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GAIN ENHANCEMENT FOR CIRCULARLY POLARIZED MICROSTRIP PATCH ANTENNA

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Abstract—A method to enhance gain of a circularly polarized (CP) microstrip patch antenna is proposed. We etch coupled square-shaped split ring resonators (CSSSRRs) on both sides of a superstrate which is separated from the patch by an air layer. Thickness of the air layer is around 0.1λ, which keeps the radome in low profile. Open gaps of each CSSSRR on opposite sides of the superstrate are orthogonally oriented to each other. This unique orientation allows the radome not only enhance gain but also maintain good CP performance.

1. INTRODUCTION

Extensive researches have been conducted to increase gain of microstrip patch antenna. In a resonance gain method [1–3], layers of dielectric are stacked above the patch. For a three-layer electromagnetically (EM) coupled structure, an air layer is often used between a substrate and a superstrate [4, 5]. The patch is etched on top surface of a grounded substrate, and a coupled patch is on top [4] or bottom [5] surface of

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the superstrate. It was reported that gain of the patch antenna can be increased by tuning thickness of the air layer. In [4], the spacing is between 0.31λ and 0.37λ. In [5], the spacing is approximately one half free space wavelength. Gain enhancement is demonstrated only for linearly polarized antenna.

In this paper, we study a three-layer EM coupled structure. We etch coupled square-shape split ring resonators (CSSSRR) on both sides of a superstrate. The coupling is now between the patch and those square rings. Between the patch and square rings, there is an air-layer. The patch is designed as a circularly polarized antenna. Therefore, we are concerned about enhancement of a circularly polarized antenna gain. We also care for its axial ratio performance.

In the literature, CSSSRR has been widely used [6, 7]. The CSSSRR unit contains two coupled open loops; therefore, it has two gaps. A similar unit denoted by gapped ring pair element was studied in [8]. In [8], we have studied that gap in an open loop may block current flow in a specified direction. This property was employed to reduce cross polarization gain of a linearly polarized reflect array. In this paper, effect of gaps of the CSSRR on gain enhancement for a circularly polarized antenna is investigated.

With CSSSRR to construct radome for a circularly polarized antenna, we should avoid induced current be blocked in either one of two orthogonal directions. To achieve this goal, we etch CSSSRRs on both sides of the superstrate of a three-layer structure. "Open gaps" on opposite side of the superstrate are orthogonally oriented to each other.

Investigation on gain versus thickness of the air layer is also studied. It reveals that the required spacing to yield a maximum gain is 0.11λ in the proposed structure.

In contrast, about a half wavelength spacing is often required to yield maximum gain in the literature [4, 5]. This half wavelength spacing is also used to enhance gain in many partial reflection antennas [9, 11–13]. In [9], a metallic sheet with square holes etched on a thin membrane was used as a superstrate. It was reported that the spacing from the patch to the radome requires a half wavelength to achieve a maximum gain. In [8], the radome or superstrate behaves as a highly reflective sheet at a spacing of 0.5λ.

In our structure, two resonant frequencies are found when the spacing is 0.01λ. The two frequencies are respectively caused by the fed patch and CSSSRRs. As the spacing is increased to 0.1λ, 0.25λ, or 0.5λ, there is only a single resonant frequency. Electrical field distribution along z-direction reveals that there is a standing wave-like pattern for either E_x or E_y component when the spacing is 0.1λ.

Therefore, the present structure can resonate at a distance of around 0.1λ, instead of about 0.5λ in the literature. This property makes our structure very useful to construct a low-profile radome.

In fact, we found that our radome behaves as a transparent sheet when the spacing is 0.5λ. Therefore, gain with spacing of a half wavelength is compatible with that of the individual patch in the proposed structure.

2. DESCRIPTION OF ANTENNA'S STRUCTURE

The proposed structure shown in Fig. 1 contains a microstripline-fed circularly polarized patch (CP) antenna with a radome. Between the CP antenna and radome, there is an air-layer. The radome is made by etching coupled square-shaped split ring resonators (CSSSRRs) on both sides of the superstrate. The CP antenna is a truncated square patch on a grounded substrate. FR4 materials are used for both dielectric layers with a thickness of $h = 0.8$ mm and $H = 1.6$ mm. Geometrical parameters of the CSSSRR unit are shown in Fig. 2 where two gaps are lined in y-direction. Two gaps can be arranged to line in x-direction by rotating 90 degrees counter clockwise with respect to its geometrical center. In Fig. 1, "gaps" on upper surface of the superstrate are all lined in x-direction, and those on lower surface are all lined in y-direction. We shall call it radome A. Alternatively, radome B and C are referred to configurations having all "gaps" on both upper and lower surfaces lined respectively in y- and x-directions. Configurations of CSSSRR on upper and lower layers for radome A, B, and C are shown in Fig. 3.

