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Antenna Mutual Coupling Suppression Over Wideband Using Embedded Periphery Slot for Antenna Arrays

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***Abstract*- This paper presents a new approach to suppress interference between neighbouring radiating elements resulting from surface wave currents. The proposed technique will enable the realization of low-profile implementation of highly dense antenna configuration necessary in SAR and MIMO communication systems. Unlike other conventional techniques of mutual coupling suppression where decoupling slab is located between the radiating antennas the proposed technique is simpler and only requires embedding linear slots near the periphery of the patch. Attributes of this technique are (i) significant improvement in the maximum isolation between the adjacent antennas by 26.7 dB in X-band, & >15 dB in Ku and K-bands; (ii) reduction in edge-to-edge gap between antennas to 10 mm (0.37λ); and (iii) improvement in gain by >40% over certain angular directions, which varies between 4.5 dBi to 8.2 dBi. The proposed technique is simple to implement at low-cost.**

***Key Words*- Mutual coupling suppression, slotted array antennas, synthetic aperture radar (SAR), Multiple-Input Multiple-Output (MIMO) systems, decoupling method.**

I. INTRODUCTION

Antennas size is determined by the operating frequency and they take the largest space in wireless systems. Reducing the antenna size can be very challenging as many factors need to be considered including size, weight, performance and cost of manufacture. Although array antennas based on microstrip technology improve these factors; however, the mutual coupling of the adjacent patches reduces the antenna performance in terms of gain, bandwidth and radiation pattern. The widespread use of microstrip array antenna therefore requires the reduction of the mutual coupling between the array elements. To extend the beam scanning range, smaller gap between patches is necessary in the array to enable scanning over a large angle. However, mutual coupling is predominately stronge in closely spaced patches which can deteriorate the input impedance of each array element to adversely affect the radiation pattern, which is mainly due to surface waves [1].

Various techniques have been previously proposed to reduce the mutual coupling between adjacent elements in an array antenna including the use of cavity backed [2], substrate removal [3], defected ground structures (DGS) [4], metamaterial insulator [5-7], slotted complementary split-ring resonators [8], defected wall structure [9], and employing EBG structures between two patches in microstrip antennas [10, 11]. These techniques may provide good mutual coupling reduction however the size of the antenna array is not reduced.

This paper presents a novel technique to reduce mutual coupling between adjacent radiating elements with no insertion of a decoupling slab or DGS. The technique involves embedding different lengths of slots near the outer most edge of the patch. The resulting antenna array exhibits significantly improved isolation between neighbouring patch elements (26.7 dB in X-band, & >15 dB in Ku and K-bands) and optimum gain performance (4.5 dBi to 8.2 dBi) over certain angular directions. In addition, the gap between the patches can be reduced to yield a smaller sized array an array that should be able to scan over a larger angle.

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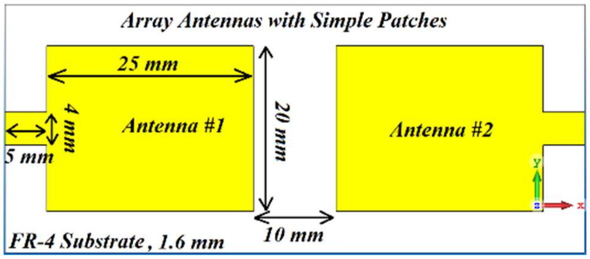
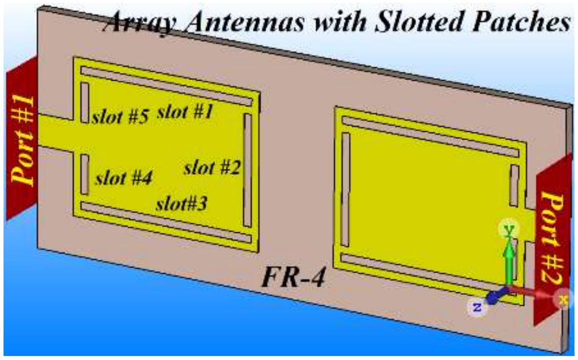
II. Proposed Slot Antenna for Antenna Arrays

The reference array antenna is a 1×2 arrangement of rectangular microstrip patches, as shown in Fig. 1(a). Standard patch design was used to implement it on a standard FR-4 lossy substrate with dielectric constant of ε_r=4.3, tanδ=0.025, and thickness of 1.6 mm. The performance of the antenna was verified using two EM tools (CST Microwave Studio and HFSS). The two patches are identical with dimensions of 25×20 mm^2 and edge-to-edge distance between radiation elements of 10 mm.

