A Technique to Suppress Mutual Coupling in Densely Packed Antenna Arrays Using Metamaterial Supersubstrate

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***Abstract*– A simple and practical technique for reducing the mutual coupling between neighbouring antennas is presented for application in densely packed antenna arrays. This is achieved by locating between the radiation elements a smaller patch with metamaterial decoupling structure (MTM-DS). In this case the radiating elements are circular patches and the MTM-DS is constructed from a hexagonal slit resonator. The consequence of implementing the MTM-DS patch is significant reduction in mutual coupling between adjacent radiating patches by 60%, improvement in impedance match by 200% and substantial increase in the antenna's fractional bandwidth by 369%. Since the ground plane is unaltered the front-to-back ratio is unaffected too. The proposed technique is easily realizable and can be used effectively in beam scanning applications.**

***Keywords*– Mutual coupling, microstrip antennas, phased antenna arrays, metamaterial, beam scanning.**

I. INTRODUCTION

Phased array antennas are becoming increasingly popular in communication networks particularly in radars and satellite-focused applications because they offer desirable characteristics of high gain, beam forming, and electronic beam scanning. To complement the high miniaturization standards of RF systems; microstrip phased arrays (MPAs) have been investigated extensively. MPA offers easy integration with other components making it suitable for compact RF system-in-package applications. MPA has been adopted widely for a range of wireless applications; however, it suffers from a trade-off between array performance and array size, as a result the mutual coupling in densely packed MPAs has been a real challenge as it degrades the arrays performance. This is because energy that should be radiated away is absorbed by the adjacent antenna. Similarly, energy that could have been captured by one antenna is instead absorbed by a nearby antenna. Hence, mutual coupling reduces the antenna efficiency and performance of antennas in both the transmit and receive mode.

Mutual coupling in antenna arrays, where the radiating elements are separated by half-wavelength or more, is dominated by surface wave effects. In densely packed arrays with element separation of less than half-wavelength suffer from both surface wave and space-wave coupling effects [1]. In multi-feed antennas, undesirable issue of mutual coupling among the radiating elements is usually overcome by using proper filtering functions [2], [3]. Various other techniques have also been proposed to suppress the effects of mutual coupling [4]–[14].

In this paper the undesirable effect of mutual coupling between neighbouring circular patch antennas is compensated with the inclusion of a metamaterial decoupling structure (MTM-DS) composed of a hexagonal slit resonator to create a metamaterial superstrate. It is shown that inclusion of the proposed MTM-DS the mutual radiation coupling between the antennas is significantly reduced. In addition, the impedance match and operational bandwidth improve with MTM-DS.

II. RADIATION DECOUPLING STRUCTURE

A unit element of metamaterial decoupling slit is shown in Fig.1. The optimized dimensions are given in Table I for X-band antenna which has been realized on Rogers RT6010 substrate with thickness of 2.54 mm, dielectric constant (ε_r) of 10.2 and $tan\delta$ of 0.0023. The hexagonal slits in the patch exhibit electric resonance for vertically polarized (polarized along *z*-axis) electric fields. Four hexagonal slits are combined to create a unit cell of MTM-DS. The effective permittivity and permeability of the MTM-DS can be calculated from scattering parameters of the structure as described in [15].

(a) (b) (c) (d)

Fig.1. Metamaterial decoupling slit (MTM-DS) with hexagonal slits: (a) with one slit, (b) with two slits, (c) with three slits, and (d) with four slits (optimized case).

TABLE I. Antenna Dimensions (in millimeters).

Radiating patch radius	MTM-DS patch radius	Length of antenna feed-line	Width of antenna feed-line	Length of substrate	Width of substrate	Thickness of substrate	Radius of MTM-DS hexagon	Width of MTM-DS slit
25	14	10.3	4	140	80	2.54	4	3

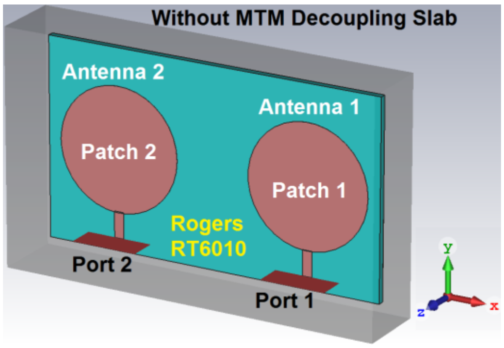
Length of ground plane	Width of ground plane	Width of structure (antennas #1 and #2 and MTM-DS)	Length of structure (antennas #1 and #2 and MTM-DS)	Gap between MTM-DS patch and radiator
140	39	35.3	66	1

