A HIGH PERFORMANCE CIRCULARLY POLARISED STACKED PATCH ANTENNA WITH LOW MUTUAL COUPLING

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A broadband circularly polarised stacked patch antenna element and a 4-element planar array, which have high efficiencies at 10 GHz, are presented in this paper. In addition to the low axial ratio given by the array, all possible bandwidths are obtained to be greater than 20% with an overall antenna efficiency greater than 75%. The mutual coupling between proposed elements at a centre-spacing of $0.667\lambda_o$ is also observed to be less than -25 dB.

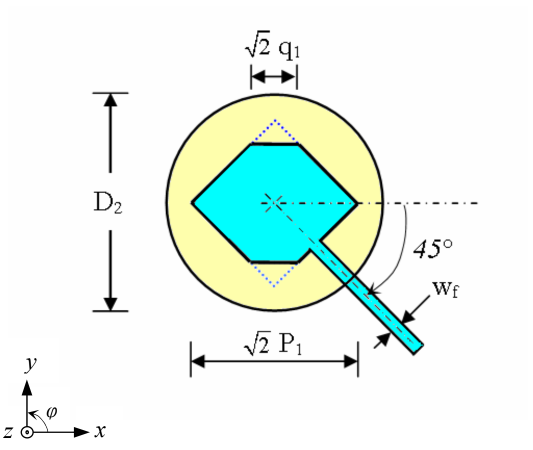
1. Introduction

A conventional two-layer electromagnetically coupled patch (EMCP) antenna is a specific type of stacked patch antenna. EMCP uses dielectric materials with low dielectric constants of around 2 to 2.5 for both the driven and parasitic layers, and uses airgap or foam as the layer separation [1-3]. However, when low dielectric constant materials are used as the driven layer the reinforcement of surface-wave power occurs. Surface-wave excitation has long been a major problem in microstrip patch antennas. It reduces antenna efficiency and increases mutual coupling when electrically thick substrates are used to increase the bandwidth for linear polarisation (LP). For circularly polarised (CP) patch antennas and arrays, surface-wave also causes severe unwanted coupling, radiation and high cross-polarisation discriminations (XPD), which in turn governs the quality of the axial ratio and its bandwidth. To overcome these problems, a radiating patch and feeding network printed on different layers using materials with different dielectric constants were suggested and realised in [7-9]. The idea presented in [7] uses a high-dielectric-constant material such as Alumina for the feed substrate allowing simple integration with the microwave circuit and bandwidth improvement for LP patch antenna. The stacked patches printed on *hi-lo* dielectric-layer combinations are also developed for CP applications in [8] to enhance surface-wave efficiency. We presented an optimal design and tuning strategy for CP-EMCP antennas [9]. A superstrate with a low dielectric constant has been included for the parasitic top-patch, which does not just improve antenna efficiency [4] but reduces mutual coupling. Thus, the EMCP element presented in [9] can also be termed as a stacked patch antenna with *hi-lo-lo* dielectric-layer combinations. We have also addressed in [9] the effect of superstrate for the determination of the top-patch size and the CP performance such as the enhancement in XPD and bandwidths, and more importantly, the trade-off between the boresight axial ratio and the axial-ratio bandwidth as a function of the perturbations on the stacked patches.

In this paper, we present another novel broadband stacked patch element in a CP-EMCP structure and show the performance of a 4-element planar array. The single element is first designed by using the design and tuning techniques introduced in [9], and a sequential feeding technique is then applied for the array to increase the gain as well as bandwidths. In addition to the impedance matching and CP performance for both the single element and the array, the overall antenna efficiencies as well as the mutual coupling between elements with different element orientations are examined.

