EM Design of Low RCS Proximity Coupled Patch Array

Avinash Singh, Deepa K. Sasidharan and Hema Singh

Abstract The low profile nature of a microstrip patch array is advantageous in stealth applications. However, the feed network of a typical corporate-fed patch array contributes considerably toward antenna scattering. A proximity coupled feeding technique can be adopted to overcome this problem. Since the feed network comes beneath the substrate, the radar cross-section (RCS) of the whole array can be reduced to an extent, with an added advantage of providing wider bandwidth. However, the multiple resonances that will be generated from proximity coupled arrays may contribute to higher RCS at corresponding frequencies. Incorporating slots in the ground plane helps in changing the path of surface current, thereby reducing the RCS peaks due to resonant modes. Further, results show that cutting slots in the ground plane of a proximity coupled patch array has aided in gain and bandwidth enhancement. A proximity coupled patch array with high impedance surface (HIS) layer and reduced slotted ground plane is proposed towards wideband structural RCS reduction from 11 to 30 GHz.

Keywords Proximity couple · High impedance surface · Structural RCS · Slotted ground plane

1 Introduction

Low profile microstrip patch arrays are often preferred in stealth technologies due to its conformal property, ease of fabrication, and light weight. One of the disadvantages of patch arrays with microstrip feed is the narrow bandwidth, normally limited to

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2–5%. Thicker substrates with lower dielectric constant can be used to improve the bandwidth. However, as the thickness is made larger, the surface waves and unwanted radiation from the feed network may increase. Further, a corporate feed network in patch arrays consumes comparatively larger area, when compared to series feed network.

Numerous techniques have been proposed to reduce the structural RCS of microstrip patch arrays. The use of high impedance surfaces (HIS) has proved to reduce the structural RCS of microstrip patch arrays over wider frequency band [1]. Apart from providing higher impedance bandwidth, aperture-coupled feed helps also in reducing structural RCS of a microstrip patch array [2]. This is due to the fact that the feed network is placed below a dielectric substrate layer, therefore the contribution of feedlines toward RCS will be minimized. It has been reported that aperture-coupled patch antenna with hybrid frequency selective surfaces (FSS)-based ground plane can provide wideband RCS reduction [3]. A chessboard configuration of two types of split-ring resonators and square patches have been used as the hybrid FSS.

In the present work, proximity coupled feeding technique has been employed to feed microstrip patch array. This has multiple advantages including higher impedance bandwidth, lower backward radiation, and minimal contribution to RCS. Appropriate overlapping of feedline and patch is required for enhancing fundamental resonance. Authors in [4] have demonstrated four configurations of proximity coupled patch array exhibiting dual resonance. However, the multiple resonances that will be generated from proximity coupled arrays may contribute to higher RCS at corresponding frequencies. Incorporating slots in the ground plane helps in changing the path of surface current, thereby reducing the RCS peaks due to resonant modes. Wu et al. [5] have proposed a technique to reduce the RCS of patch antenna by cutting slots of varying width in the ground plane. Along with cutting slots in ground plane, loading with chip resistor along the patch has been found to provide low RCS patch antenna [2]. A compact resonator consisting of metallic layer with vias connecting to ground plane can be used along the feedline of patch antenna to suppress the harmonic radiations [6]. The harmonic radiations can also be reduced by varying the dimension and position of the feed [7].

In this paper, the RCS reduction feature of HIS and proximity coupled feed network is combined to design a patch array with reduced RCS. A combination of JC-square patch elements arranged in a chessboard configuration has been used as the HIS layer. The EM design of a 4-element proximity coupled microstrip patch array with HIS layer resonating in the X-band is described and compared with the conventional patch array without any HIS layer. The array performance in terms of their radiation and scattering characteristics has been presented. The motivation behind the work being carried out is to achieve a significant reduction in structural RCS. Moreover, efforts have been put while designing, so that there is no degradation in the antenna radiation characteristics.