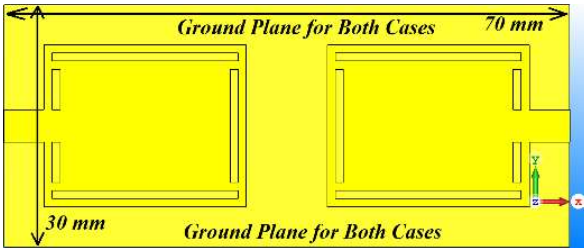
The return-loss (S_{11}) and isolation (S_{12}) of the reference array are plotted in Fig. 2. It's clear that, the reference antenna array covers three bands, i.e. X, Ku, and K. To increase the isolation between elements in the array linear slots are embedded around the periphery of the patch, as illustrated in Fig. 1(b). Dimensions of the slot are given in Fig. 1(b), and the overall size of the array is given in Fig. 1(c). The return-loss and isolation responses of the reference and proposed antenna array are shown in Fig. 2. The average and peak mutual coupling improvement resulting from proposed technique are 14 dB & 26.7 dB (X-band); 10 dB & 12.6 dB (first Ku-band); 13 dB & >11 dB (second Ku-band); and 10 dB & 15 dB (third Ku-band and K-band). To facilitate comparison the maximum and average isolation of the reference and the proposed arrays over X, Ku and K-bands are given in Tables I-IV, where the bandwidth is defined for $|S_{11} \leq -10dB|$. It is also evident from the plots in Fig. 2 that the slotted antenna array has a significantly better impedance match performance than the reference array.



(a) Simple reference array antenna



(b) Proposed slotted array antenna. Length of slots #1 to #5 are 23 mm, 14 mm, 23 mm, 5 mm, & 5 mm, respectively. Slot width is 1 mm.



(c) Ground plane for both simple and slotted arrays

Fig. 1. Array antenna prototypes (reference and proposed).

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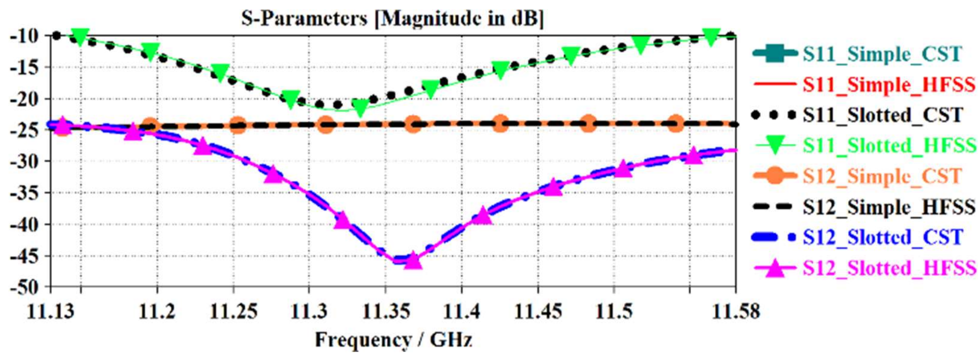
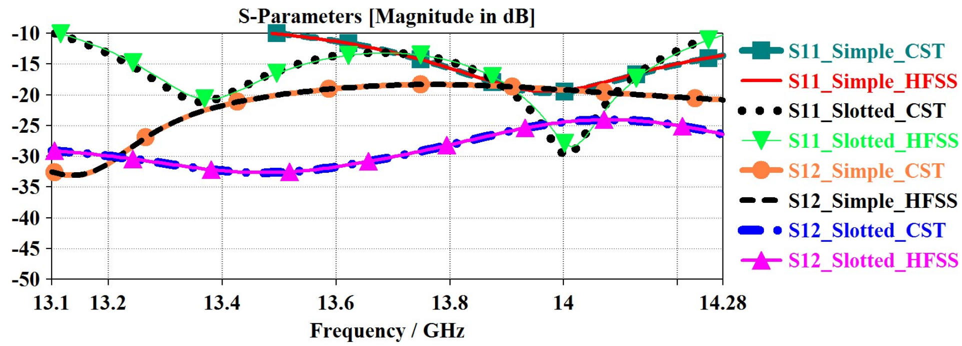
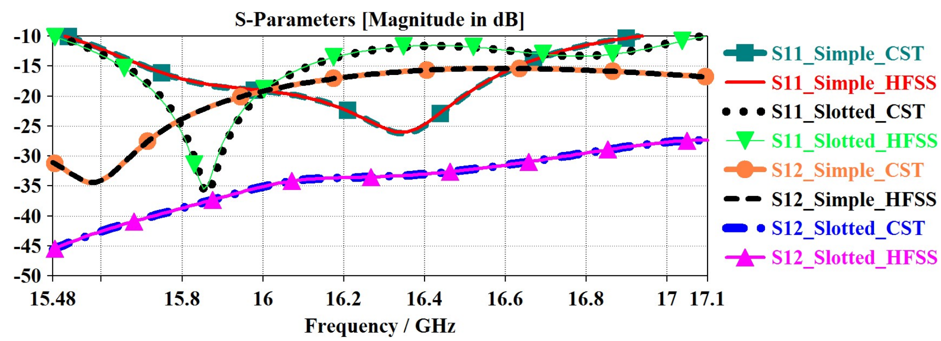


