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ENHANCE GAIN AND BANDWIDTH OF CIRCULARLY POLARIZED MICROSTRIP PATCH ANTENNA USING GAP-COUPLED METHOD

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Abstract—In this paper, one 3×3 and one 5×5 antenna arrays are studied. In each array, one probe-fed circularly polarized (CP) microstrip patch antenna is placed at the center as the driven antenna and is gapped coupled to the remaining elements. It is investigated that CP performance of the patch can be proved by properly arranging these parasitic elements. The driven patch is a perturbed square one with two diagonal corners truncated. The remaining elements are square patches slightly smaller than the driven patch. The proposed antennas have been constructed and measured. The 3×3 array has a measured gain of 7.7 dBic with a 3 dB axial ratio bandwidth of 3.3%. The 5×5 array has a measured gain of 9.3 dBic with a 3 dB axial ratio bandwidth of 8.1%.

1. INTRODUCTION

Microstrip antennas are widely used in a broad range of military and commercial applications. However, they usually suffer from narrow impedance bandwidth, low gain and low efficiency for linearly and even worse for circularly polarized antennas. For circularly polarized antennas, axial ratio bandwidth also needs to be catered for in addition to impedance bandwidth.

In the past, many techniques have been proposed to enhance gain or widen bandwidth of a linearly polarized microstrip patch antenna. Some of them resort to the material side by using thicker or bi-layered substrate [1, 2] or reducing the dielectric constant [3]. Some of them solve the problem from the structure side by using array technique [4] or by using gap-coupled method [5–10]. In principle, the

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two strategies should also work well for a circularly polarized microstrip patch antenna. However, there is another issue of axial ratio bandwidth that needs to be concerned especially for a circularly polarized patch antenna. One technique developed uniquely and efficiently to enhance both impedance and axial ratio bandwidth for a circularly polarized patch antenna is the sequential rotation method [11, 12]. Moreover, as the sequential rotation method is basically an array technique, the gain of the antenna can also be increased. By using sequential rotation method, the antenna array usually requires a corporate network to feed each separate radiator. This feeding network may cause additional conductor and dielectric losses not to mention the already complicated structure.

In contrast to the corporate feed network, gap-coupled method may be a good replacement to achieve a medium gain array. In [13], a medium gain of 14 dB is achieved using gap-coupled method applied to a linearly polarized case. The microstrip patch antenna is formed by an $N_x \times N_y$ array (N_x, N_y: numbers of elements in x or y direction, respectively) of rectangular metal patch radiators with parallel sides of length dx in the x direction and parallel sides of length dy in the y direction. It is also suggested in [13] that the gap-coupled method can be applied to a circularly polarized case by adjusting dx equal or near to dy. However, only 3 dB gain with a less than 2 axial ratio bandwidth of 2.2% (130 MHz/5830 MHz) is experimentally verified for a 2×2 array. Hence, there leaves plenty of room to be improved for circularly polarized waves while using the gap-coupled method.

In this paper, we continue effort on this area. We note that all elements in [13] include the driven patch and the parasitic elements, are of equal size. Though using different sized elements to widen impedance bandwidth is commonly seen in the literature for linearly polarized wave, its effect on widening axial ratio bandwidth for circularly polarized wave is seldom investigated. Our investigation reveals that multi-narrow axial ratio bandwidth band can be achieved if sizes of the driven patch and parasitic elements are made equal. However, one single wide axial ratio bandwidth band can be realized by using different sized driven and parasitic elements. Furthermore, gain of the array is also increased as equivalent radiation area increases in association with the increased gap-coupled area.