2 Proximity Coupling in Patch Array

Proximity coupled feed is a noncontact feeding technique employed in a patch antenna/array. Figure 1 shows the schematic of a proximity coupled patch antenna. The patch elements are electromagnetically fed through a feed network designed between the two substrates. In proximity coupling, the patch elements and the feed network are separated by a dielectric medium; the coupling between feed and patch is capacitive in nature. The dielectric constant of both the substrates can be either same or different, based on the specifications. Generally, dielectric material with lower permittivity is preferred for upper substrate to enhance radiation into free space and better efficiency. The bottom substrate is designed with thin dielectric with higher permittivity to minimize spurious radiation from feed [8]. When compared to coplanar feed, noncontact feed does not have patch-to-feedline discontinuities, hence facilitate minimizing of resulting unwanted radiation. The fundamental resonant frequency depends on the extent of overlapping of feedline with the patch. In order to obtain an optimum return loss, the ratio of feed-to-patch overlap (L_{ovl}) to patch length has to be greater than 0.55 [6].

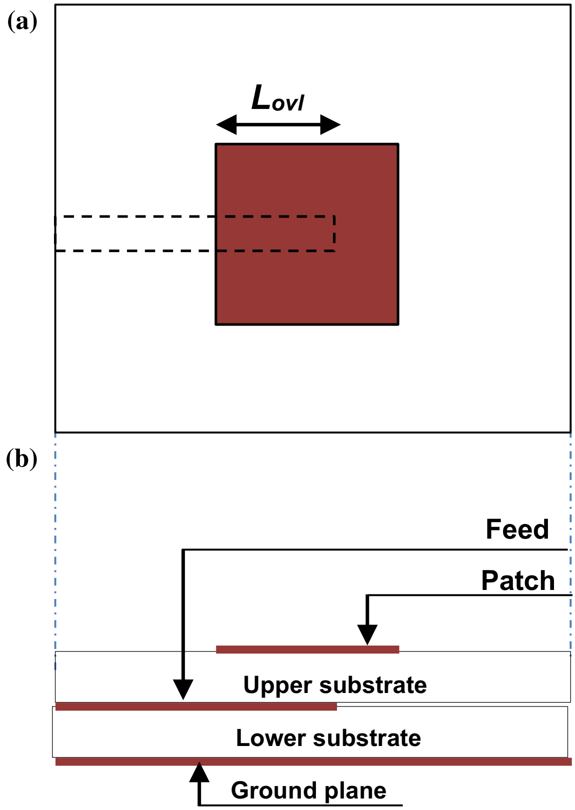

Fig. 1 A proximity coupled patch antenna—Schematic. **a** Top view **b** Side view

Proximity coupled feed provides maximum bandwidth of nearly 13%, when compared to coplanar and aperture-coupled feeding technique [8]. The radiation performance of a proximity coupled patch array can be improved by providing slots in the ground plane. The length of the slot is generally taken as λ/2, while the width to length ratio of the slot is maintained at 1:10. Slots with length comparable to λ/2 are called resonant slots, while smaller slots are called nonresonant. For maximum coupling, slots are to be placed beneath the center of the patch [6].

The deployment of slots in the ground plane also helps in reducing RCS of the patch array caused by the harmonic resonant modes. Incorporating slots causes change in the path of surface current, thereby suppressing the harmonic resonant modes [5]. Vertical slots cut off horizontally directed current, whereas horizontal slots cut off vertically directed current. In this way, the orientation of slots affects the array characteristics.

3 Radiation Performance of Proximity Coupled Patch Array

This section deals with the radiation characteristics (return loss, VSWR, and gain) of the proximity coupled 4-element patch array with conventional metallic ground plane, slotted ground plane and HIS layer with reduced slotted ground plane.