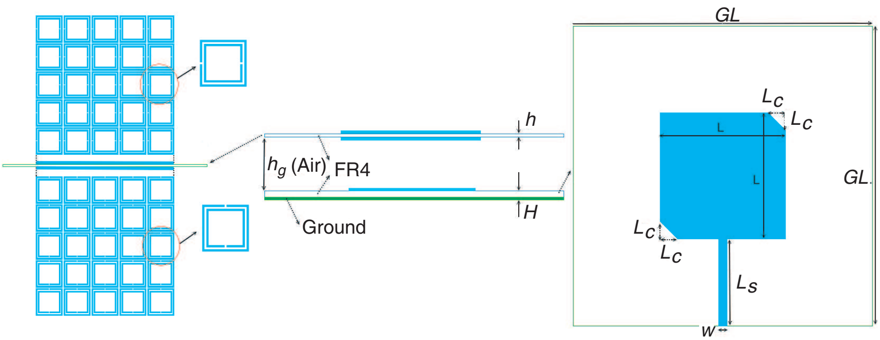


Figure 1. The proposed structure used to enhance gain of a CP antenna.

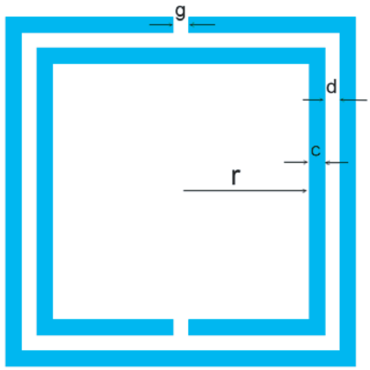


Figure 2. Geometry of a CSSSRR unit.

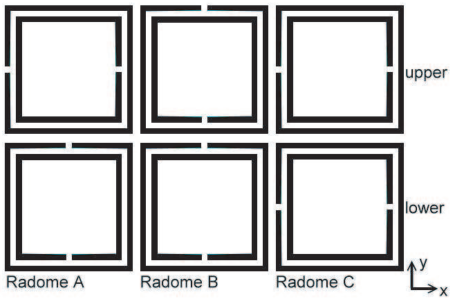


Figure 3. Configurations of CSSSRR on upper and lower layers for radome A, B, and C.

Table 1.

Unit: mm

L	GL	L_s	w	L_c	r	c	d	g	s	h_g	h	H
29	69	20	2	4	3.1	0.4	0.4	0.2	0.4	13	0.8	1.6

There are 25 CSSSRRs with five in row and five in column respectively on both sides of the superstrate. We have studied that further increase in the number of elements shall yield deterioration in axial ratio though the gain can be further enhanced. Table 1 lists parameters of the patch and CSSSRR unit of a designed example, where r, c, d, g, and s are for the CSSSRR unit, and others are for the patch. S is the spacing between two adjacent CSSSRR units.

3. ANALYSIS AND MEASUREMENT

With the radome removed, it results in an isolated patch. Simulated return loss and axial ratio of an isolated CP patch antenna is shown in Fig. 4. It is shown that this antenna resonates at around 2.495 GHz with an overlapped 10 dB return loss and 3 dB axial ratio bandwidths of around 1.2%. The antenna has a flat gain of 2.8 dBic within 2.47–2.52 GHz. Gain of the patch can be increased by adding a radome.

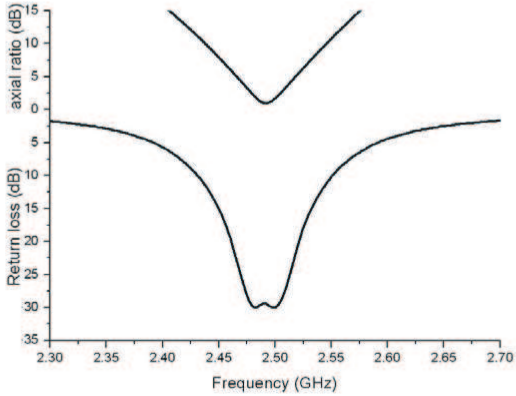


Figure 4. Performance of an isolated patch antenna.

If the radome is composed of layered dielectrics, the radome can increase the same level of x- and y-polarized partial gains in a broadside direction. This is an important property for a radome to increase gain for a circularly polarized wave to its maximum extent. For a circularly polarized antenna, the gain relative to an ideal isotropic CP antenna can be calculated via a partial gain method [14, 15].