2. Geometry of stacked patches and 2x2 array

The proposed CP-EMCP element is singly-fed by a microstrip line and has a desired centre frequency of 10 GHz. The array consists of four elements, which are 90° sequentially rotated in a square lattice of size D. The microwave laminate selected for the substrate is Rogers® RO3006 (ε_r=6.15, tanδ=0.002) with a thickness h_1 of $0.021\lambda_o$ whereas the superstrate is RT/duriod 5880 (ε_r=2.2, tanδ=0.0009) has a thickness h_3 of $0.026\lambda_o$. The thickness of the air-layer, h_2 is optimised at $0.11\lambda_o$ to obtain a low boresight axial ratio. The use of a material having a dielectric constant of 6.15 instead of 10.2 [8-9] for the driven-layer/substrate is based on the trade-offs amongst a number of parameters that not only dictate the CP performance, but also consider the dielectric losses as well as the manufacturing tolerance at X-band. In the proposed antenna element, the parasitic patch is a circular disc of diameter D_2 with no perturbation. The driven patch can be considered quasi-elliptical, which is actually a rotated hexagon having a major axis at $\sqrt{2}\ P_1$ and a minor axis at $\sqrt{2}\ (P_1-q_1)$; where q_1 is the perturbation amount for a singly-fed circularly polarised (SFCP) square patch. A microstrip feed-line is located 45° clockwise relative to the major axis, so that the resultant radiation is right-hand circularly polarised [6]. The geometry of the single element composed of the quasi-elliptical and circular patches with all the dimensions are shown in Fig. 1, whereas the silhouette of the 4-element planar array is shown in Fig. 2, where λ^H, λ^L and λ_o is the microstrip patch wavelength in substrate, superstrate and free-space wavelength, respectively, at the centre frequency.



$P_1 = 0.513\ \lambda^H$, $q_1 = 0.132\ \lambda^H$
$D_2 = 0.544\ \lambda^L$, $h_2 = 0.11\ \lambda_o$
$w_f = 0.082\ \lambda^H$ (50 ohm line)

Fig. 1 The geometry and dimensions of a right-hand CP-EMCP element at X-band.

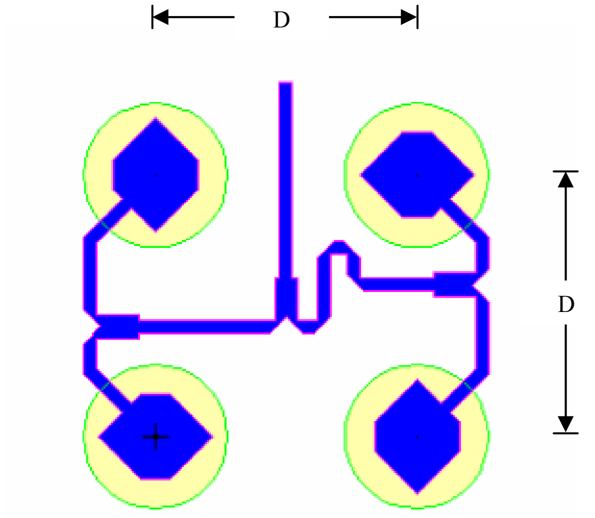


Fig. 2 The geometry of the 4 elements with 90 degree sequentially rotated and connected in a square grid of size D.

3. Antenna performance and mutual coupling

All the designs and tunings were simulated using a full-wave analysis tool – Ansoft Ensemble™. The impedance matching characteristic and the calculated antenna efficiencies for a single element as well as the 2x2 array are plotted together for comparison in Fig. 3. It can be seen that the impedance bandwidth (VSWR $\leq$ 2) is 19% and 27% with a mean frequency of about 10.2 GHz for a single element and the array, respectively. The overall antenna efficiencies are calculated by using the *gain-directivity method*. The directivity is first calculated by numerically integrating the radiation patterns for 4 cuts (two principle and two diagonal cuts) in azimuth plane and dividing into 4π. The overall efficiency is obtained by subtracting the directivity from the output gain from Ensemble. The overall efficiencies for both the single element and 2x2 array are calculated to be as high as 85% around the centre frequency owing to the enhancement in the surface-wave efficiency for such *hi-lo* material combinations [8]. Another reason should be attributed to the infinite ground-plane used in simulation, which ideally allows no backward radiation. However, this calculated efficiency can be regarded as the upper bound on obtainable overall antenna efficiencies for the proposed antenna with *hi-lo-lo* dielectric layers over the X-band. It can be seen from Fig. 3, the efficiency of the array is slightly higher than that of a single element but decreases rapidly in the band edges for both the cases. Fig. 4 shows the gain and axial-ratio versus frequency for the single element and the CP array. The minimum obtainable axial-ratio for both the single element and the array is less than 0.5 dB. The 2-dB A_xBW of 5.3% obtained for the single element has increased to 19.5% for the 2x2 array whereas the gain bandwidth (≥10-dBic) of the array is 22% with a mean frequency of 10.3 GHz.

