OPTIMIZATION OF STACKED MICROSTRIP ANTENNA FOR CIRCULAR POLARIZATION

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ABSTRACT

We propose a new C-type feed location to achieve circular polarization from stacked rectangular microstrip antennas. A systematic process to optimise the axial ratio (AR) bandwidth and ellipticity is presented. A main radiator and a parasitic patch of identical size are considered and the separation between them has been optimized to achieve a directive gain of 8.82 dBi, 3-dB AR-bandwidth of 14% and ellipticity (minimum AR) of 0.07dB at centre frequency. The proposed technique is very useful for rapid design of circularly polarized stacked microstrip antennas with high gain and large AR-bandwidth.

INTRODUCTION

Microstrip patch antenna elements are very popular in wireless and satellite communication. They are used for both linear and circular polarizations. A circularly polarized EM-wave is generated when an antenna radiates two orthogonal field components having equal amplitude with a quadrature phase difference between them. Several geometrical configurations of microstrip patch antennas can provide such dual orthogonal field components with proper excitation of the patch cavity. Normally two orthogonal field components are excited in the patch cavity using dual orthogonal feeds and splitting input microwave power in various ways [1]. This method generally gives a large AR-bandwidth. However, the external power divider increases the size and complexity of the system; thus preference is given to single-feed circularly polarized microstrip antennas. A perturbed symmetrical patch cavity for example, of square or circular shape, supports two orthogonal modes, which can be excited with a single feed. Haneishi et al. [2] have classified two types of single feed locations: A-type when feed is located on the X or Y-axis parallel to the edge of the square patch, B-type when feed is located at the diagonal of the square patch. In both arrangements, the feed is located diagonal to the perturbation to produce two orthogonally degenerate modes. An off-square patch with aspect ratio of about 1.01 has also been used to achieve circular polarization [3], [4]. The typical AR-bandwidth of these antennas is about 1% and this is not sufficient for modern wireless communication systems requiring bandwidths in the order of 8%-10%.

Lee et al. [5] have introduced an almost square parasitic element with an almost square patch radiator to improve the AR-bandwidth, however the AR-bandwidth could only be improved from 0.175% for the single patch to about 0.45% for the stacked patch. Normally such stacked patch antennas are used to increase the gain and/or impedance bandwidth of a patch antenna. Egashira and Nishiyama [6] have used triple stacked circular patches with dual feed to achieve a directivity of 10.6 dBi, an AR-bandwidth of 8.5% and impedance bandwidth of 10%. However, the total thickness of the antenna is more than $\lambda/2$. They have further investigated the structure by using the FDTD method [7]. Herscovici et al. [8] used a probe-fed rectangular patch (aspect ratio = 1.205) with an almost square parasitic element (aspect ratio = 1.0625) to achieve an AR-bandwidth of 13%. Their radiating patch is on a foam substrate that is 0.04054λ thick and the total thickness of the antenna, including the parasitic patch, is 0.085λ. They have not provided any information on the directive gain and have not discussed any process to properly locate the feed point to achieve AR around unity. They have also not discussed the effect of the separation between the main patch (lower patch) and the parasitic element on the gain and AR-bandwidth. However, they have noted that the AR-bandwidth is less than the impedance bandwidth and these do not overlap each other, i.e., the 3-dB AR-bandwidth is not within the 10-dB return loss bandwidth. The overlapping of both bandwidths is important for the proper operation of a circularly polarized microstrip antenna.

We report a circularly polarised stacked rectangular microstrip antenna with an optimum AR-bandwidth, achieved by optimising the feed location and foam thickness between the main (radiating) and parasitic patches. Following the single feed location classification of Haneishi et al. [2] mentioned above to achieve the circular polarization, we call this C-type feed location, i.e., the feed is located neither along X/Y axis nor along the diagonal. It is located at a rotation angle (θ), where $0^0 < \theta < 45^0$. We have also noted that by optimising θ, we can bring the AR-bandwidth within the impedance bandwidth. The feed rotation angle θ, and the separation between the two identical patches have been optimised to achieve a 14% AR-bandwidth with 8.82 dBi directive gain. This design and optimization has been done using Microwave Studio commercial 3D-EM software from Computer Simulation Technology (CST) [9].