For radome B or C, orientations of "gaps" are in the same direction. They can increase polarization-dependent partial gain. For radome A, gaps on opposite side are orthogonally disposed. Since we will see almost the same structure (neglect the thickness of h) from either x or y direction, we expect that partial gain achieved by radome A is less sensitive to polarization direction. Therefore, radome A is expected to have more CP gains than B and C. On the other hand, radome B or C has low x or y-polarized partial gain as the "gaps" may block current flow.

Figure 5 shows gain comparisons in a linearly polarized case. In this investigation, two corners of the patch shown in Fig. 1 are not truncated. All other parameters remain the same as shown in Table 1. Therefore, we have a square patch with a broadside radiation polarized in y-direction. The gains shown in Fig. 5 are all referred to y-polarized gains in the broadside direction. The solid line represents gain of this isolated linearly polarized patch. The curve marked with "o" signs represents gain of the patch loaded with radome C. It is found that y-polarized gain of the patch can be increased by adding radome A and B.

Since a circularly polarized wave can be decomposed into two orthogonally linearly polarized waves, we need both x- and y-polarized

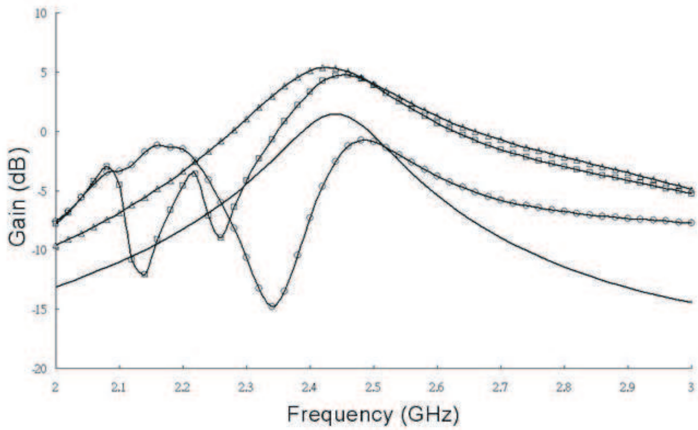


Figure 5. Simulated y-polarized gains for an isolated patch (with solid line) and for the same patch loaded by radome A (□), B (△), and C (◯).

partial gains to yield an increase of the total gain for a CP wave. Therefore, radome B and C are not suitable as they will have low partial gain either in x or y direction. On the contrary, array A is a better choice than B or C as it has gaps in both directions. Therefore, it can boost both x- and y-polarized partial gains.

Figure 6 shows simulated return loss, gain, and axial ratio performances of radome A, B, and C along with a circularly polarized patch. The air thickness, h_g, is 13 mm for all cases. This distance is optimized to maximize the gain as shown in Fig. 7. It also shows that the best operating frequency is shifted to 2.47 GHz. In [4], it was addressed that the distance is between 0.31λ and 0.37λ for an electromagnetically coupled rectangular patch antenna. In our case, the distance is only 0.11λ at 2.5 GHz. It is shown that an enhancement of gain around 2.6 dBic at 2.5 GHz can be achieved with radome A. Less than 3 dB axial ratio bandwidth ranges from 2.46 to 2.49 GHz, within which a flat gain of 5.4 dBic and less than 10 dB return loss can be realized. As for radome B or C, either gain increase or axial ratio performance is inferior to radome A.

Evident from above comparisons, a radome suitable for a circularly polarized wave should possess equal partial gain for two orthogonal linearly polarized waves.

To further support this viewpoint, we study another radome. Structure of a closed-loop radome is the same as that shown in Figs. 1 and 2 except that all gaps are closed by setting $g = 0$. In radome A,