III. Implementation of Mutual Radiation Decoupling in Microstrip Phased Arrays

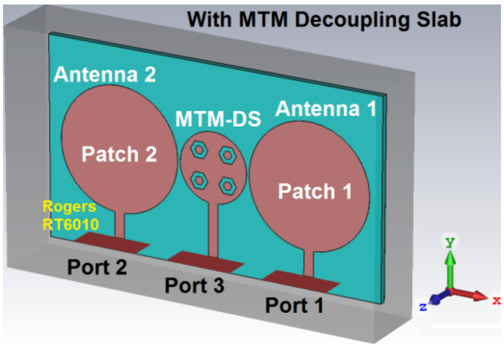
The initial antenna array consists of two circular radiation patches, as shown in Fig. 2(a), which are excited through individual feed-lines. As described earlier the antenna array is constructed on Rogers RT6010 substrate. The antenna's reflection and transmission coefficient response (magnitude and phase) are shown in Fig. 3. Without the metamaterial decoupling structure the antenna operates over a frequency range from 9.55 GHz to 10.0 GHz for $S_{11} \leq$-10 dB with maximum impedance matching of -13 dB at a resonance frequency of 10.73 GHz. In addition, the antenna's insertion loss over this frequency range varies from -17 dB to -19 dB.

In order to minimise the degrading effects of mutual coupling between the two circular patches a metamaterial decoupling structure has been inserted between the two radiators, as shown in Fig. 2(b). The MTM-DS structure consists of four identical hexagonal slits embedded in a smaller patch. By doing this Fig. 2 confirms the antennas impedance bandwidth is increased, the insertion loss or attenuation between the two radiators increased and its operational bandwidth improved. Fig. 3 shows how the reflection and transmission coefficient responses are affected by increasing the number of hexagonal slits. Results of this analysis are given in Table II. It is evident that MTM-DS with one slit (i) substantially increases the fractional bandwidth by 369%; (ii) attenuates the coupling between the two radiators over the bandwidth by 60% on average; and (iii) the significantly increases the impedance match by 200%. By increasing the number of MTM-DS from one slit to four slits significantly erodes the fractional bandwidth, moderately reduces the attenuation of the radiation coupling and impedance match.

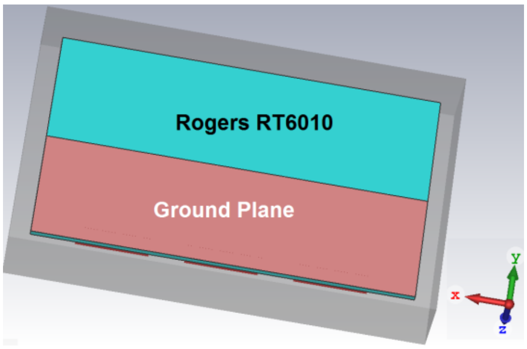
The antenna's radiation patterns are shown in Fig. 4 at its resonance frequencies of 9.86 GHz and 10.16 GHz. The 3 dB beamwidth of the antenna is 34.5 degrees at 9.86 GHz, which increases to 51.8 degrees at 10.16 GHz.



(a)