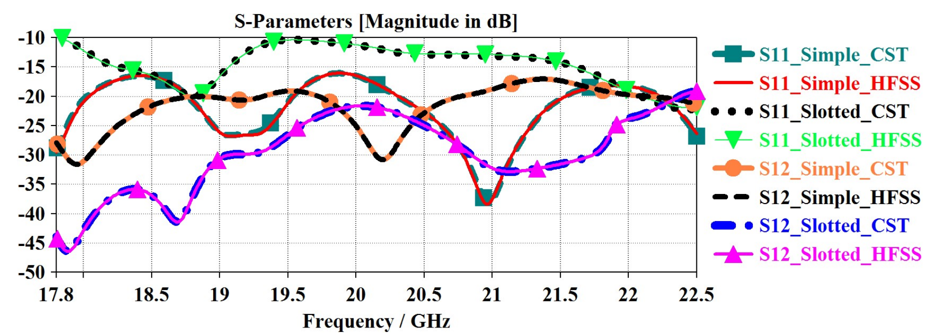
(a) Coverage over X-band



(b) Coverage over the first Ku-band



(c) Coverage over the second Ku-band



(d) Coverage over the third Ku-band and K-band

Fig. 2. Reflection and transition coefficients of the reference and proposed antenna array.

TABLE I. ISOLATION IN THE X-BAND

First Band:11.13–11.58 GHz (Δf=450 MHz, FBW=3.88%)		
	Maximum	Average
Reference Patch Antennas	-24 dB @ 11.36 GHz	-24 dB
Slotted Patch Antennas	-45.7 dB @ 11.36 GHz	-38 dB
Supression Improvement	26.7 dB @ 11.36 GHz	14 dB

TABLE II. ISOLATION IN THE FIRST Ku-BAND

Second Band: 13.1–14.28 GHz (Δf=1.18 GHz, FBW=8.62%)		
	Maximum	Average
Reference Patch Antennas	-20 dB @ 14.28 GHz	-19 dB
Slotted Patch Antennas	-32.63 dB @ 13.56 GHz	-29 dB
Supression Improvement	12.6 dB	10 dB