2. ANTENNA STRUCTURE

Figure 1 shows geometry of the proposed gap-coupled array printed on a substrate of thickness h and relative permittivity e_r. The ground plane is a square in shape and is dimensioned as L_{sub} by L_{sub}. One

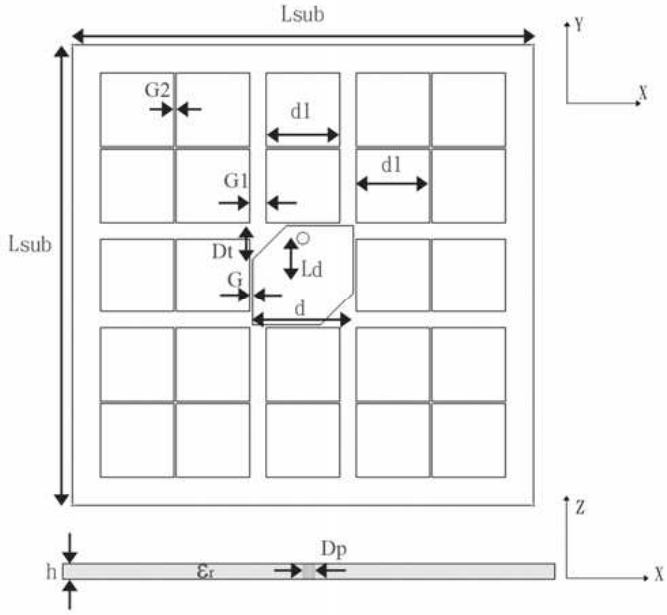

Figure 1. Geometry of a 5×5 microstrip patch array.

probe-fed circularly polarized (CP) microstrip patch antenna is placed at the center as the driven antenna and is gapped coupled to the remaining elements. The driven patch is perturbed from one d by d square patch by cutting two opposite corners with the truncation depth determined by the parameter D_t. L_d is the distance from the feed point to the center of the driven patch. Aside from the driven patch, all parasitic patches are square in shape. Side length of each parasitic patch is d_1 and is made smaller than side length d of the driven patch as we found that using different side length helps improve array's axial ratio performance. As a result of using different side length, it is shown that two parameters, G and G_1, are introduced to denote different separations between elements. In most cases, G_2 can be made equal to G to enhance coupling to outmost elements.

3. PARAMETER STUDY

In Fig. 1, the driven patch is surrounded by 8 elements in the inner ring and 16 elements in the outer ring. A 3×3 array can be formed by removing outer ring elements from the 5×5 array. Apparently, G_2 needs not to be appeared in a 3×3 array. For a 5×5 array, G_2

however can be used to control energy coupled from the driven patch to elements on the outer ring. If G_2 is made too large, little energy can

Table 1. Parameters common to 3×3 and 5×5 arrays.

variable	L_{sub}	L_d	D_t	d	G_1	G	d_1	h	D_p
(in mm)	50	4.1	3.7	11	1.75	0.25	8	1.6	1.3

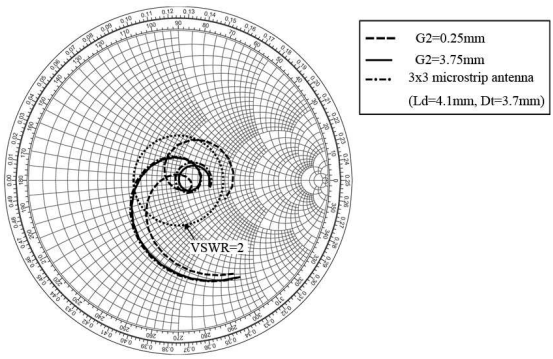

Figure 2. Impedance loci of one 3×3 array and two 5×5 arrays.