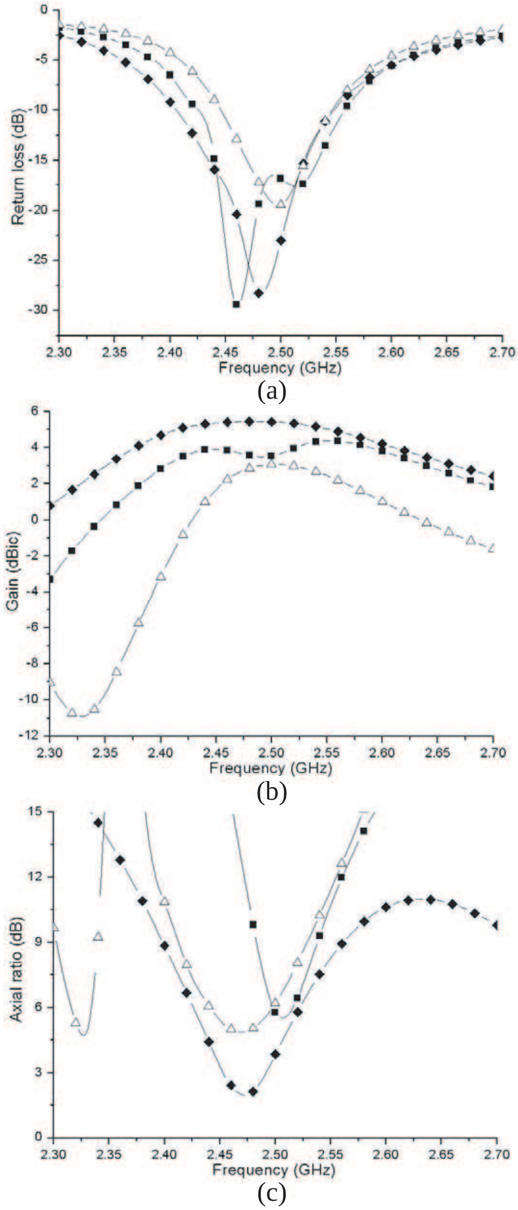


Figure 6. Simulated performances for radome A (◆), B (△), and C (■): (a) Return loss, (b) gain, and (c) axial ratio.

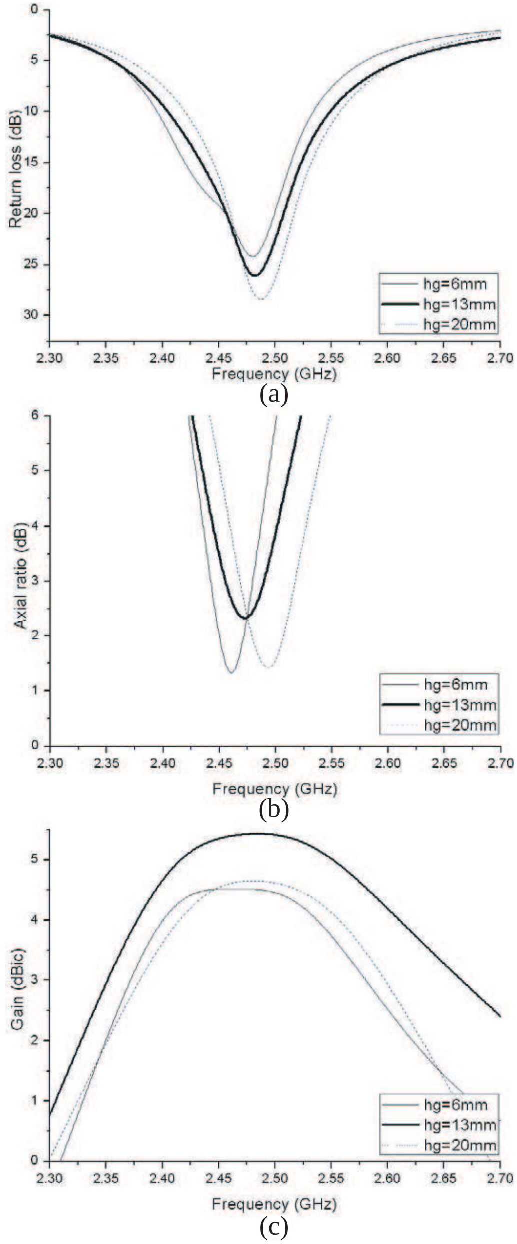


Figure 7. Simulated performances of the CP patch with radome A by varying the air thickness.