TABLE III. ISOLATION IN THE SECOND Ku-BAND

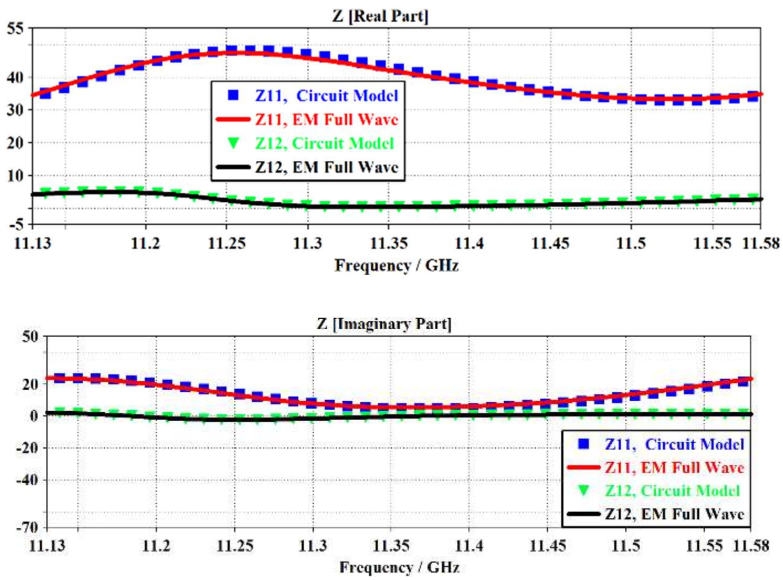
Third Band: 15.48–17.1 GHz (Δf=1.62 GHz, FBW=9.95%)		
	Maximum	Average
Reference Patch Antennas	-34.4 dB @ 15 GHz	-24 dB
Slotted Patch Antennas	-45.6 dB @ 15 GHz	-37 dB
Supression Improvement	>11 dB @ 15 GHz	13 dB

TABLE IV. ISOLATION IN THE THIRD Ku-BAND AND K-BAND

Fourth Band: 17.8–22.5 GHz (Δf = 4.7 GHz, FBW = 23.32%)		
	Maximum	Average
Simple Patches	-31.6 dB @ 17.9 GHz	-24 dB
Slotted Antennas	-46.4 dB @ 17.9 GHz	-34 dB
Supression Improvement	15 dB @ 17.9 GHz	10 dB

The input impedance and admittance of the proposed slotted antenna array its operating range using circuit model and CST Microwave Studio are shown in Fig. 3. There is very good correlation in input impedance and admittance responses between the circuit model and CST Microwave Studio.

Surface current distribution over the reference and the slotted antenna array are shown in Fig. 4. It is evident from these figures the slots behave as a decoupling structure that soak up the surface waves that would otherwise couple with the adjacent radiating elements.