SELECTION OF RADIATING AND PARASITIC PATCHES

A probe-fed rectangular stacked microstrip antenna is shown in Fig. 1. Its C-type feed is located in the first quadrant as discussed above. In our investigation, we move the probe feed position along the arc of the circle with radius X_o points P_1 (X_o, 0) and P_2 $\left(\frac{X_o}{\sqrt{2}},\frac{X_o}{\sqrt{2}}\right)$. The feed location is defined by the rotation angle (θ) shown in Fig. 1. The polarization of the antenna can be changed from linear to elliptical to circular by changing θ and have controlling the relative amplitudes and phases of the degenerate modes in the microstrip cavity. For a given substrate, the size of the rectangular patch is obtained for the design frequency [1]. We have assumed that the aspect ratio of the patch (Length (L_1)/Width (W_1)) is 1.143 as this value is found to be suitable to achieve circular polarisation. The aspect ratio determines the condition for dual orthogonal modes. To begin with, the initial feed position P_1 (X_o, 0) is determined for 50 Ω impedance matching. It is obtained for the single patch in the usual way and then position has been adjusted loss for the stacked antenna using Microwave Studio. In order to achieve a good circular polarization, we need to move the feed position on the arc by changing the feed position (X, Y) according to

$$X = X_o \cos(\theta),\ Y = X_o \sin(\theta) \qquad (1)$$

To achieve optimum AR bandwidth, we need to determine the relative size ($L_2 \times W_2$) of the parasitic rectangular patch with respect to the size ($L_1 \times W_1$) of the main radiating patch. The dimensions of six stacked microstrip antenna configurations investigated here are given in the Table 1.

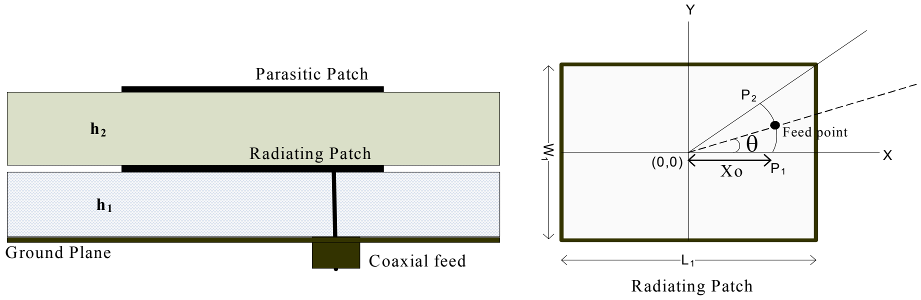

Fig. 1. Wideband circular polarized stacked microstrip antenna.

We found that, for the stacked microstrip antenna gives good impedance match and a feed rotation angle of 35° leads to good circular polarisation initially.

Table I: Dimensions of six stacked microstrip antenna configurations
(ε_{r1} = 2.2, h_1 = 1.575 mm, $\tan\delta_1$ = 0.0009, ε_{r2} = 1.07 (foam), h_2 = 5.8 mm, X_o = 4.0 mm, rotation of the feed (θ) = 35°)

Antenna configuration	Lower Radiating Patch		Upper Parasitic Patch	
	L_1 (mm)	W_1 (mm)	L_2(mm)	W_2(mm)
Case #1	16.0	14.0	16.0	14.0
Case #2	16.0	14.0	16.0	16.0
Case #3	16.0	14.0	14.0	14.0
Case #4	16.0	14.0	15.0	13.0
Case #5	16.0	16.0	16.0	14.0
Case #6	16.0	16.0	16.0	16.0

The investigation for all six cases was performed using Microwave Studio [9] and the performance figures are shown in Table II. Fig. 2(a), 2(b) and 2(c) show the variation of AR, return loss and directive gain respectively, versus frequency for all the six cases. The Case #1, (where the parasitic patch is identical to the radiating patch) and the case #4, (where the parasitic patch is smaller than the radiating patch) provide very good circular polarisation. Furthermore, case #1 also gives the maximum AR-bandwidth of 10.7% and a maximum directive gain in the range of (8.88 dBi-8.32 dBi) over the impedance bandwidth. The 3-dB ellipticity defines the AR-bandwidth for the acceptable performance of the circularly polarised microstrip antenna. Thus for further optimisation we have selected the case #1. The parasitic patch larger than the main radiating patch is not a suitable choice to obtain circular polarisation. Likewise, the square radiating and parasitic patch structure also does not give circular polarization. The AR-bandwidths of the case #1 and case #4 do not fall within the10 dB return loss bandwidth. This could be achieved only for a limited range of the feed rotation angle on the arc.