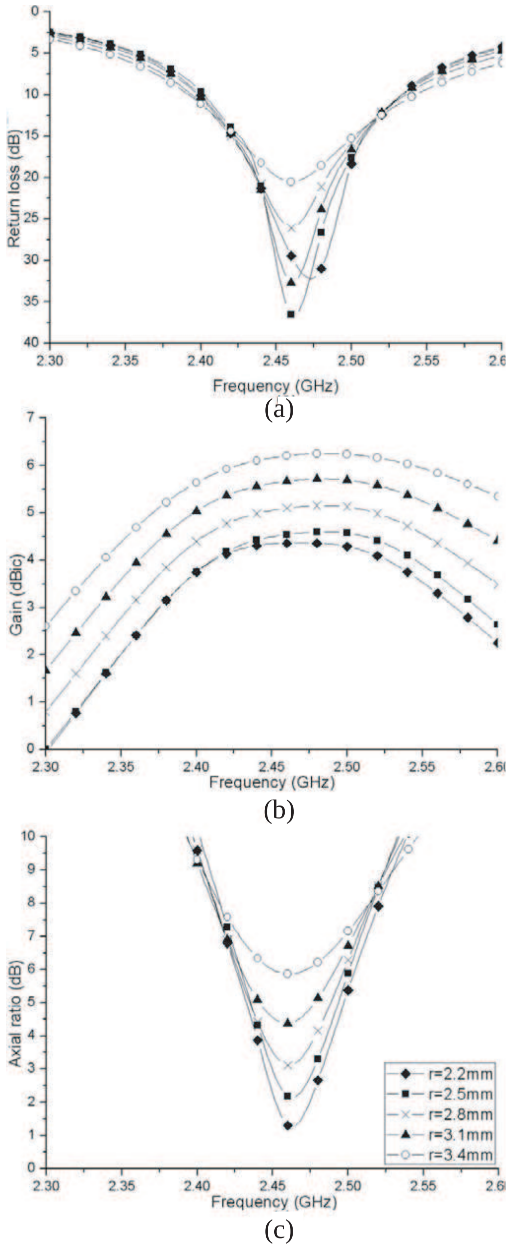


Figure 8. Simulated performance of the antenna loaded with a closed-ring radome. (a) Return loss, (b) gain, and (c) axial ratio.

radius of the inner loop is fixed at $r = 3.1\,\mathrm{mm}$. This radius is also an optimum choice for the closed-loop radome as shown in Fig. 8. To further increase the radius may deteriorate the CP performance though the gain can be further increased.

In Fig. 8, we found that gain increases up to 5.4 dBic with $r = 3.1\,\mathrm{mm}$. However, the achievable minimum axial ratio is 4.5 dB. With radome A, we can achieve 5.4 dBic gain with an axial ratio value less than 3 dB.

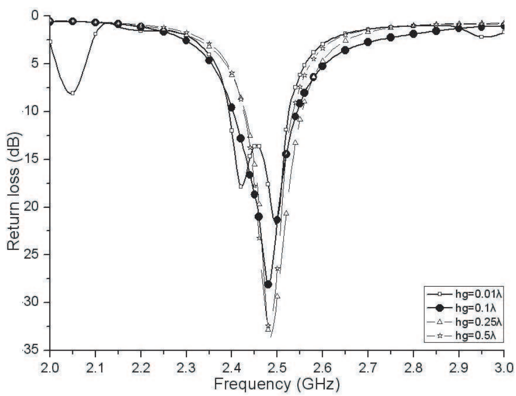


Figure 9. Return loss of the patch with radome A by varying different thickness.

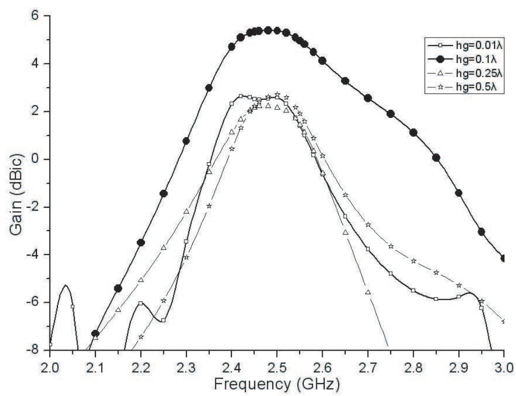


Figure 10. Gain of the patch with radome A by varying different thickness.

4. FIELD DISTRIBUTION

Though we have demonstrated a low profile radome, we are more interested in how it can be achieved. To answer this question, we now concentrate on array A. Fig. 9 shows return loss of array A with various spacing (h_g) between the fed patch and radome. Fig. 10 shows the CP gain with various spacing. It is interesting to find that there are two resonant frequencies when the fed patch and radome are close to within 0.01λ. Instead, there is only one resonant frequency for other spacing, including those shown in Fig. 7. In Fig. 9, we found that the antenna has the widest 10 dB return loss bandwidth when the spacing is 0.01λ. In Fig. 10, the antenna has the highest gain when the spacing is 0.1λ.