(a) Coverage over X-band

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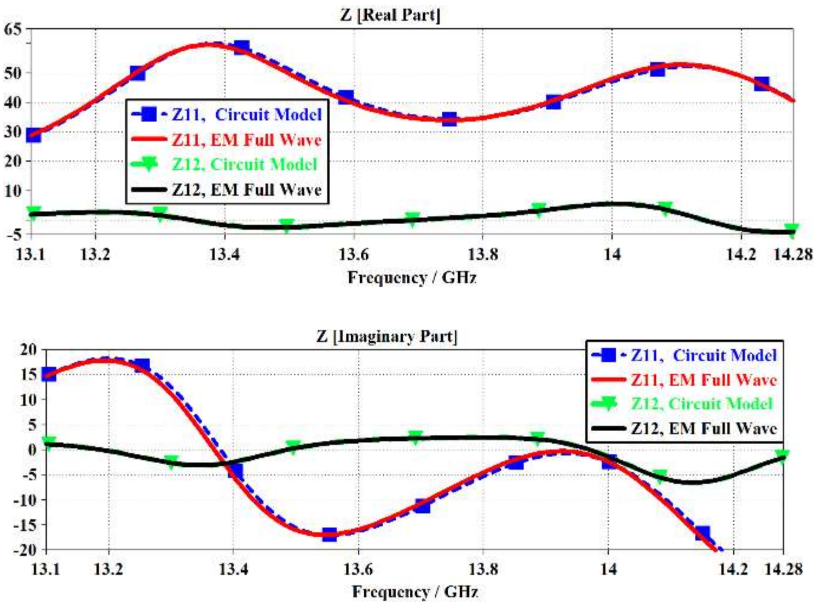
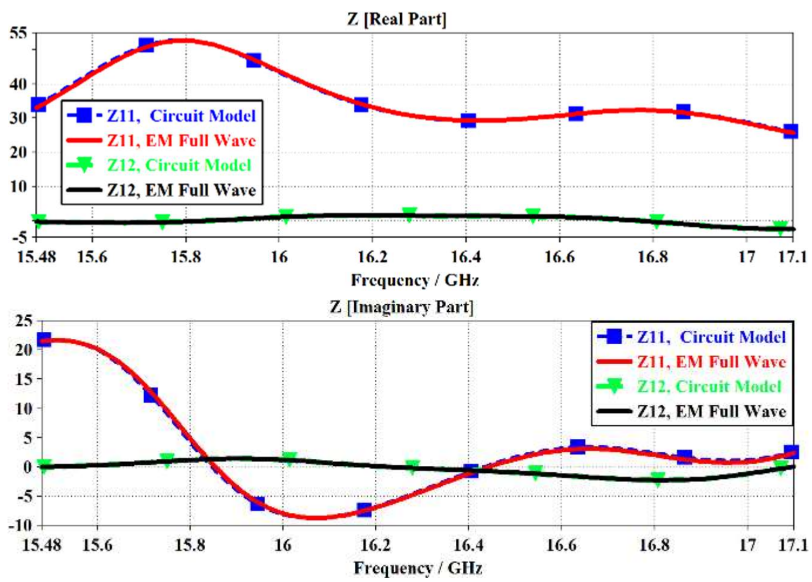
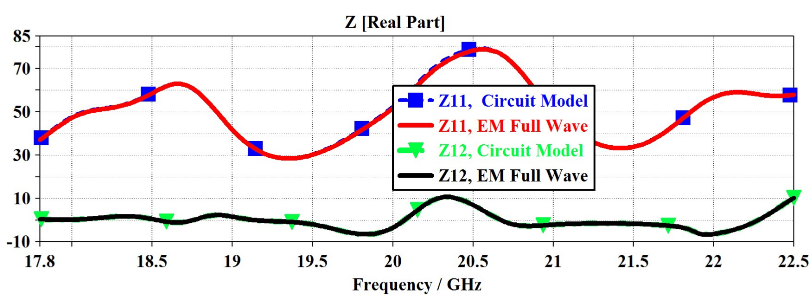


(b) Coverage over the first Ku-band



(c) Coverage over the second Ku-band



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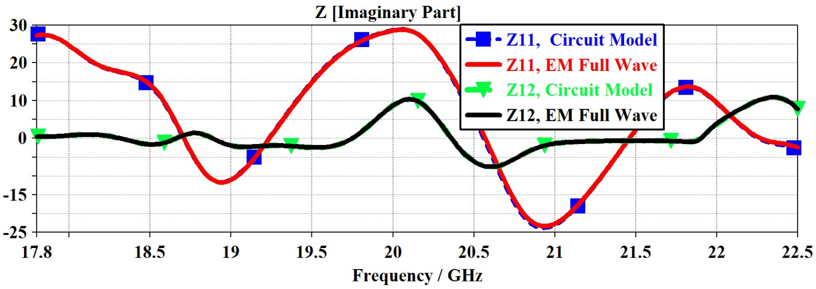
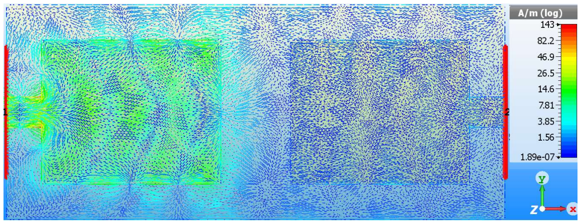
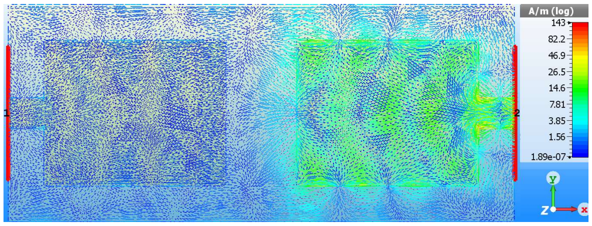


(d) Coverage over the third Ku-band and K-band

Fig. 3. Input impedance (Ω) & admittance (1/Ω) of the proposed slotted array antenna.