3.1 Conventional Metallic Ground Plane

The structure of a 4-element corporate-fed proximity coupled patch array with conventional ground plane, designed in X-band is shown in Fig. 2a. The top layer comprises of four metallic patch elements on a dielectric substrate (Fig. 2b). The patch dimensions are taken as 9.07 mm × 11.86 mm for 10 GHz resonant frequency. The substrate has a dimension of 49 mm × 90 mm. The patch elements are fed through electromagnetically coupled corporate-fed network designed as the middle layer (Fig. 2c). The overlapping distance of feedline from the edge of the patch (L_{ovl}) is 6 mm.

The feed network is sandwiched between two dielectric layers (Fig. 2c). Both the substrate layers are made of dielectric, RT Duroid ($\varepsilon_r = 2.2$, $\tan \delta = 0.0009$) of the same thickness (1.58 mm). These layers are backed by a metallic ground plane. Copper ($\sigma = 5.8 \times 10^7$ S/m) with thickness 0.018 mm is chosen for all the metallic portions. Figure 3 shows the variation of return loss of the proximity coupled patch array with respect to the ratio L_{ovl}/L_p. Here, L_{ovl} represents the length of feed from edge of the patch to the open end of the feed, and L_p is the length of patch element. It can be observed that the proximity coupled patch array is resonant for L_{ovl}/L_p greater than 0.68.

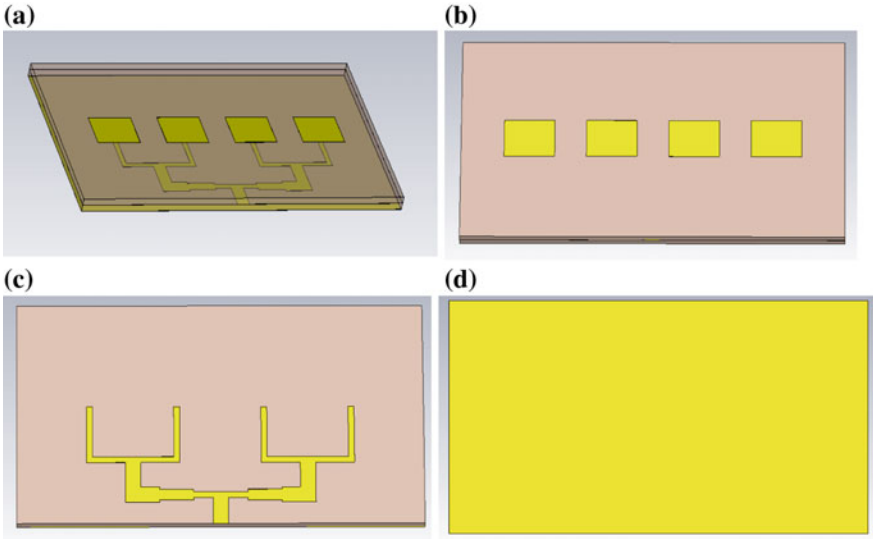

Fig. 2 A 4-element proximity coupled linear patch array with a conventional ground plane. **a** Perspective view **b** Top layer **c** Middle layer **d** Ground Plane

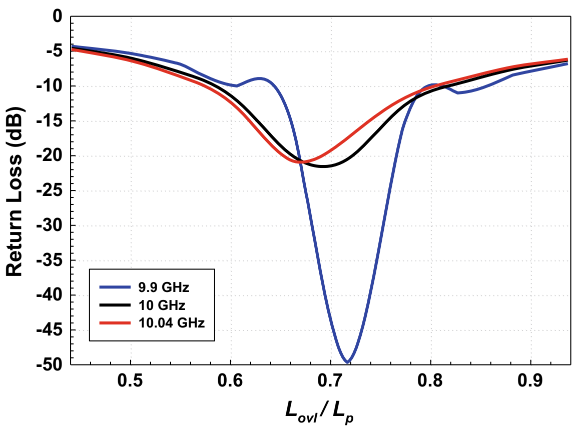

Fig. 3 Return loss of a proximity coupled 4-element linear patch array with respect to L_{ovl}/L_p overlap distance

While analyzing the radiation characteristics of the patch array, it can be observed that the array resonates at 10.04 GHz with a return loss of −20.76 dB. A bandwidth of 6% is obtained for the patch array. The VSWR obtained at the resonant frequency is 1.2. The gain of patch array along the specular direction is 7.58 dB, which is relatively small for a 4-element patch array. The side lobe level is −2.8 dB, and HPBW is 24.3°. This may be due to ineffective coupling of feed to the patch surface.