Table II: Performance figures of circularly polarized stacked microstrip antennas

Antenna configuration	Resonance frequency f_r (GHz)	Impedance BW (%)	Gain variation over impedance BW (dBi)	Circular polarization	AR bandwidth (%)
Case #1	6.475	20.3	8.88-8.32	Very good	High (10.7)
Case #2	6.500	20.0	9.04-8.42	Good	Low (3.8)
Case #3	6.475	22.8	8.54-8.20	Good	Low (4.1)
Case #4	6.375	20.6	8.63-8.25	Very good	High (6.5)
Case #5	6.167	15.8	8.82-8.70	Not good	Nil
Case #6	6.157	16.7	8.99-8.88	Nil	Nil

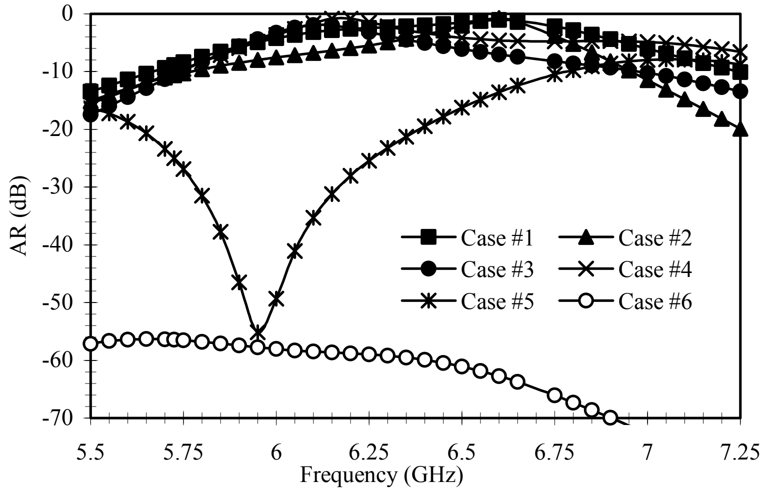

Fig. 2(a). Broadside AR versus frequency for six of stacked microstrip antenna configurations.

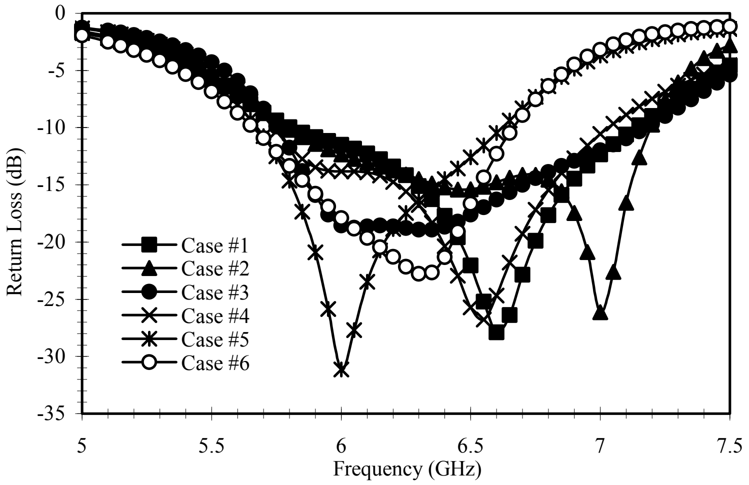

Fig. 2(b). Return loss versus frequency for six stacked microstrip antenna configurations.

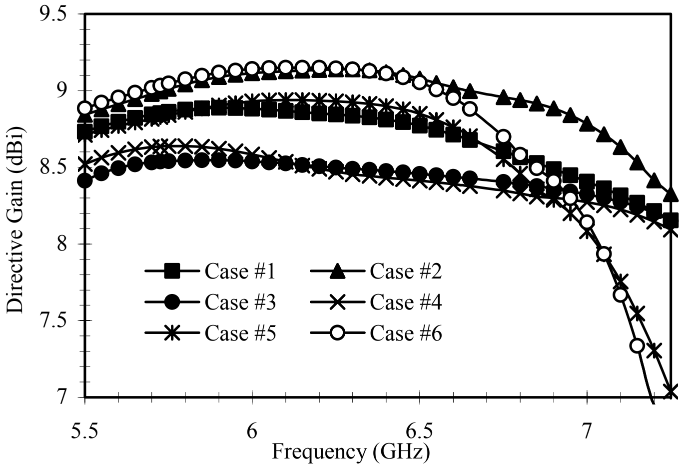

Fig. 2(c). Gain versus frequency for the six stacked microstrip antenna configurations.