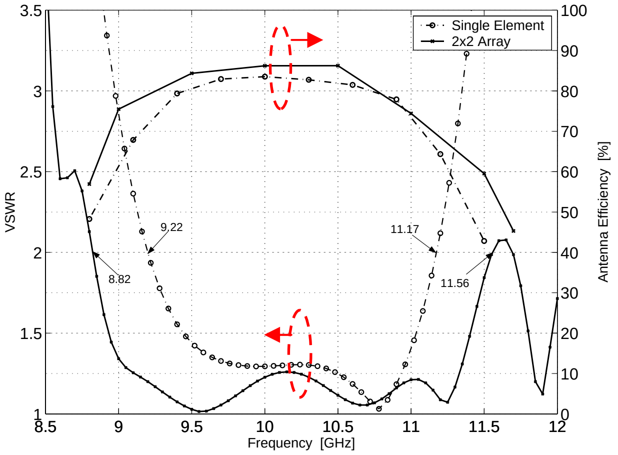


Fig. 3 VSWR and Antenna Efficiency plots for a single element and the 4-element array.

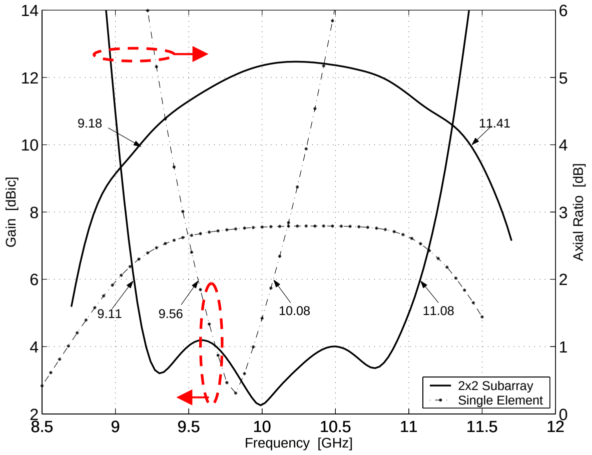


Fig. 4 Gain and Axial Ratio plots for a single element and the 4-element array.

It is well known that the mutual coupling of a conventional *three-layer*, corner-fed stacked square patch antenna is much stronger than its single-layer counterpart [3]: -25 dB compared to -35 dB at an element centre-spacing of $0.7\lambda_o$. This is owing to the presence of additional patches and the superstrate, which reinforce both the space- and the surface-wave coupling. A higher mutual coupling of the stacked patch antenna, leads to increased distortion in radiation patterns and lowers the scan capability in phased arrays. However, the proposed CP stacked patch element shows considerable improvement in its mutual coupling characteristics and is even comparable to a circular patch printed on a single-layer substrate with a dielectric constant of 2.55 [5]. To confirm the suitability of these elements for use in a sequentially rotated array, a simple two-element array was considered with 4 different scenarios which include elements aligned in (A) inner orthogonal (315°-45°), (B) outer orthogonal (45°-315°), (C) and (D) the anti-parallel planes, viz., 0°-180 and 180°-0° orientations. Each

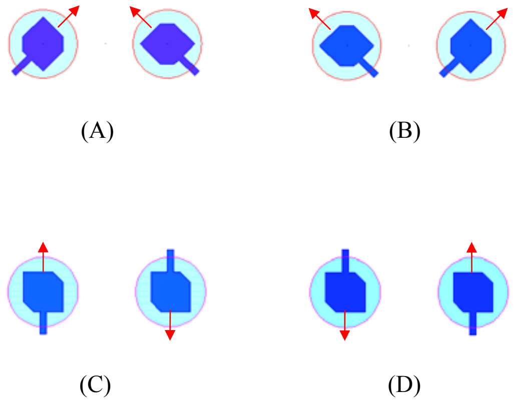


Fig. 5(a) The 2-element array arranged in four scenarios: (A) Inner orthogonal (315°-45°), (B) Outer orthogonal (45°-315°), two D-planes: (C) 0°-180° and (D) 180°-0°.