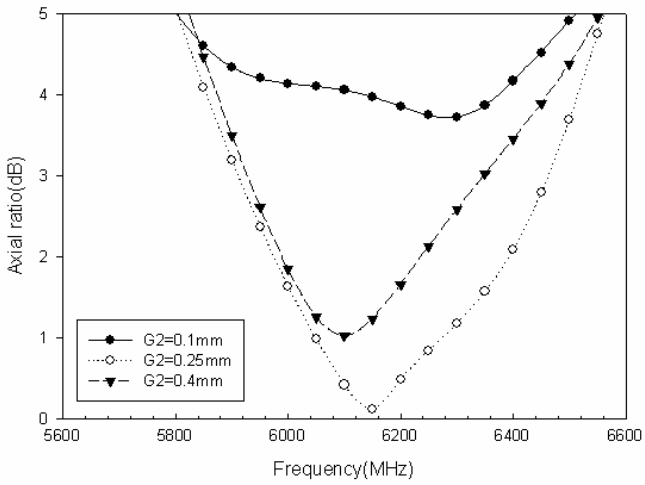

Figure 3. Axial ratio performances of the 5×5 array by varying G_2 while G_1 is fixed at 0.25 mm (other parameters are listed in Table 1).

be reached to those outer ring elements for a 5×5 array. It is shown in Fig. 2 that impedance loci for a 5×5 array with $G_2 = 3.75$ mm is almost overlapped with those of a 3×3 array. Therefore, G_2 should be made less than 3.75 mm in a 5×5 array. In this investigation, parameters common to both 3×3 and 5×5 arrays are listed in Table 1. In Table 1, G is 0.25 mm. Fig. 3 shows axial ratio performances for several 5×5 arrays by fixing G at 0.25 mm while varying G_2. In Fig. 4, axial ratio performances are again investigated by varying G and G_2 simultaneously. It is concluded from either Fig. 3 or Fig. 4 that the widest axial ratio bandwidth can be achieved by choosing $G = G_2 = 0.25$ mm. With $G = G_2 = 0.25$ mm and other parameters except D_t the same as listed in Table 1 in a 5×5 array, Figs. 5 and 6 show that both impedance and axial ratio performances varied in association with a chang in D_t. The 10 dB impedance bandwidth is larger than the 3 dB axial ratio bandwidth in all cases. The overlapped bandwidth is therefore determined by the axial ratio bandwidth. In Fig. 6, we know that the larger the value of D_t is, the higher the center

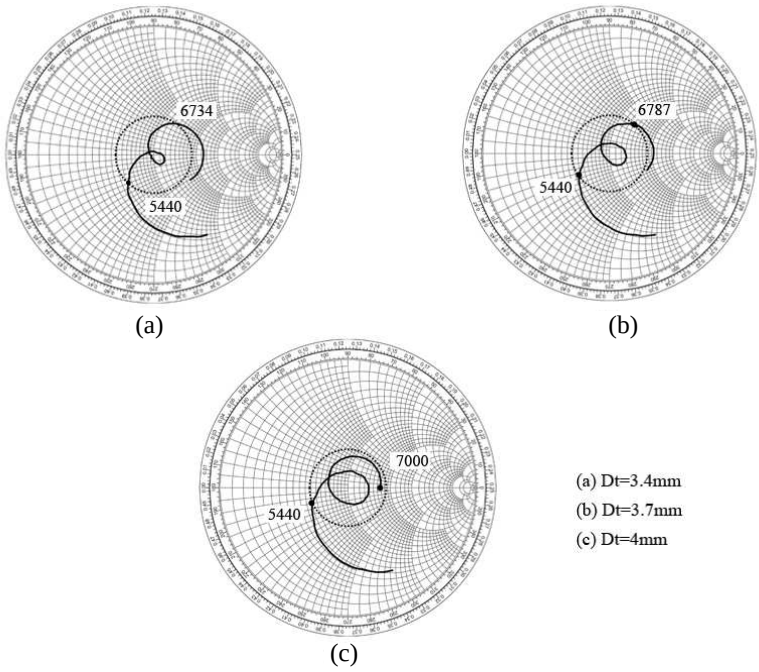

Figure 4. Axial ratio performances of the 5×5 array by varying G_1 and G_2 simultaneously (Other parameters are listed in Table 1).