Coupling to the radiating patch elements can be improved by cutting slots in the ground plane. This may help in improving the radiation performance of the patch array.

3.2 Slotted Ground Plane

The ground plane of the proximity coupled patch array described in Sect. 3.1 has been modified by incorporating slots. Figure 4 shows the ground plane with the incorporated slots. A horizontal slot of dimension 59.2 mm × 1.5 mm has been cut in the ground plane directly beneath the patch array. The position of the slot is made below the center of patch along the length, so as to facilitate maximum coupling. When the radiation characteristics have been analyzed by placing a single horizontal slot, it is found that the maximum gain obtained is nearly 10 dB.

Further, two vertical slots have been added with length, λ/2 (15 mm) and width, λ/20 (1.5 mm), respectively. The width and length of the vertical slot are calculated in the ratio 1:10. The radiation characteristics of the proximity coupled patch array with slotted ground pane, illustrated in Fig. 4, are shown in Fig. 6a and b. It can be observed from Fig. 10a that the array resonates at 9.76 GHz, with a return loss of −33.33 dB. It can further be noted that the bandwidth has improved significantly to 12.94%, as compared to the proximity coupled patch array without slots (6% bandwidth). The VSWR is obtained as 1.04 (Fig. 10b). The gain of the array is 11.2 dB, which is 3.62 dB higher than the gain of proximity coupled patch array without slots. This clearly shows the effect of adding slots in increasing the coupling of input power to the patch surface. The array has a side lobe level of −6.7 dB, and HPBW of 20.8°.

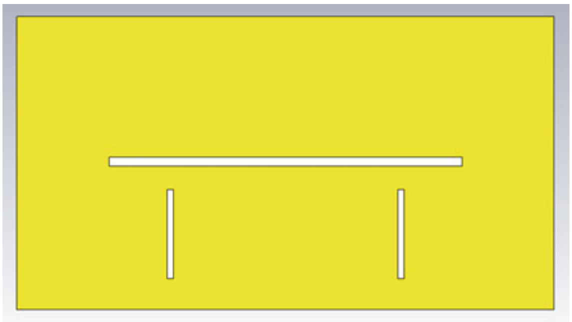

Fig. 4 Slotted ground plane of a 4-element proximity coupled linear patch array

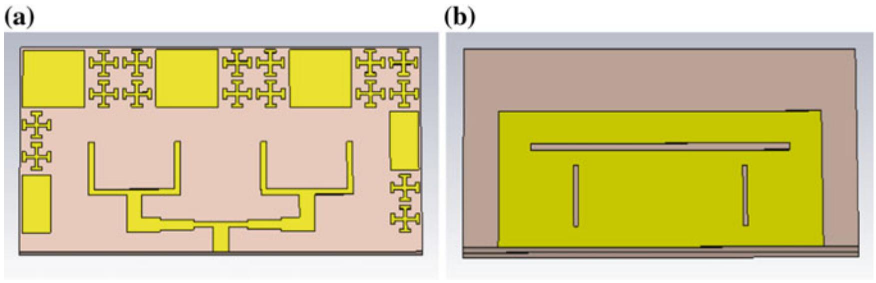

Fig. 5 A 4-element proximity coupled linear patch array with HIS layer with reduced ground plane **a** Middle layer **b** Slotted ground plane

3.3 HIS Layer with Reduced Slotted Ground Plane

The patch array design to be discussed in this section is a modification of the design already described in Sect. 3.2. The middle layer and the slotted ground plane of the proximity coupled patch array have been modified as shown in Fig. 5.