OPTIMIZATION OF THE FEED ROTATION ANGLE

Our objective here is to adjust the range of rotation angle (θ) for case #1 such that the 3-dB AR-bandwidth (from AR-f_{min} to AR-f_{max}) falls within the 10-dB return-loss bandwidth (from RL-f_{min} to RL-f_{max}) and hence to achieve both impedance matching and circular polarization over the same band of frequencies. The results of our investigation are shown in Fig. 3. Both the lower limit (RL-f_{min}) and upper limit (RL-f_{max}) the return-loss bandwidth increase with the feed rotation angle. However, the AR-bandwidth lower frequency (f1) and upper frequency (f2) decrease with the feed rotation angle. The impedance bandwidth and the AR-bandwidth cross over each other with the change of the feed rotation angle. The cross over for the upper frequency limit is at $\theta_1 = 28^o$ and for the lower frequency limit is at $\theta_2 = 41.6^o$. Therefore, the AR-bandwidth is within the impedance bandwidth for $28^o \leq \theta \leq 41.6^o$. Fig. 4 shows that within this range of the feed rotation angle, the directive gain of the antenna does not change in a significant way and is around 8.8 dBi. Within this range of feed rotation angle the antenna matching is also very good (return-loss is better than 18 dB).

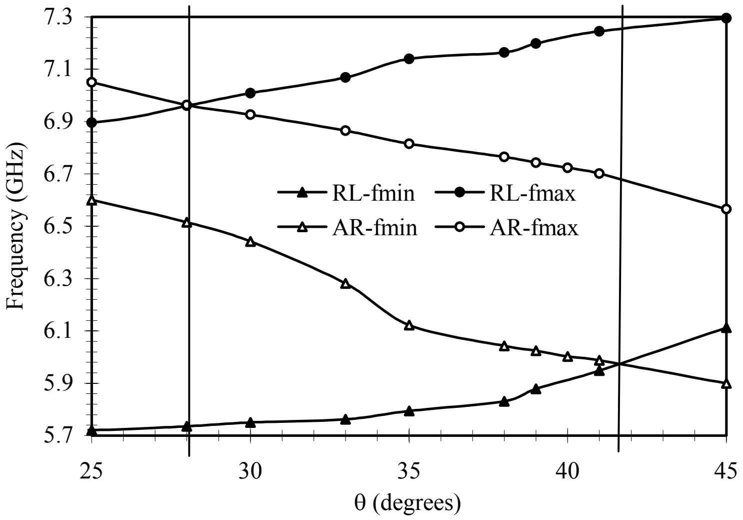

Fig. 3. Impedance bandwith and AR bandwidth variation with rotation of the feed angle.

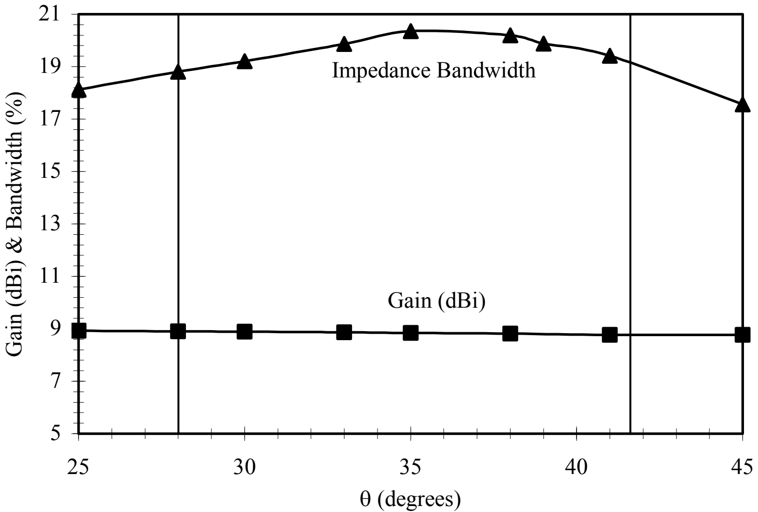

Fig. 4. Variation of directive gain and impedance bandwidth with the rotation of feed angle.

We can then obtain the optimum feed rotation angle (θ_{opt}) within the range of $28^o \le \theta \le 41.6^o$ to achieve circular polarisation of high quality. The quality of circular polarisation is determined by two performance figures:

(a) Minimum AR
(b) AR-bandwidth

The AR defines the quality of the circular polarisation; say 0.0 dB AR indicates perfect circular polarisation and an increase in the AR shows increase in ellipticity of polarisation. The variation of both these parameters with respect to the rotation angle is shown in Fig. 5. Both the minimum AR and AR-bandwidth first increase with the rotation angle to reach maxima around 40^0 and then decrease. Hence, a designer can select θ_{opt} within $28^o \le \theta \le 41.6^o$ as a compromise between minimum AR and AR-bandwidth. An angle of 40^o gives the best AR-bandwidth of 11.34% whereas an angle of 28^o gives the best minimum AR of 0.25 dB. A good compromise is angle 38^o where both the AR-bandwidth and the minimum AR are excellent (11% & 1.4 dB respectively).