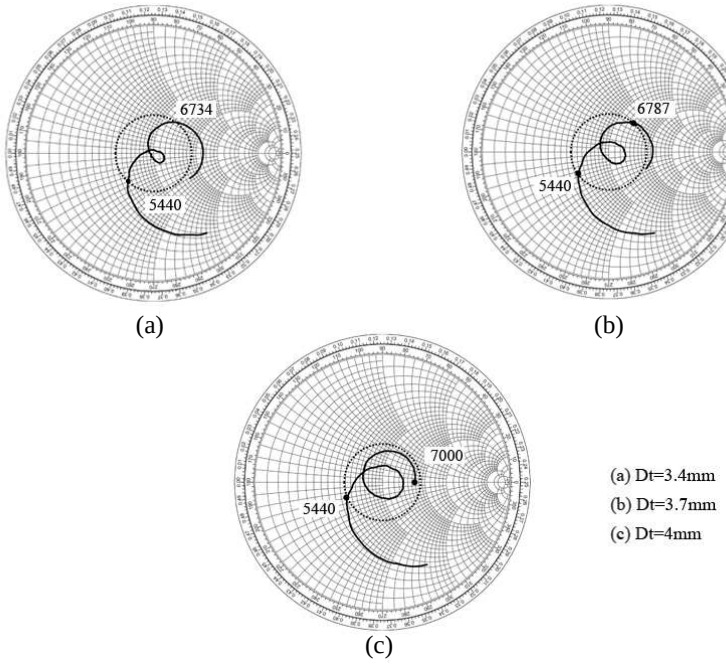

Figure 5. Impedance loci of the 5×5 array by varying D_t ($G_2 = G = 0.25\,\text{mm}$).

frequency within the overlapped bandwidth. For $D_t = 3.7\,\text{mm}$, the operational (overlapped) bandwidth is maximum and a very low axial ratio value can be reached at center frequency within the band.

In the above simulation, we choose $d_1 = 8\,\text{mm}$, which is less than the value of $d = 11\,\text{mm}$. Fig. 7 shows that array's axial ratio performance is largely dependent on the choice of d_1. For $d_1 = d = 11\,\text{mm}$, three separated narrow axial ratio bandwidth bands are observed. Since the driven patch is gapped coupled to parasitic elements, resonant frequencies may come from different coupling mechanisms. Though it is hard to identify each coupling mechanism, it is shown in Fig. 7 that one single wide 3 dB axial ratio bandwidth band can be obtained by tuning d_1 to an optimized value. For example, we may choose $d_1 = 8\,\text{mm}$. It is also investigated that the gain with $d_1 = 8\,\text{mm}$ is much higher than that with $d_1 = 11\,\text{mm}$.

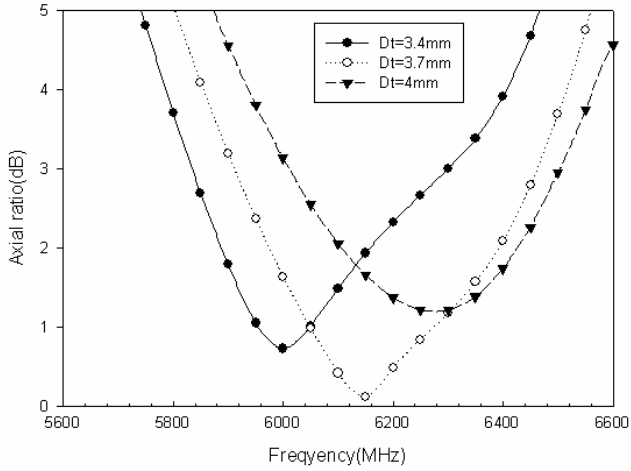

Figure 6. Axial ratio performances of the 5×5 array by varying D_t ($G_2 = G = 0.25$ mm).