The HIS layer consists of alternately oriented 2×2 array of Jerusalem Cross (JC) elements and a metallic square patch. The radiation characteristics of the proximity coupled patch array with HIS layer-based slotted ground plane are analyzed. A comparison between these results with the radiation characteristics of proximity coupled patch array with conventional and slotted ground plane is illustrated in Fig. 5. It is evident that the radiation performance of patch array with slotted ground plane is not much affected by incorporating the HIS layer. It can be observed from Fig. 6a that the patch array with HIS layer and slotted ground plane resonates at the same frequency (i.e., 9.76 GHz) as that of conventional slotted ground plane. The return loss at the resonant frequency is obtained to be −34.16 GHz, and has a bandwidth of 11.3%. The radiating patch array has a minimum VSWR of 1.03 at the resonant frequency. The designed patch array shows a gain of 10.9 dB at $\theta = 0°$. The sidelobe level has reduced to −7.3 dB, and the HPBW is 19.5° (Fig. 6b).

4 Scattering Performance of Proximity Coupled Patch Array

The scattering characteristics of the patch array have been analyzed in terms of monostatic structural RCS. The simulated results of the structural RCS are illustrated in Fig. 7. The monostatic RCS pattern has been simulated at their respective resonant frequencies for $-90° \leq \theta \leq +90°$. It can be observed that the structural RCS value of the 4-element proximity coupled patch array with slotted ground plane and HIS layer

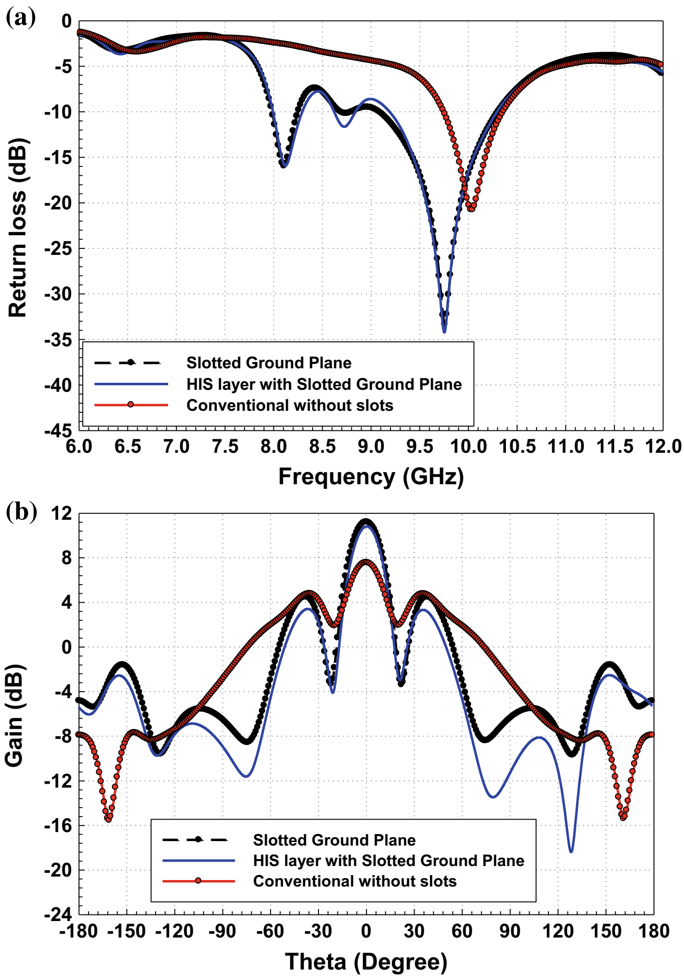

Fig. 6 Radiation characteristics and RCS of a 4-element proximity coupled patch array with different configurations. **a** Return loss **b** Gain

with reduced slotted ground plane is −7.46 dBsm and −7.85 dBsm, respectively. Further, the specular structural RCS of the proximity coupled patch array with HIS layer based reduced slotted ground plane is simulated with respect to frequency (Fig. 7b) and compared to that of conventional metallic ground plane (reference antenna). It can be observed that the specular structural RCS of the reference antenna increases with the frequency. It can be noted that a wideband reduction in RCS has been achieved from 11 to 30 GHz and beyond when compared to the reference antenna. A maximum reduction of 18.83 dBsm is observed at 24 GHz when compared to the reference antenna.