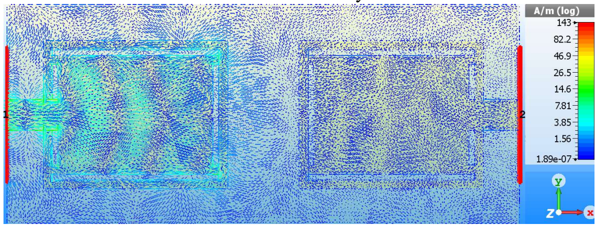


Port #1 excited

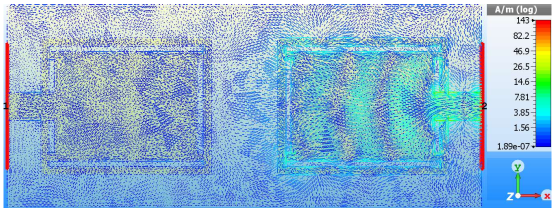


Port #2 excited

Reference Array



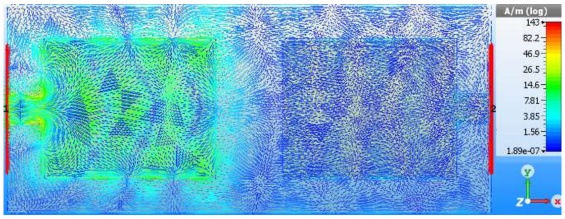
Port #1 excited



Port #2 excited

Proposed Slotted Array

@ 11.37 GHz in X-band



Port #1 excited

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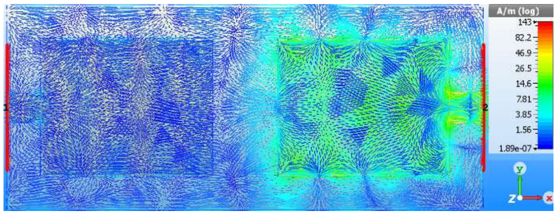
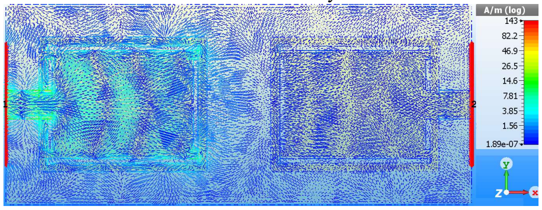
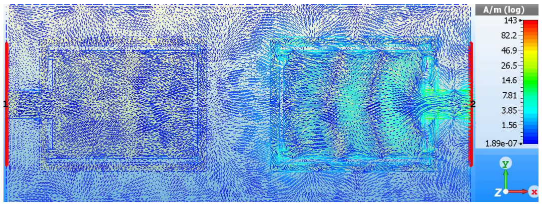


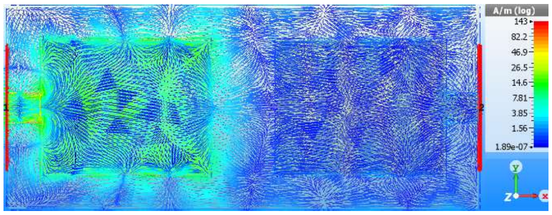
Port #2 excited
Reference Array



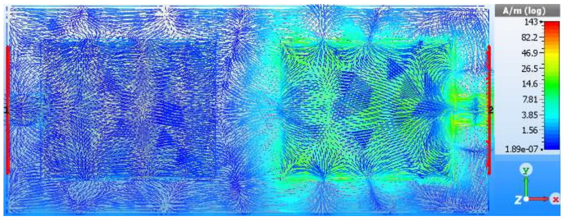
Port #1 excited



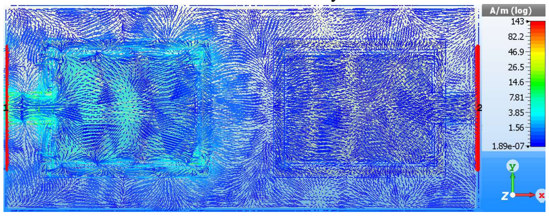
Port #2 excited
Proposed Slotted Array
@ 13.6 GHz in Ku-band