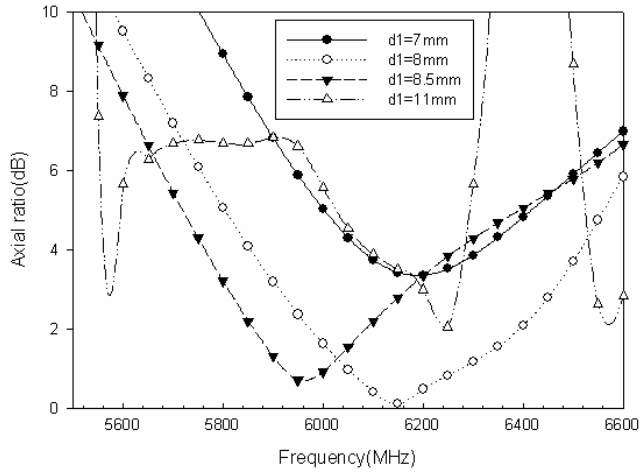

Figure 7. Axial ratio performances of the 5×5 array by varying d_1 ($G_2 = G = 0.25$ mm).

4. EXPERIMENT

Initially, we assume that relative permittivity ε_r of the FR4 substrate is 4.4 in simulation. However, measured center frequencies of antennas are always higher than simulated ones. Because of possible wide

variations in dielectric constant encountered among different vendors and even between different orders from the same vendor, we decide to determine dielectric constant of FR4 using a method based on frequency of a rectangular resonant cavity.

The substrate is metalized on all sides to form a rectangular resonant cavity. In the center of the substrate, a small hole is drilled through the material for insertion of a probe feed. Next, the S_{11} parameter is obtained experimentally using a network analyzer. The dimension of the rectangular cavity is chosen such that the first dip in $|S_{11}|$ versus frequency corresponds to the resonant frequency of the TE_{110} mode within the cavity. The theoretical resonant frequency for TE_{110} mode is given by

$$f = \frac{c}{2\pi\sqrt{\varepsilon_r \mu_r}} \sqrt{\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2},$$

where μ_r is relative permeability of the substrate. For FR4, μ_r is equal to one; c is the speed of light in free space; a and b are the length and width of the substrate, respectively. Thus, if the resonant frequency, f, is measured, ε_r can be obtained by solving the equation.

The cavity is with dimensions of 15 mm by 30 mm by 0.8 mm. S_{11} measurements were performed by using the HP 8510C network analyzer. Measured resonant frequency f is 5.55 GHz. Therefore, the dielectric constant ε_r is calculated as 4.06 by solving the above equation. It is understood that data presented in previous paragraph are all simulated assuming a relative dielectric constant of 4.06.

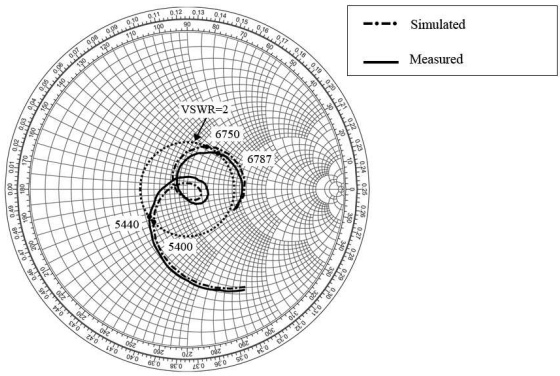

Figure 8. Measured and simulated input impedances of the 5×5 microstrip patch array.

Simulated and measured results of the 5×5 array are shown in Figs. 8, 9, and 10 for impedances, axial ratios and gains respectively. There are good agreements between simulations and measurements.

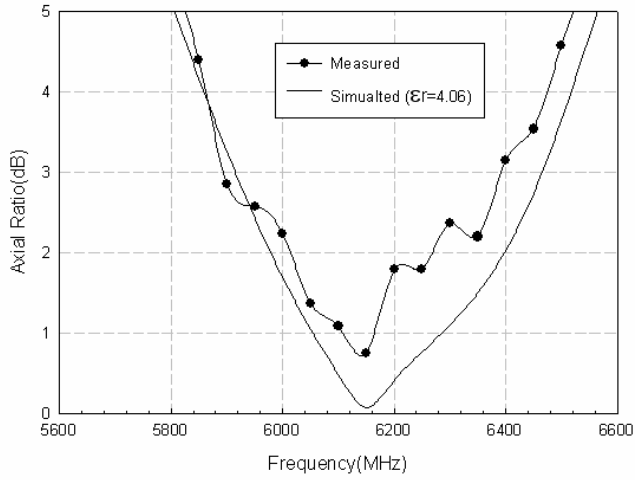

Figure 9. Measured and simulated axial ratios of the 5×5 microstrip patch array.