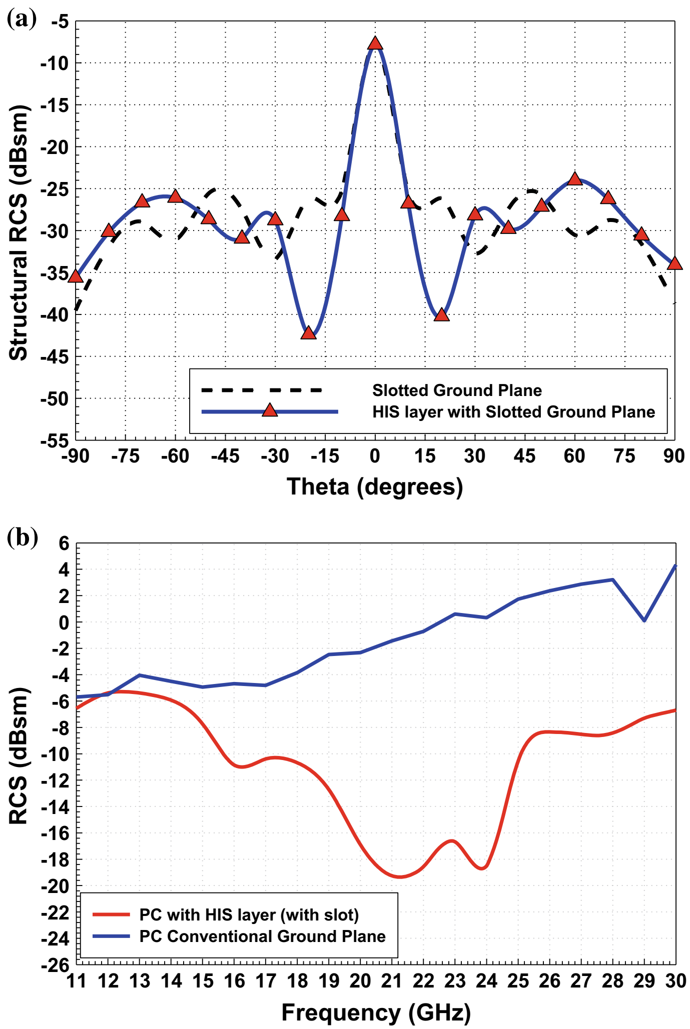

Fig. 7 Structural RCS of proximity coupled patch array. **a** Comparison of RCS pattern of slotted ground plane and HIS layer with reduced slotted ground plane **b** Comparison of specular structural RCS

5 Conclusion

The low profile nature of a microstrip patch array is advantageous in stealth applications. However, the feed network of a typical corporate-fed microstrip patch array will have more contribution towards antenna scattering. A proximity coupled feeding technique is adopted to overcome this problem. Since the feed network comes beneath the substrate, the RCS of the whole array can be reduced to an extent, with an added advantage of providing higher gain and bandwidth by cutting slots in the ground plane of a proximity coupled patch array. The patch array with slotted ground plane has shown a gain increment of 3.62 dB when compared to the conventional metallic ground plane. Moreover, the percentage bandwidth has doubled (6–12.94%) when slots were added to the ground plane of conventional proximity coupled patch array. The RCS reduction has been achieved by incorporating a HIS layer in the patch array. Specular RCS has been reduced significantly from 12 to 30 GHz and beyond, when compared to the other patch array configurations.

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