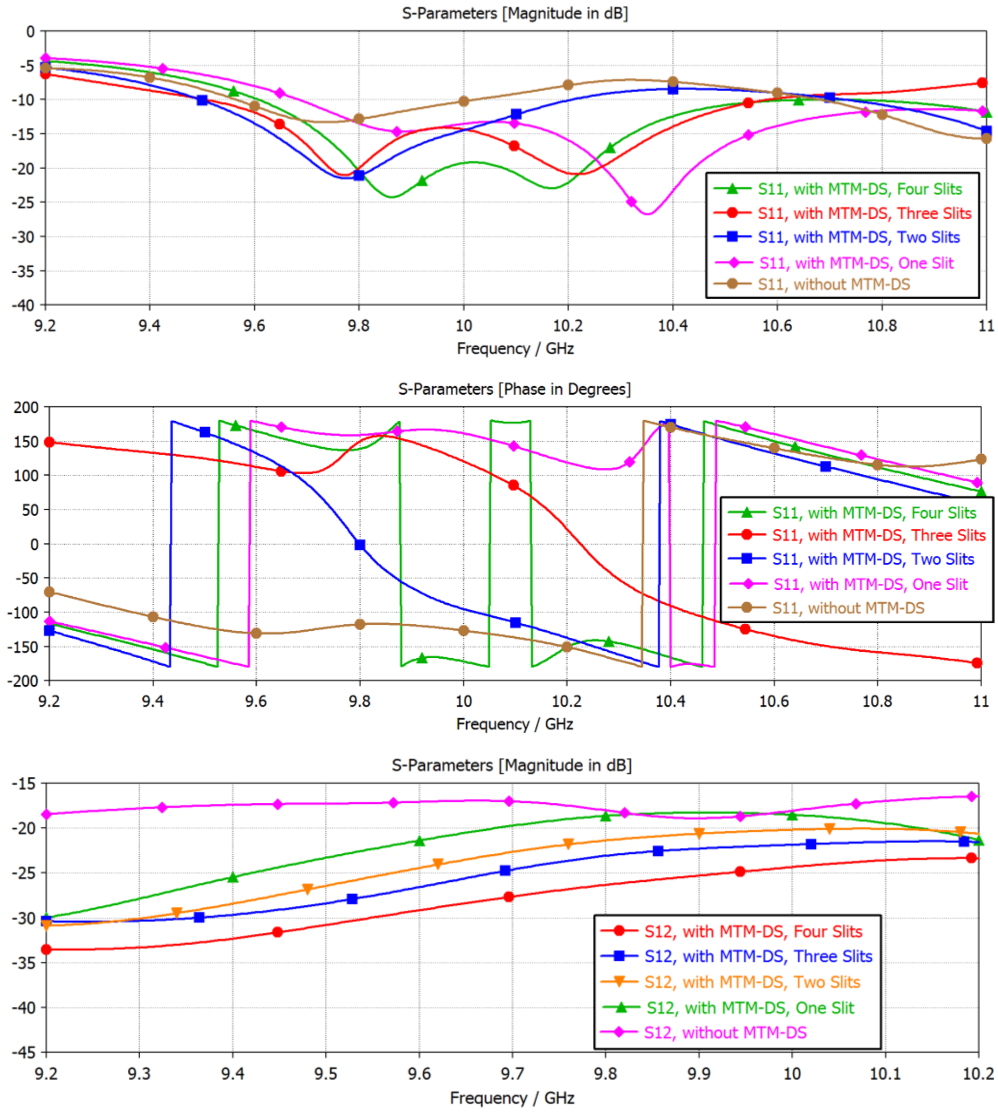


(b)



(c)

Fig.2. The proposed antenna structure: (a) without MTM-DS, (b) with multiple MTM-DS, and (c) ground plane of the antenna.



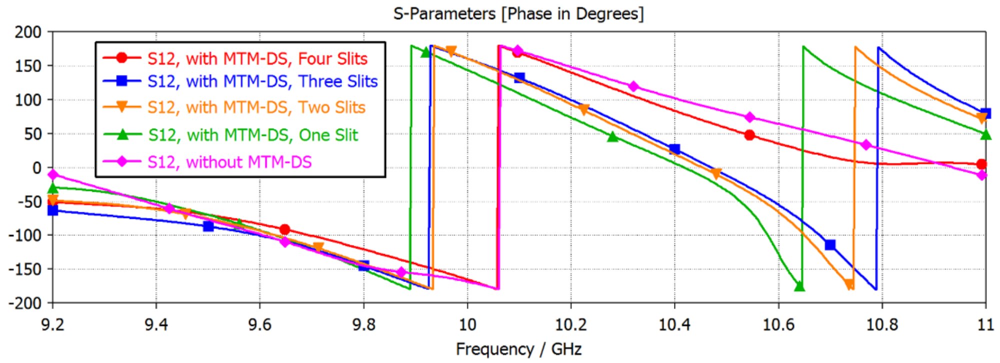


Fig.3. Reflection and transmission coefficient magnitude and phase response of the antenna array without and with MTM-DS mutual radiation decoupling structure. Response is also shown as a function of number of MTM-DS used.