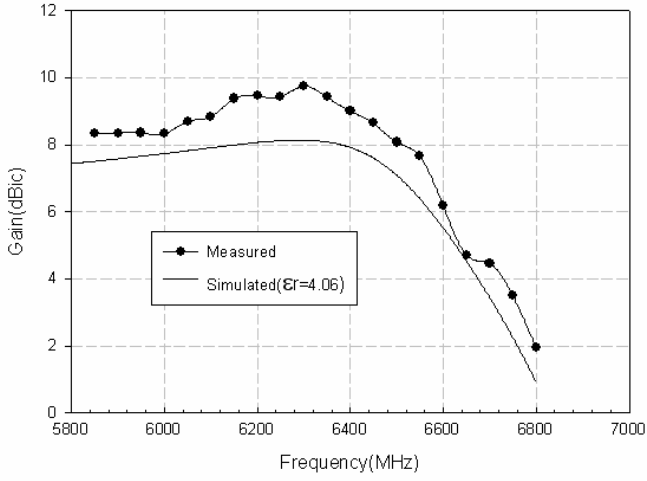

Figure 10. Measured and simulated gains of the 5×5 microstrip patch array.

Simulated and measured center frequencies in the loci of input impedance and axial ratio are almost overlapped. Measured 10 dB (or VSWR less than 2) return loss bandwidth is from 5440 to 6787 MHz, within which the measured 3 dB axial ratio bandwidth is from 5850 to 6400 MHz. The traces of simulated and measured gain with frequency

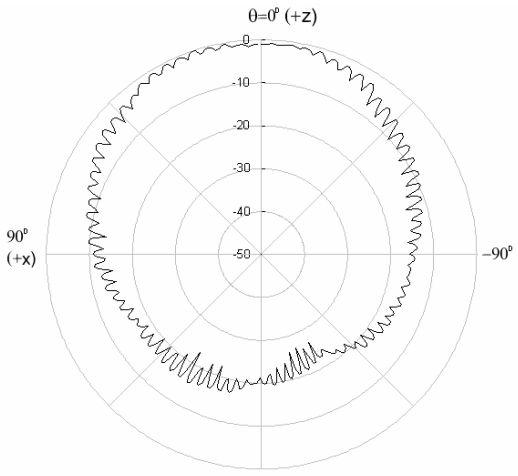

Figure 11. Measured spinning linear radiation pattern in xz-plane for the 5×5 microstrip array at the center frequency.

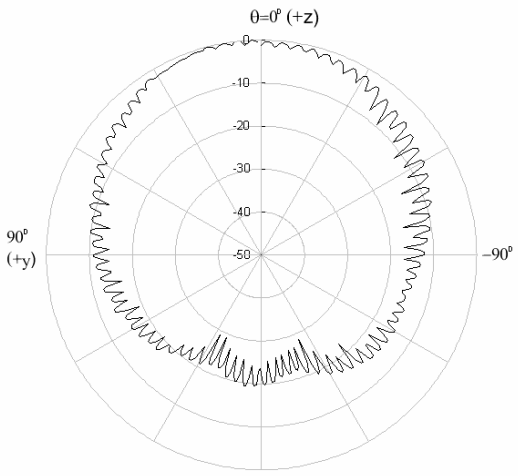

Figure 12. Measured spinning linear radiation pattern in yz-plane for the 5×5 microstrip array at the center frequency.

are similar with simulated gain less than the measured one. Measured patterns in xz- and yz-planes by receiving signal from a rotating linearly polarized transmitting antenna are shown in Figs. 11 and 12, respectively. It is shown that very low axial ratio can be obtained near the bore sight direction.