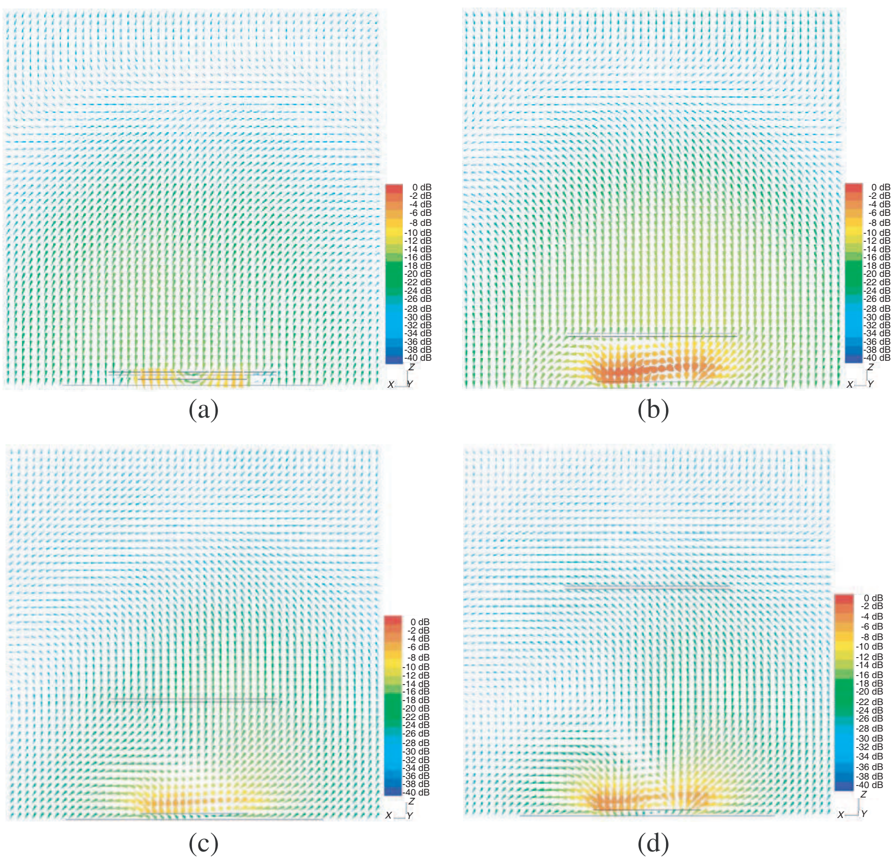
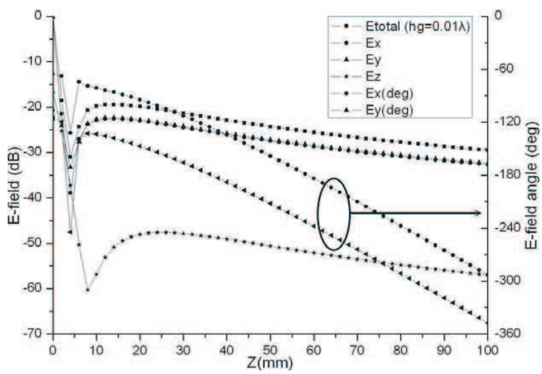


Figure 11. Near field distribution on xz-plane of the patch with radome A (a) $h_g = 0.01\lambda$ (b) $h_g = 0.1\lambda$ (c) $h_g = 0.25\lambda$ (d) $h_g = 0.5\lambda$.

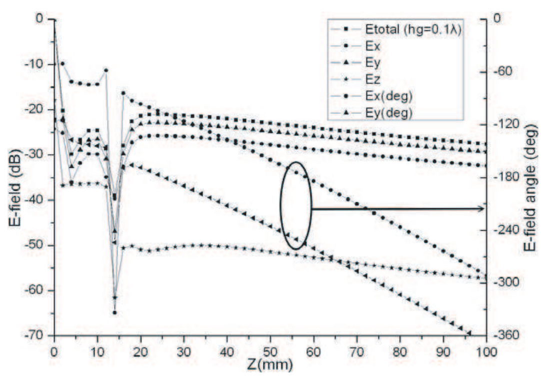
The widest 0.5 dB gain bandwidth of the antenna is found when the spacing is 0.01λ. The increase in return loss and gain bandwidth when the spacing is 0.01λ is apparently due to the coupling between the fed patch and those CSSSRRs.

Figures 11(a), (b), (c), and (d) show the vector field distribution of array A with $h_g = 0.01\lambda$, 0.1λ, 0.25λ, and 0.5λ respectively. The distribution is plotted within an area spanned along z-axis from 0 mm to 100 mm and along x-axis from -50 mm to 50 mm. The locations of the finite ground plane, fed patch and radome are easily identified from each plot. It is shown that different field distributions arise as spacing is increased from 0.01λ to 0.25λ.

