Research Article

Reduction of the In-Band RCS of Microstrip Patch Antenna by Using Offset Feeding Technique

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This paper presents a method for implementing a low in-band scattering design for microstrip patch antennas based on the analysis of structural mode scattering and radiation characteristics. The antenna structure is first designed to have the lowest structural mode scattering in a desired frequency band. The operating frequency band of the antenna is then changed to coincide with that of the lowest structural mode scattering by adjusting the feed position on the antenna (offset feeding) to achieve an antenna with low in-band radar cross section (RCS). In order to reduce the level of cross polarization of the antenna caused by offset feeding, symmetry feeding structures for both single patch antennas and two-patch arrays are proposed. Examples that show the efficiency of the method are given, and the results illustrate that the in-band RCS of the proposed antennas can be reduced by as much as 17 dBsm for plane waves impinging from the normal direction compared to patch antennas fed by conventional methods.

1. Introduction

Considerable research concerning antenna scattering has been undertaken [1–5], and many methods for reducing antenna scattering were proposed, such as using a thin AMC structure and frequency-selective surface radome [6, 7], EBG and RAM radar absorbing material [8–13], or a slotted patch or slotted ground [14, 15]. Normally, total antenna scattering is composed of two parts—the structural mode scattering and the antenna mode scattering—where the antenna mode scattering is related to the load of the antenna. This means that the complete scattering of the antenna is primarily due to the structural mode if the feeding port is impedance matched. Usually, the frequency band of the low structural mode scattering does not coincide with the operating frequency band of the antenna, so the in-band scattering of a conventional microstrip patch antenna can be even larger than the scattering in the outside band. If the operating frequency band of the antenna is properly designed to coincide with that of the low structural mode scattering, we can expect an antenna with minimum

in-band scattering. This paper attempts to use this feature to design low in-band scattering patch antennas by using offset feeding technique to shift the operating frequency band so it coincides with that of the low structural mode scattering. In order to suppress the cross polarization caused by the offset feeding, symmetrical feeding structures are proposed. Using these methods significantly reduces the in-band scattering of the patch antenna, while the radiation characteristics remain unchanged.

2. Antenna Structure and Parameters

Figure 1(a) shows the configuration of the microstrip patch antennas considered in this paper. Figure 1(b) shows the corresponding fabricated patch antennas used in the experiment, where two kinds of feeding structures at different positions are used. The thickness and relative permittivity of the dielectric substrate are 2.4 mm and 2.6, respectively. The patches are fed by coaxial probes with a 50 Ω characteristic impedance. Usually, the antenna is fed at the center of one patch edge, as shown by point 1 in Figure 1(a).

FIGURE 1: Configuration of the microstrip patch antennas: (a) $L = 98$ mm, $W = 60$ mm, $H = 2.4$ mm, $w = 20$ mm, $l = 34$ mm, $a = 32$ mm, $b = 20$ mm, $c = 7$ mm, and $d = 5$ mm and (b) the fabricated antennas.

FIGURE 2: Monostatic RCS and S_{11} of the antennas in Figure 1 for two feeding cases, where the x - and y -polarized plane waves are incident to the normal direction.

3. Simulation and Measurement Results

Figure 2(a) shows the scattering characteristics of the microstrip patch antennas for a plane wave incident to the normal direction. From this figure, we can see that the lowest scattering occurs at 4.145 GHz and 2.633 GHz for the y - and x -polarized incident waves, respectively. The antenna structure in terms of the patch size and dielectric constant of the substrate primarily determines this scattering characteristic, which changes little with feeding position if the antenna is impedance matched. The simulated S -parameters of the antenna are also given in Figure 2(a), which shows that the resonant frequency of the antenna is 4.319 GHz with edge center feeding. Therefore, the frequency band of the low scattering is lower than the antenna operating frequency band, and the in-band scattering for the y -direction polarized incident wave will be significant. As we know, the position of the feeding point has little effect on the scattering characteristics of an impedance matched antenna but does significantly change its operating frequency. Therefore, for this paper we changed the location of the feeding point from the edge center to an offset point near the corner of the patch, as shown by point 2 in Figure 1(a). This change

