Proceedings of ISAP'04, Sendai, JAPAN

EXPERIMENTAL STUDY ON THE PERFORMANCE OF CIRCULARLY POLARISED STACKED PATCH ANTENNA AGAINST LAYER DISPLACEMENTS

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1. Introduction

The offset/displaced patch and layer-misalignment of the multilayer patch antenna have both positive and negative effects on antenna performance. The offset patch is a bandwidth broadening technique that deliberately displaces the parasitic (top) patch, off-centred in stacked patch antennas, in order to increase the impedance bandwidth [1]-[2]. Such a technique, however, has been found to be only appropriate for linearly polarised electromagnetically-coupled patch (LP-EMCP) antennas. Usually, the stacked patches of LP-EMCP printed on dielectric materials having a *low* dielectric constant of around 2 to 3, with or without an airgap used between the dielectric layers [1]-[3]. When the method and/or materials employed for the offset patch is inappropriate, broadband becomes the adjacent, narrow dual bands due to the separation of the two resonant frequencies [4]. The layer-misalignment, on the other hand, is an inevitable after-effect of the multilayer structure due to material and fabrication tolerances. The aperture coupled patch antenna, one of the multilayer antennas, suffers from high sensitivity to the degraded circularly polarised (CP) performance due to layer-misalignments [5], especially when the antenna element is singly-fed. The authors have shown in [6], that a LP stacked patch antenna (LP-EMCP) with *high-low-low* dielectric constant materials combination [7]-[8] has robust characteristics against patch/layer displacements. Such an antenna has an interesting characteristic: as the displacement increases the resonant frequencies tend to merge resulting in bandwidth reduction, which is contrary to the conventional stacked patch antennas with *low-low* combination [6]. In this paper, we extend our investigation to a singly-fed CP-EMCP element. The effects of the offset patch or non-centred stacked patches on the antenna performance will be experimentally examined. It will be shown that such an EMCP structure has robust characteristics not just on the impedance bandwidth but also the CP bandwidth against the layer-displacements.

2. Antenna Geometry and Experimental Method

The CP-EMCP antenna element under examination is a singly-fed X-band design with its right-hand CP geometry as shown in Fig. 1. The antenna element is a *modified Type-E element* [8] with a desired centre frequency of 10 GHz. There are unequal-sized, stacked patches printed on high (6.15) and low (2.2) dielectric constants materials, separated by a middle layer - an air dielectric. This CP element was designed by transforming from its LP counterpart with perturbations added into the driven patch. The thickness of the air dielectric (d_2) was increased to 3.3 mm in order to yield the low boresight axial ratio with no perturbation (q_2=0.0) is included on the top-patch [9]. The displacement X–Δ map shown in Fig. 2 illustrates the linear displacement from 2, 4 to 6 mm in three principle directions of 90°, 180° and 270°, and from 4 to 6 mm in the diagonal directions of 135° and 225° are made for the return loss ($-S_{11}$ in dB) measurement. The Δ represents the locations where the axial ratio (AR) measurements after layer displacement were studied. It can be seen that *eight* locations other than its normal (aligned) position are considered for the AR measurements. Small holes were precisely drilled into the top-layer to realise the linear displacement of the specified locations as shown in the map whilst the bottom-layer is stationary.

ISBN: 4-88552-206-4 C3055©IEICE

3. Experimental Results and Discussion

Fig. 3 shows the measured return-loss versus frequency for the (a) 4-mm and (b) 6-mm linear displacements, respectively. It shows that the CP-EMCP antenna has robust impedance characteristics even better than its LP counterpart as reported in [6]. Table 1 shows the 10-dB impedance bandwidths (ZBW) are all above 10%, including the maximum displacement of 6 mm in all directions. The CP element has an important bandwidth of boresight axial-ratio which gauges the quality of the element and must be taken into account in evaluating the allowable displacement limits. Figs. 4(a) and 4(b) shows the axial ratio versus frequency for the linear displacement of 2 and 4 mm in 3 and 5 directions, respectively, whereas the corresponding 3-dB axial-ratio bandwidth (A_xBW) is also summarised in the table.