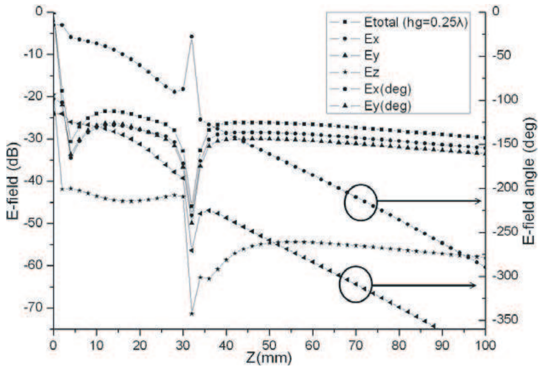
Field distributions along z-axis for $x = 0$ and $y = 0$ are displayed in Fig. 12. As the antenna is designed to radiate a CP wave along z-direction, we can see that E_z is relatively less than E_x or E_y in each case. Ideally, E_x and E_y should better have equal magnitude and have a phase difference of 90 degrees if they were in a far field range.



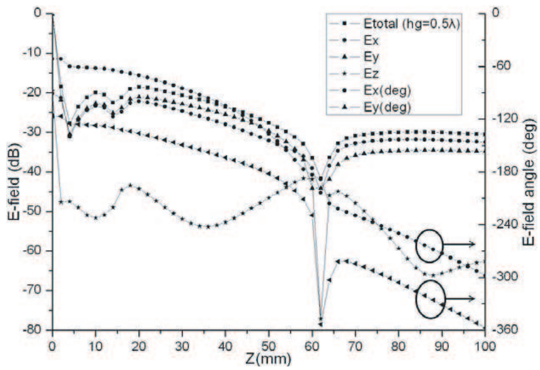
(a)



(b)



(c)

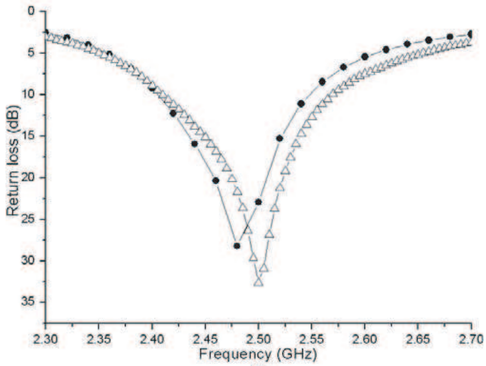


(d)

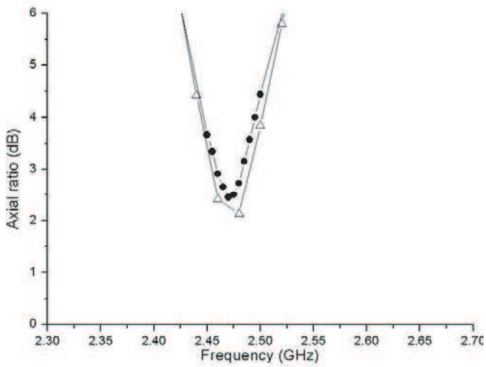
Figure 12. Near field distribution along Z-axis of the patch with radome A (a) $h_g = 0.01\lambda$ (b) $h_g = 0.1\lambda$ (c) $h_g = 0.25\lambda$ (d) $h_g = 0.5$.

It is shown that field components E_x, E_y, and E_z change from a relatively minimum value at $z = 3\,\text{mm}$ to a maximum value at $z = 10\,\text{mm}$, then, to a minimum value at 14 mm when the spacing is 0.1λ (about 12 mm). This standing wave-like distribution along z-axis reveals that resonance in z-direction could possibly happen at this short distance. It also results in a maximum gain. Beyond 0.1λ, however, gain is not increased. In our viewpoint, those CSSSRRs could possibly behave just like a frequency selective (FSS) unit when the distance between the fed patch and radome is beyond a specified range, around 0.1λ in our case. When the radome functions as an FSS unit, it simply passes energy of the fed patch at a certain specified frequency. In Fig. 10, we have seen that the gain of array A is compatible with that of the fed patch when the spacing is 0.25λ or 0.5λ.

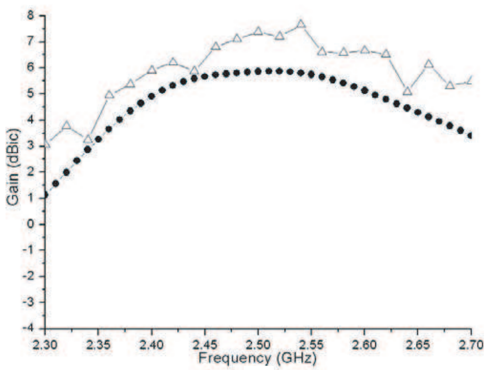
At a spacing of 0.1λ, those CSSSRRs are strongly excited. It



(a)



(b)



(c)

Figure 13. Simulated (●) and measured (△) performances for a CP patch loaded with radome A: (a) Return loss, (b) axial ratio, and (c) gain.