TABLE II. PARAMETRIC STUDY ON S-PARAMETERS WITHOUT AND WITH MTM-DS

	without MTM-DS	MTM-DS with one slit	MTM-DS with two slits	MTM-DS with three slits	MTM-DS with four slits
S_{11} (GHz)	9.55 to 10.0	9.7 to 11.5	9.5 to 10.2	9.5 to 10.6	9.6 to 10.6
Fractional Bandwidth (%)	4.6	16.98	7.1	10.94	9.9
S_{12} (dB)	-17 to -19	-20 to -40	-20 to -26	-21 to -31	-23 to -30
Max. Impedance Matching (dB)	-13	-26	-21	-20	-25

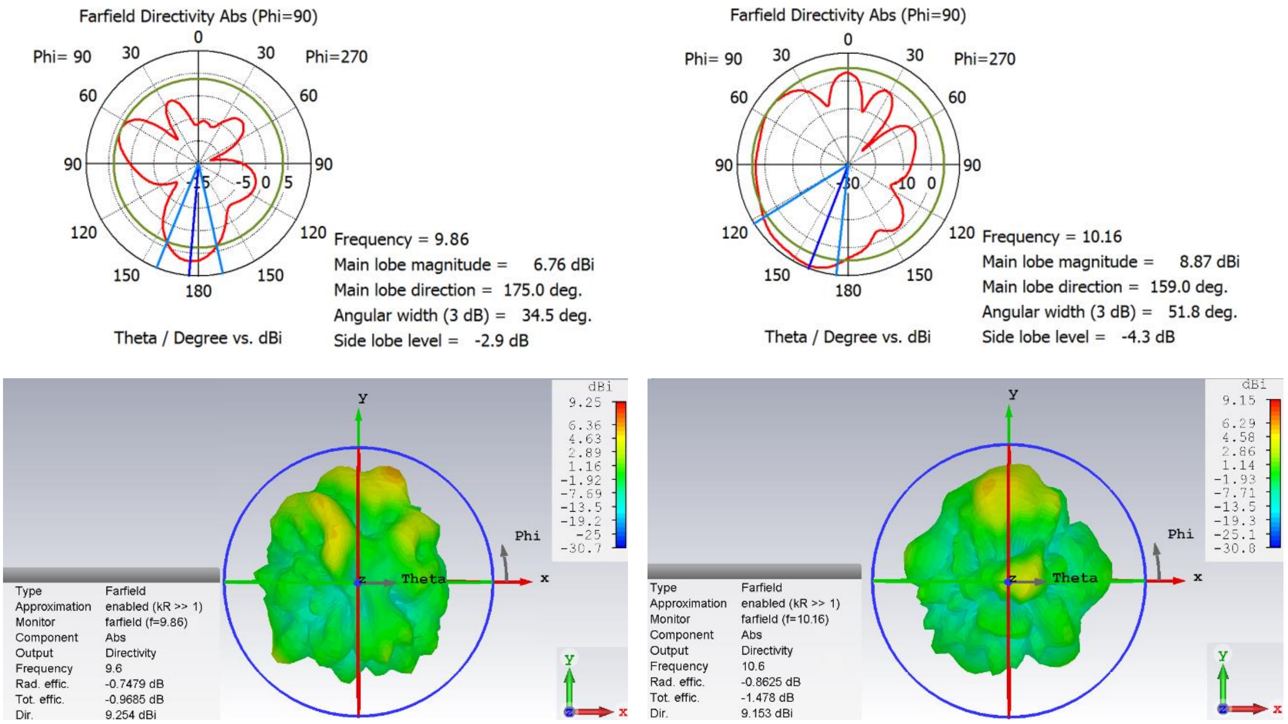


Fig.4. Two and three dimensional radiation patterns of the proposed antenna with MTM-DS with four hexagonal slits at the resonance frequencies of 9.86 GHz and 10.16 GHz.

IV. CONCLUSION

The feasibility of reducing the radiation coupling between adjacent antennas, which is encountered in densely packed antenna arrays, has been demonstrated using metamaterial decoupling structure. The proposed technique is simple to implement and incorporate in the antenna array. The metamaterial decoupling structure is a hexagonal slit etched in a smaller patch which is inserted between radiating patches. Reduction in undesirable coupling between two radiator is 60% on average over the operational bandwidth of the antenna. The benefit of this technique is substantial increase in the fractional bandwidth by 369%.

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