shifted the operating frequency of the antenna to 4.163 GHz, illustrated in Figure 2(a), causing the operating frequency band of the antenna to be coincident with the frequency of the low scattering. Thus, we can expect a low in-band RCS for the antenna for the y -direction polarized incident wave. The corresponding measurement results are given in Figure 2(b). As we can see from the figure, the measured resonant frequencies and the low scattering frequencies of the antennas are slightly higher than those of simulation; the discrepancies mainly arise due to fabrication and measurement errors. However, the trends appearing in the simulation results are in good agreement with those of the experimental results, and the measurement results do indicate that the antenna in-band RCS can be reduced using offset feeding.

Figure 3 shows the simulated and measured radiation patterns of the antennas for the two feeding cases, Figure 4 shows the simulated gains of the antennas, and Figures 5 and 6 show the scattering characteristics of these two cases. It can be seen from the figures that there is no significant difference in the copolarization radiation patterns of the two antennas, and the simulated results are in good agreement with measurement results. Figure 4 shows that offset feeding can excite two orthogonal radiation modes with different

FIGURE 3: Simulated and measured radiation patterns of the edge center fed antenna ($f = 4.319$ GHz) and offset fed antenna ($f = 4.163$ GHz): (a) copolar and (b) cross-polar in the xoz -plane (H-plane) and (c) copolar and (d) cross-polar in the yo z-plane (E-plane).

resonant frequencies, so the cross polarization of the offset fed antenna is higher than that of the edge center fed antenna. Because the resonant frequencies of the two modes are widely separated (about 1.5 GHz), the level of cross polarization at the operating frequency of the offset fed antenna (4.163 GHz) is still 18 dB lower than copolarization in the main beam direction. However, the scattering characteristics of the two antennas are significantly different. From Figures 5 and 6, we can see that the monostatic RCS of the offset fed antenna is lower than that of the edge center fed antenna in the angular range of $[0^\circ, 30^\circ]$ in the xoz -plane (H-plane). Furthermore, the bistatic RCS of the offset fed antenna is also significantly

lower in the angular range of $[-60^\circ, 60^\circ]$ in the yo z-plane (E-plane) as well as in the $[-35^\circ, 35^\circ]$ angular range in the xoz -plane (H-plane) for a y -polarized incident wave. The maximum reduction in monostatic RCS for the offset fed antenna is about 17 dBsm compared to that of the edge center fed antenna.

4. Reduction of Cross Polarization

Although the offset feeding technique can significantly reduce the in-band RCS of the antenna, the cross polarization

FIGURE 4: Gains in the main beam direction calculated by copolar and cross-polar components of the offset fed and edge center fed antennas as a function of frequency.

FIGURE 5: Monostatic in-band RCS of the edge center fed antenna ($f = 4.319$ GHz) and offset fed antenna ($f = 4.163$ GHz).

of the radiation field in the main beam direction remains high compared to that of an edge center fed antenna, as shown in Figure 3(b). This is due to the asymmetry of the feeding structure, which destroys current distribution symmetry on the patch. In order to reduce the cross-polarization level of the radiation field while still maintaining a low level of in-band scattering, we propose two modified feeding structures. The first is to feed the patch symmetrically at two corners, as shown in Figure 7(a) (symmetry feeding), while the second is to arrange two offset feeding patches symmetrically as an array (offset feeding array), as shown in Figure 7(b). Figure 8 shows photographs of the fabricated patch antennas and

FIGURE 6: Bistatic in-band RCS of the edge center fed antenna ($f = 4.319$ GHz) and offset fed antenna ($f = 4.163$ GHz) for a normal incident plane wave: (a) yoz -plane (E-plane) and (b) xoz -plane (H-plane).

the power divider used in our experiment, while Figure 9 gives the surface current distributions of the edge center fed and offset fed patches, respectively. We can see from Figure 9(c) that the two symmetry ports excite symmetrically vertical current components on the patch, so the far fields from the patches are superposed in phase in the normal direction. Meanwhile, the horizontal current components on the patch are inversely symmetrically excited, so the far fields from these components can cancel each other in the normal direction. Therefore, symmetrical feeding structures can significantly suppress cross polarization. This property is similar to that of the edge center fed patch, as shown in Figure 9(a). The same conclusion can be drawn for the patch arrays illustrated in Figure 7(b). The simulated