can also be found (not presented here) that current distribution on CSSSRR elements have the highest intensity when the spacing is 0.1λ. Therefore, those CSSSRRs along with the fed patch and ground plane behave like a partially reflective surface (PRS), which can be used to enhance the gain of the feeding element [11, 12]. Conventionally, the PRS is placed at a distance of 0.5λ from the feeding element. It is shown here that we can make resonance happen at a very short distance and still have enough gain increase. Since the resonance can occur at a spacing of 0.1λ, a spacing of 0.25λ or 0.5λ seems too far to let the radome behave like an effective PRS unit, instead the radome with a spacing of 0.25λ or 0.5λ behaves as an FSS unit. The FSS unit usually functions in the "far-field" range (as it is usually illuminated by a uniform plane wave) as a filter.

5. EXPERIMENTS

Figure 13 shows comparisons of simulated and measured return loss, axial ratio and gain of the microstrip circularly polarization patch antenna covered with radome A. It can be seen that measured center frequency slightly moves toward higher frequency. The measured 10 dB return loss bandwidth is 146 MHz (from 2.41 to 2.56 GHz). Measured 3 dB axial-ratio bandwidth is 25 MHz (from 2.475 GHz to 2.5 GHz). Measured maximum gain is 7.1 dBic at 2.48 GHz. The gain with a radome is 3.1 dBic greater than the isolated patch. Measured H- and

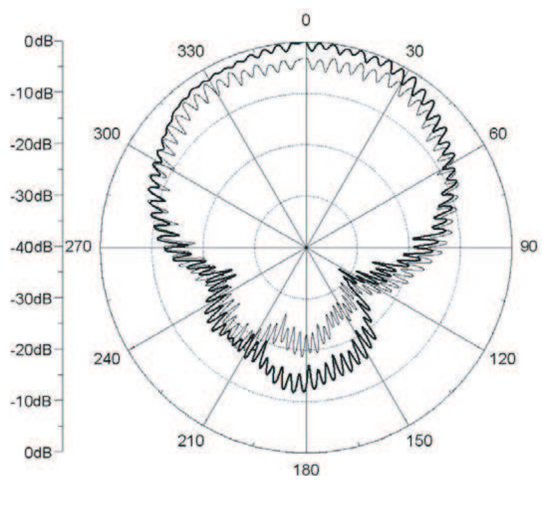


Figure 14. Measured H-plane pattern of the patch with (in black) and without (in gray) radome A.

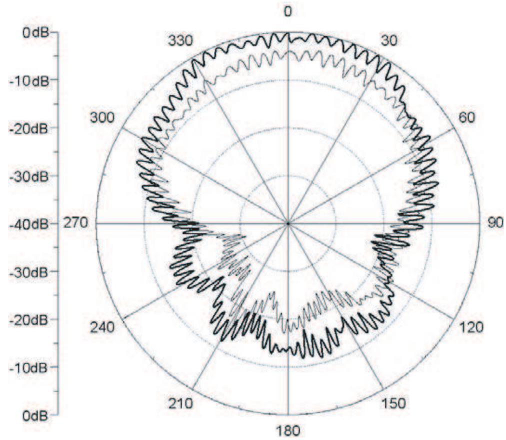


Figure 15. Measured E-plane pattern of the patch with (in black) and without (in gray) radome A.

E-plane pattern at 2.48 GHz for the isolated and radome-covered patch is respectively shown in Fig. 14 and Fig. 15.

6. CONCLUSION

In this paper, a radome is formed by etching CSSSRRs on both sides of a superstrate. If all "gaps' of the CSSSRRs lie in the same direction, the radome is viewed differently from two orthogonal directions.

Hence, it brings a question whether it is suitable to increase gain for a circularly polarized antenna. After studying three different configurations, we find that "gaps" on opposite side of the superstrate should be orthogonally oriented. By this unique arrangement, not only the gain of a CP antenna can be increased but also good CP performance can be kept.

Another interesting issue is that the required distance from the patch to the radome can be reduced to only 0.11λ. This distance is shorter than that required in [4, 5], and [9]. A study on return loss versus spacing between the fed patch and radome reveals that the present structure can be used either to increase the bandwidth or gain of the fed patch. To increase the bandwidth, the spacing is 0.01λ. Beyond 0.01λ and within 0.1λ, the fed patch and radome can function as an effective PRS unit. Beyond 0.1λ, the whole structure looks like just an FSS unit. We also provide near field distribution to give some explanations. The field distribution supports that the present structure can resonate at a distance of 0.1λ while enhancing gain of the fed patch.

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