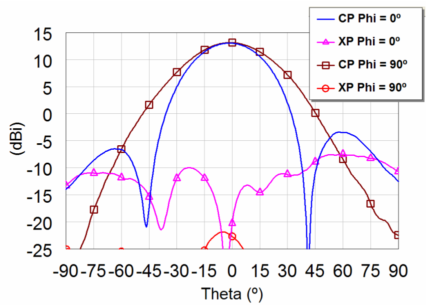


Figure 9. Measured gain radiation pattern of dual array without polarizer at 3.5 GHz.

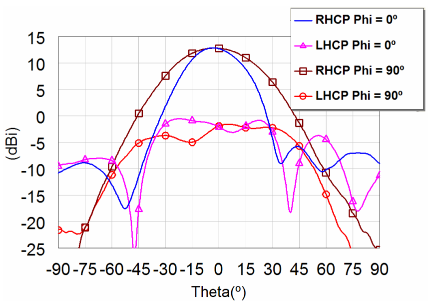


Figure 10. Measured gain radiation pattern of dual array with polarizer at 3.5 GHz.

shows, the single patch and 2×2 array simulations and measurements are presented. A 0.08 GHz frequency displacement is observed for both single and array structures in comparison with simulations. Therefore, the length of the polarizer strips should be slightly increased in order to correct this effect. Moreover, a deterioration of the array polarization is observed in comparison with the single patch response. A 0.5 dB average axial ratio increment is observed in simulations while in measurements this value increases to 1 dB. The simulated circular polarization bandwidth (3 dB criteria) is 8.7% for single element and array configurations. The single patch measured bandwidth is 7%, which deteriorates to 4% in the array case. These results show a satisfactory bandwidth behavior in comparison with other circularly polarized structures in previously published works: hybrid-fed patch antennas (13%), probe fed sequentially rotated linear polarized patch antennas (7.7%) [19], or notch disc patch array with sequential rotation (6%) [20]. A future modification of the strips dimension, as well as, a more precise mechanism in the layer placement and polarizer etching (as Fig. 6 shows, each layer of the polarizer was manufactured in two pieces due to laboratory limitations), will contribute to minimize the single over array measurement variation. In addition, a model to include and compensate coupling effects in the feeding network [21], will adequate the array polarization response to the single patch case.

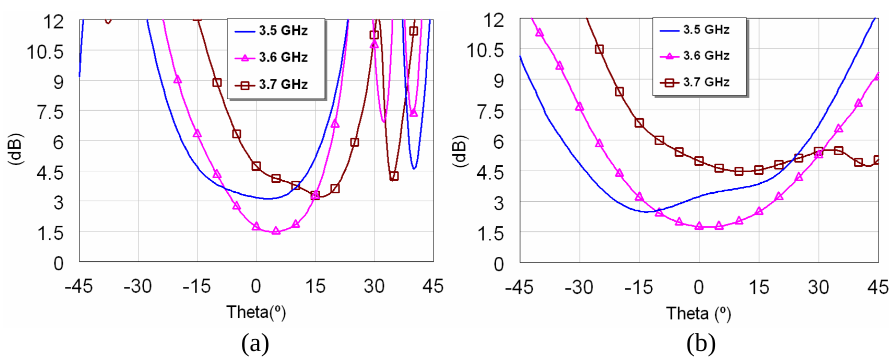


Figure 11. Measured frequency evolution of dual array axial ratio with polarizer over angle variation: (a) $\phi = 0°$ cut plane, (b) $\phi = 90°$ cut plane.

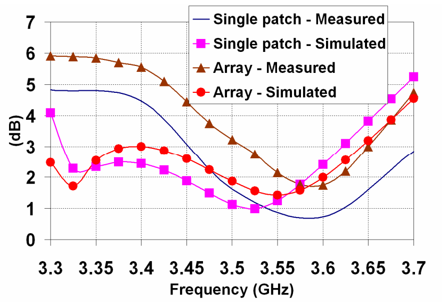


Figure 12. Single patch and array axial ratio. Measured v simulated results.

4. CONCLUSION AND FURTHER RESEARCH

A double-layer planar polarizer with 45° tilted metallic strips has been presented to operate in the 3.5 GHz WiMAX band. A dual linear/circular polarization patch antenna has been designed by the incorporation of the polarizer with a low profile structure. The polarizer operation principle and effects have been discussed. An array prototype has been manufactured, and an optimum broadband dual linear/circular polarization behavior has been achieved, although some undesired effects have been detected: high coupling and radiation asymmetry. Nevertheless, a significant reduction of the distance between radiating and polarizing structures is obtained. Next steps in this research are focused on the coupling compensation to improve the reflection and polarization results, besides the design and implementation of a dually polarized high gain array with digital control of the antenna pointing angle.

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