According to the measured 10-dB impedance bandwidth (ZBW) values listed in Table 1, a 10% criterion in ZBW of VSWR ≤ 2 is used, the CP-EMCP element has a larger limit than the LP-EMCP element. A conservative limit can be located as **6 mm** in the entire *x-y* plane. When the linear displacement is 6∡270°, the LP-EMCP has a ZBW of nearly 0% [6] but the CP-EMCP is maintained above 12%, and is only few percent smaller than that obtained from the other directions. This difference is attributed to the perturbation on the driven patch, which alters the fringing field line distribution along the patch. In other words, it is due to the two orthogonal modes on the singly-fed patch rather than a single TM_{01} mode as exhibited in the LP case. The displacement limit for the impedance bandwidth is higher than the LP element. However, it becomes smaller if axial-ratio bandwidth has to be taken into account. Based on the axial-ratio plots in Fig. 4, and using a value of 5% for the 3-dB axial ratio bandwidths (A_xBW) as the criterion, the displacement limit can be determined from the results listed in Table 1, and is concluded in Table 2.

Table 1 Summary of 10-dB Impedance Bandwidths and 3-dB Axial Ratio Bandwidths for Linear Displacements applied to CP-EMCP Element

Displacement	f_m^Z [GHz]	10-dB ZBW	f_m^A [GHz]	3-dB A_xBW
0∡0°	10.1	23.8%	9.6	8.0%
2∡90°	10.1	24.8%	9.6	9.0%
2∡180°	10.1	24.2%	9.6	8.6%
2∡270°	10.1	24.0%	9.6	8.7%
4∡90°	10.1	24.0%	9.6	5.3%
4∡135°	10.0	23.5%	9.6	6.0%
4∡180°	10.1	23.2%	9.5	6.4%
4∡225°	10.1	21.7%	9.5	3.8%
4∡270°	9.8	17.8%	9.5	2.7%
6∡90°	9.6	13.1%		
6∡135°	9.6	15.2%		
6∡180°	9.7	13.5%		
6∡225°	9.8	14.2%		
6∡270°	9.7	12.2%		

4. Conclusions

In this paper, an experimental study on the performance of a singly-fed CP stacked patch antenna against patch/layer displacement is presented. The antenna element is designed for RHCP operations in X-band with a *high-low-low* (6.15-1.0-2.2) dielectric constant materials combination. The experimental results show that the CP element has very robust impedance and axial ratio characteristics against the layer-displacements. For a 10% impedance bandwidth criterion, this element can withstand a 6-mm linear displacement in the entire *x-y* plane. However, when one considers the criterion of 5% axial-ratio bandwidth, the displacement limit would be reduced to 3 and 4 mm in the lower and upper *x-y* plane, respectively.

Table 2 Linear Displacement Limits for the CP-EMCP Element based on a 3-dB A_xBW Criterion of 5%

Upper *x-y* plane ($0° \leq \varphi \leq 180°$)	**4 mm** ($0.133\lambda_o$)
Lower x-y plane ($180° < \varphi < 360°$)	**3 mm** ($0.1\lambda_o$)

Acknowledgements

The authors would like to thank the CSIRO ICT centre for allowing access to their anechoic chamber and help with conducting the various measurements. Thanks also to the Rogers® Corporation for the supply of dielectric material used in this study.

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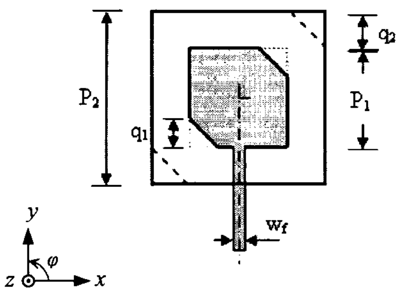


$P_1 = 6.0$ mm, $q_1 = 1.60$ mm
$P_2 = 9.40$ mm, $q_2 = 0.0$,
$d_2 =$ **3.30 mm** ($0.11\lambda_o$)
$w_f = 1.0$ mm (50 ohm line)

Figure 1 X-band CP stacked patch antenna with *hi-lo-lo* (6.15-1.0-2.2) dielectric layer combination.