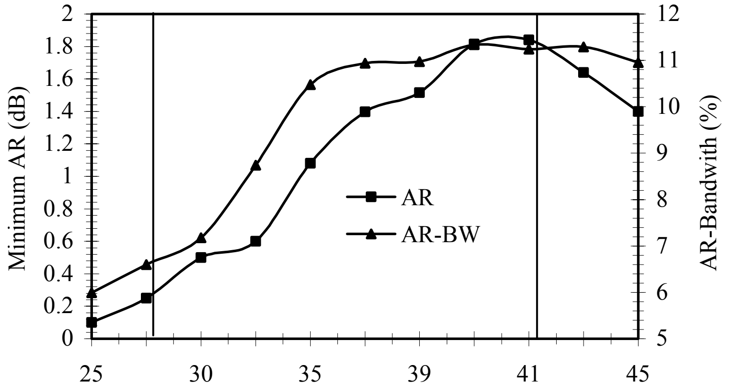

Fig. 5. Variation of the min. AR and AR-bandwidth with rotation of the feed angle.

OPTIMIZATION OF THE SEPARATION BETWEEN TWO PATCHES

In this section we consider the optimization of the separation h_2 between the two patches with the aim of further improving the AR-bandwidth and/or minimum AR. In this investigation, we select the rotation angle of 28^o for the minimum AR, 41^o for the maximum AR-bandwidth and 38^o as a compromise between the minimum AR and AR-bandwidth. Fig. 6 shows the results of this exercise. For the rotation angle of 28^o, the min AR and AR-bandwidth are not significantly sensitive to h_2. However, for the rotation angles of 38^o and 41^o, the AR-bandwidth decreases almost linearly with the increase of h_2/h_l ratio, whereas the min AR shows a dip at h_2/h_l= 4.127 giving the best min AR of 0.07dB with a reduced AR-bandwidth of 8%. The AR-bandwidth increases with decrease in the separation between two patches. However, for $h_2/h_1 < 3.75$ the mim AR is more than 3-dB and degradation in circular polarisation is beyond the acceptable limit. Therefore we must maintain $3.57 \le {}^{h_2}\!/_{h_1} \le 4.127$ limit to optimise mim AR and AR-bandwidth. The optimisation depends on the individual objectives of the designer.

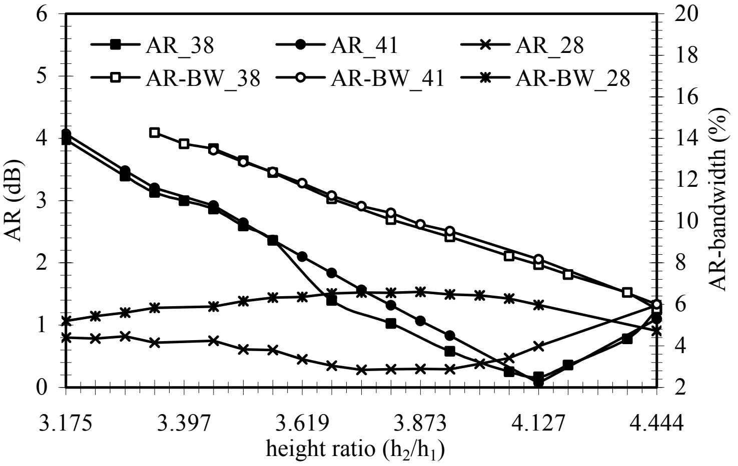

Fig. 6. Variation of the AR and AR-bandwidth with separation of patches.

Once the feed rotation angle and separation h_2 have been optimised we must ensure that the AR-bandwidth is within the impedance bandwidth. We have done such verification and found that for feed rotation angles in the range from 38^o to 41^o, the AR bandwidth is within the impedance bandwidth. Thus for the case#1, the directive gain of antenna is 8.82 dBi, the AR-bandwidth is 14% and the total thickness of antenna is 0.15 λ. It has a 3-dB beamwidth of 74^o in both E- and H-planes for the feed rotation angle of 38^0. The side lobe and back lobe levels are –19.6 dB and –17.07 dB, respectively.

CONCLUSION

We have presented a novel feed location optimization process for circularly polarized stacked rectangular microstrip antennas to achieve a 14% AR-bandwidth. Further optimization of the substrate thickness and the aspect ratio of the radiating patch is possible to obtain an even wider AR-bandwidth. The proposed optimization process is very efficient for rapid design of wideband circularly polarized microstrip antennas with increased gain. The proposed structure is under fabrication and experimental results will be presented at the conference.

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