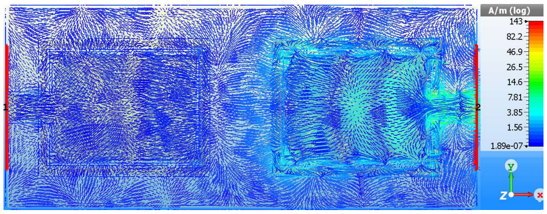
Port #1 excited



Port #2 excited
Reference Array



Port #1 excited



Port #2 excited
Proposed Slotted Array

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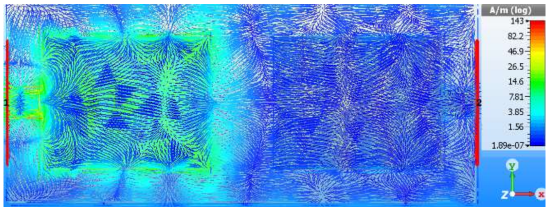
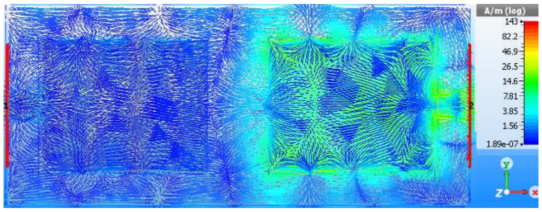
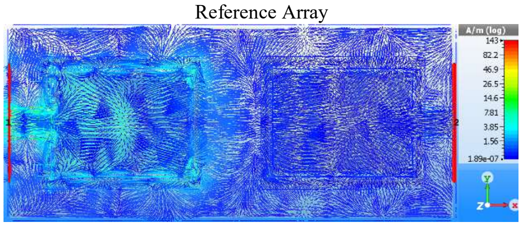
@ 15.9 GHz in Ku-band



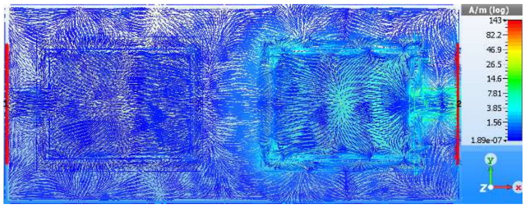
Port #1 excited



Port #2 excited
Reference Array



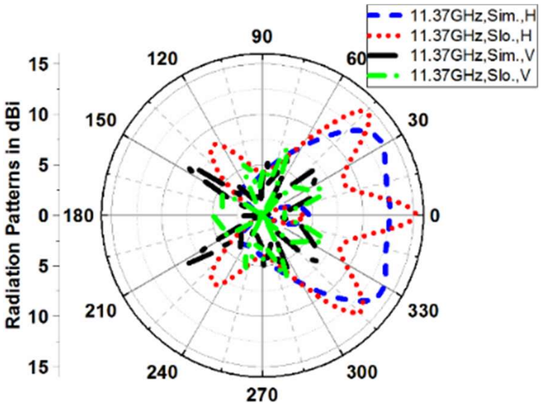
Port #1 excited



Port #2 excited
Proposed Slotted Array
@ 18.7 GHz in K-band

Fig. 4. Surface current distribution over the reference and slotted arrays.

Radiation patterns of the simple reference (Sim.) and proposed slotted (Slo.) antenna arrays in the horizontal (H) and vertical (V) planes are shown in Fig. 5. After applying the proposed slots to the patch array the radiation pattern in the H-plane is distorted with large ripples. Over certain angular directions the array exhibits better gain performance than others. At 11.37 GHz the gain varies from 5.9 dBi to 8.2 dBi, and at 15.9 GHz it varies from 3.1 dBi to 4.5 dBi.