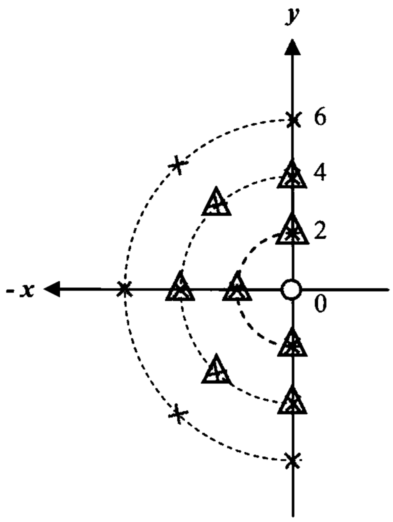
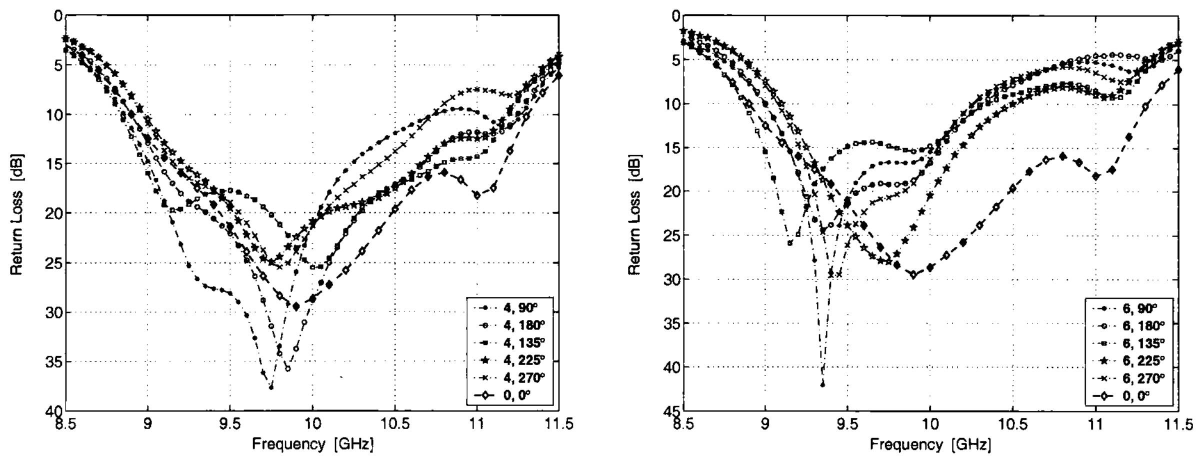
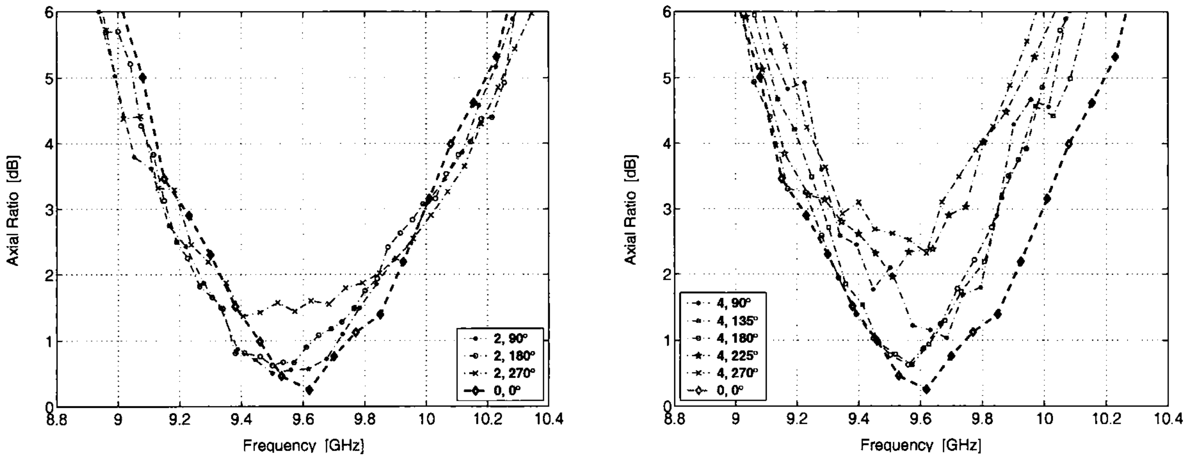


Figure 2 The loci of displacement for the top-patch in the Left Half Plane.



(a) (b)

Figure 3 The measured return loss for the (a) **4-mm**, (b) **6-mm** displacements in *5 directions* (90°, 135°, 180°, 225° and 270°), and compared to the normal alignment (0, 0°).



(a) (b)

Figure 4 The measured axial ratio vs. frequency for (a) **2-mm** displacement in *3 directions* (90°, 180° and 270°); (b) **4-mm** displacement in *5 directions* (90°, 135°, 180°, 225° and 270°).