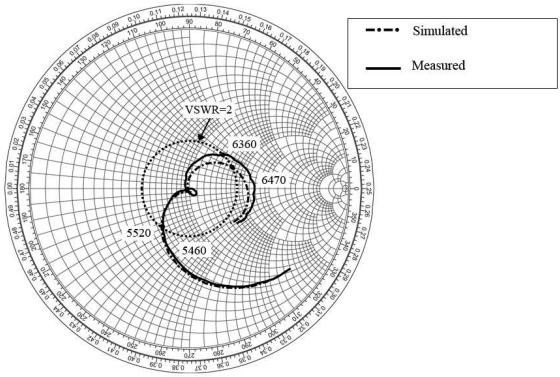

Figure 13. Measured and simulated input impedances of the 3×3 microstrip patch array.

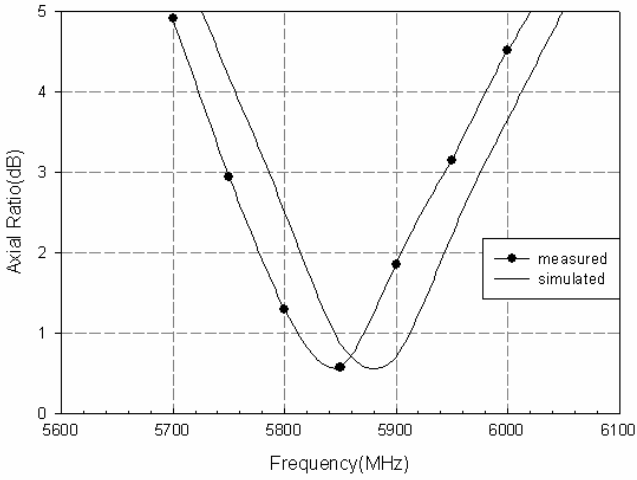

Figure 14. Measured and simulated axial ratios of the 3×3 microstrip patch array.

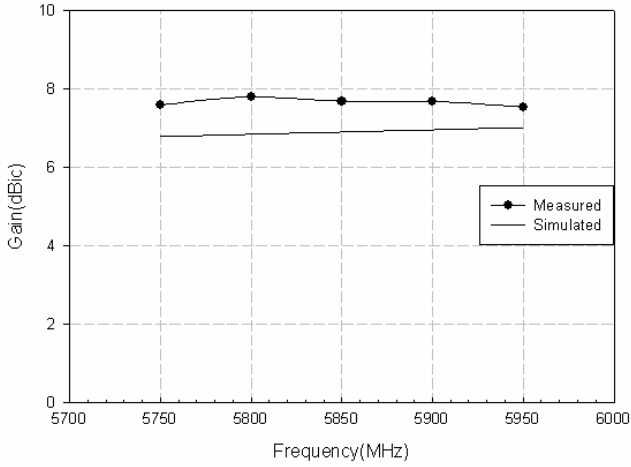

Figure 15. Measured and simulated gains of the 3×3 microstrip patch array.

5. CONCLUSION

In this paper, we have proposed a method to enhance gain and impedance/axial ratio bandwidth of a circularly polarized microstrip patch antenna by using gap-coupled method. The 3×3 and 5×5 antenna arrays are presented. Parameters of the proposed antennas have been studied. The array and the referenced single patch antenna have the same ground plane size and the same substrate thickness. Therefore, the proposed arrays do not increase dimension and thickness of the single isolated patch. However, measured CP bandwidth of the 5×5 antenna array can be increased up to 8.1% or 5.4 times compared to that of the referenced antenna. Besides, measured gain is up to 9.3 dBic at center frequency. It is 3.6 dBic higher than gain of the referenced antenna. Good performance is due to use of different sized driven and parasitic patch elements. Our investigation reveals that only multi-narrow axial ratio bandwidth band can be achieved if sizes of the driven patch and parasitic elements are made equal. However, one single wide axial ratio bandwidth band with enough gain can be realized by using different sized driven and parasitic elements.

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