FIGURE 7: Two cases of modified feeding structures for reducing cross polarization: (a) $L' = 98$ mm, $W' = 60$ mm, $H' = 2.4$ mm, $w' = 20$ mm, $l' = 34$ mm, $a' = 32$ mm, $b' = 20$ mm, $c' = 7$ mm, and $d' = 7$ mm and (b) $L'' = 128$ mm, $W'' = 60$ mm, $H'' = 2.4$ mm, $w'' = 20$ mm, $l'' = 34$ mm, $a'' = 32$ mm, $b'' = 20$ mm, $c'' = 6$ mm, and $d'' = 6$ mm.

FIGURE 8: ((a), (b)) Photographs of the fabricated antennas and (c) photograph of the power divider used in the experiment.

FIGURE 9: Surface currents of antennas with different feeding structures.

FIGURE 10: Simulated and measured radiation patterns of the antennas from Figure 7 in the xoz -plane (H-plane): (a) copolar and (b) cross-polar components of the patch antennas and (c) copolar and (d) cross-polar components of the patch arrays. Note that $f = 4.155$ GHz for the symmetry offset fed patch antenna, $f = 4.43$ GHz for the edge center fed patch array, and $f = 4.19$ GHz for the symmetry offset fed patch array.

and measured radiation patterns and scattering patterns of the two antenna types shown in Figures 7 and 8 are provided in Figures 10 and 11, respectively. The results for an edge center fed antenna with the same structure are also given for comparison. By comparing Figure 10(b) with Figure 3(b), we can see that the modified feeding structures efficiently suppress the cross polarization of the antenna.

Figures 10 and 11 also show that the simulated radiation patterns and scattering characteristics are in good agreement with our measurements. The cross-polarization levels of the two antennas with modified feeding structures as functions of frequency are given in Figures 12 and 13. Due to fabrication errors, the measured resonant frequencies and low scattering frequencies of the antennas are a little bit higher than the

FIGURE 11: Comparison of monostatic RCS and S_{11} of the two antennas from Figure 7, with x - and y -polarized plane waves incident to the normal direction: (a) simulated and (b) measured results of the symmetry offset fed patch antenna and (c) simulated and (d) measured results of the offset fed patch array.

simulated values, but both the simulated and measured trends are in good agreement. From these figures, we can conclude that modified symmetrical offset feeding structures can significantly reduce scattering while maintaining the same radiation characteristics as an edge center fed antenna.

From the above analysis, we can summarize our proposed design procedure for a low in-band scattering patch antenna. First, find the low scattering frequency band and change that band to the desired frequency band by adjusting the antenna's configuration and size. Next, find a feeding position on the radiating patch at which the antenna impedance matches the feeding line. If low cross polarization is required, a symmetrical feeding structure should be employed. With

this procedure, it is possible to reliably design low in-band scattering antennas.

5. Conclusion

Since antenna mode scattering is very small for impedance matched antennas, structural mode scattering is normally the main contributor to in-band scattering of an antenna and is an inherent feature of the size and material of the antenna. In order to reduce in-band scattering for an antenna, the frequency band for the low scattering should coincide with the resonant frequency of the antenna itself. Based on these features, this paper provided a novel method to

FIGURE 12: Gains in the main beam direction calculated by copolarization and cross-polarization field components of the symmetry offset fed and edge center fed patch antennas as functions of frequency.

FIGURE 13: Gains in the main beam direction calculated by copolarization and cross-polarization field components of the offset fed and edge center fed patch arrays as functions of frequency.

design a low in-band scattering antenna by adjusting the location of the feeding port (offset feeding). Offset feeding provides an additional freedom of design, such that we can easily achieve the “matching” of resonant frequencies for transmission and low scattering. To suppress the higher cross polarization caused by offset feeding, two modified symmetry feeding structures were proposed, which achieved low in-band scattering while keeping cross polarization low. Our simulation and measurement results showed that this

method is efficient for designing low in-band scattering patch antennas.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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