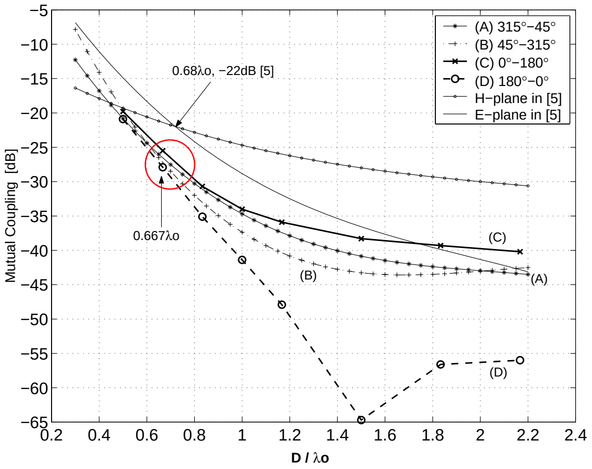


Fig. 5(b) The calculated mutual coupling of the proposed CP-EMCP elements arranged in the 4 scenarios and compared with the referenced single-layer circular patch in [5].

element of the 2-element array includes a small microstrip-line with a length of $\lambda_t/4$ in all scenarios, where λ_t is the microstrip-line wavelength in the substrate. In this way, we have taken the effect of the small feed-lines into account as in the array case. The physical element arrangements for scenarios (A) to (D) are shown in Fig. 5(a). The calculated mutual coupling versus element centre-spacing, D at 10 GHz as well as a comparison of the mutual coupling between single-layer circular-patch elements from [5] is shown in Fig. 5(b). It clearly shows that the mutual coupling of the proposed element is lower than the single-layer element in all cases, except for when $D < 0.45\lambda_o$ in both the orthogonal planes. Further, the mutual coupling are all below -24 dB for $D > 0.6\lambda_o$ in all scenarios. It was suggested in [5] that the cross-over point ($0.68\lambda_o$) of the E- & H-plane mutual coupling curves (-22dB) would be a suitable element spacing for CP arrays. For the CP stacked patch elements, the cross-over point of the mutual coupling curves in the inner and outer orthogonal orientations is -24.4 dB at $0.6\lambda_o$. In the 2x2 array as shown in Fig. 2, however, we use a spacing of $D = 0.667\lambda_o$ at which the mutual coupling is -26.3 dB and -27 dB making the D-plane mutual coupling of about -33 dB and -39 dB, as in the scenarios (A) to (D), respectively. We believe this point to be an optimal spacing at which the suppression of grating lobes are balanced by the mutual coupling between the elements in the principle planes, and also, the space for accommodating the feed network in the driven layer.

4. Conclusions

A novel broadband circularly polarised EMCP element in a stacked patch structure and a 4-element planar array has been introduced in this paper. This element has a parasitic circular patch printed at the bottom-side of a low dielectric constant material (superstrate), which is coupled to a quasi-elliptical patch printed on a medium dielectric constant material (substrate) via air dielectric. Besides the low axial-ratio and wideband (impedance, gain and axial ratio) characteristics, the antenna element exhibits high efficiency and low mutual coupling. A 2x2 array was designed and their element-spacing are based on the mutual coupling in the orthogonal planes. The array has an impedance bandwidth ($VSWR \leq 2$) of 27%, 2-dB axial ratio bandwidth of 19.5% and a 10-dBic gain bandwidth in excess of 22%. The theoretical antenna efficiency exceeds 75% for the sequentially rotated array over a frequency range of 9 to 11 GHz, making the bandwidth to be 20% related to the centre frequency.

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