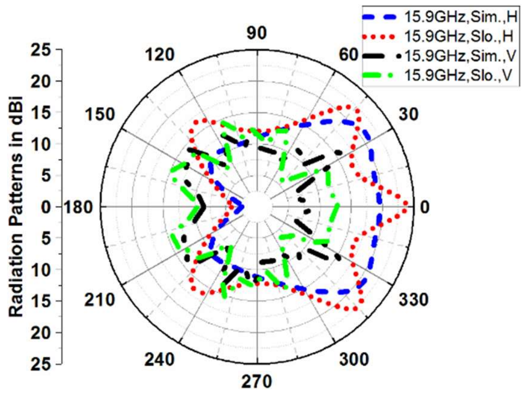


Fig. 5. Radiation patterns of the simple reference (sim.) and proposed slotted (slo.) array antennas in the horizontal (H) and vertical (V) planes at 11.37 GHz & 15.9 GHz.

The performance of the proposed technique is compared with other mutual coupling reduction mechanisms in Table V. Application of decoupling slab between the array's elements is a popular technique. Although this results in reducing mutual coupling it does not contribute in reducing the overall size of the array. It is demonstrated here the proposed techniques provides a simple solution of both reducing the surface currents and size reduction, but further work is needed to improve its radiation characteristics. The proposed method offers an average and maximum isolation between transmit and receive antennas of ~15 dB and more than >26 dB, respectively, over a narrow angular range which is better than other techniques. The advantage of the proposed technique is its simplicity.

TABLE V. Comparison Between The Proposed Array With The Recent Works

Ref.	Method	Max. isolation	Bandwidth	Bands	Reduction in bandwidth	Rad. pattern deterioration	No. of elements	Use of DGS	Edge-to-Edge Gap
[11]	EBG	8.8 dB	Narrow	Single	Yes	-	2	Yes	$0.75\lambda_0$
[12]	Fractal load & DGS	16 dB	Narrow	Single	Yes	No	2	Yes	$0.22\lambda_0$
[13]	U-Shaped Resonator	10 dB	Narrow	Single	Yes	Yes	2	Yes	$0.6\lambda_0$
[14]	I-Shaped Resonator	30 dB	Narrow	Single	Yes	Yes	2	Yes	$0.45\lambda_0$
[15]	W/g MTM	18 dB	Narrow	Single	Yes	No	2	Yes	$0.093\lambda_0$
[16]	Ground Slot	40 dB	Narrow	Single	Yes	Yes	2	Yes	$0.23\lambda_0$
[17]	SCSRR	10 dB	Narrow	Single	Yes	Yes	2	Yes	$0.25\lambda_0$
[18]	SCSSRR	14.6 dB	Narrow	Single	Yes	Yes	2	Yes	$0.125\lambda_0$
[19]	Compact EBG	17 dB	Narrow	Single	Yes	Yes	2	Yes	$0.8\lambda_0$
[20]	Meander line	10 dB	Narrow	Single	Yes	No	2	Yes	$0.055\lambda_0$
[21]	UC-EBG	14 dB	Narrow	Single	Yes	Yes	2	Yes	$0.5\lambda_0$
[22]	EBG	10 dB	Narrow	Single	Yes	Yes	2	Yes	$0.5\lambda_0$
[23]	EBG	5 dB	Medium	Single	Yes	-	2	Yes	$0.6\lambda_0$
[24]	EBG	13 dB	Medium	Single	Yes	Yes	2	Yes	$0.5\lambda_0$
[25]	EBG&DGS	16 dB	Narrow	Single	Yes	No	2	Yes	$0.6\lambda_0$
[26]	EBG	4 dB	Narrow	Single	Yes	Yes	2	Yes	$0.84\lambda_0$
[27]	Slotted meander-line	16 dB	Narrow	Single	Yes	Yes	2	No	$0.11\lambda_0$
[28]	W/g MTM	20 dB	Narrow	Single	Yes	No	2	Yes	$0.125\lambda_0$
This work	Slots	>26 dB	Wide (>23%)	Four	No	No	4	No	$0.37\lambda_0$

III. Conclusion

A simple technique is demonstrated to reduce mutual coupling between adjacent radiating elements which allows the edge-to-edge gap between adjacent elements in an array to be reduced. This should that enable beam-scanning over a larger angle. This is achieved by embedding different lengths of slots near periphery of the patch antenna. The resulting antenna array exhibits significantly improved isolation between neighbouring patch elements and gain performance over a narrower angular direction.

Acknowledgments

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