A New Study to Suppress Mutual-Coupling between Waveguide Slot Array Antennas based on Metasurface Bulkhead for MIMO Systems

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Abstract: **In this paper, a new method is proposed to reduce mutual coupling between waveguide slot array (WSA) antennas based on metasurface technology. This is achieved by placing a metasurface bulkhead between the two WSA antennas. Performance of the dual-waveguide antenna structure is shown to substantially enhance when compared against an identical reference WSA antenna with no metasurface. WSA antennas used in the study has dimensions 40×20×5mm^3 and operates over 1.7-3.66 GHz, which corresponds to a fractional bandwidth of 73.13%. The average isolation of the reference WSA antennas is -20 dB; however, with a metasurface bulkhead the isolation is shown to increase to -36.5 dB. In addition, the bandwidth extends by ~10%, and the gain improves by 14.66%. The proposed method is should find application in MIMO systems where high isolation between neighbouring radiation elements is required to improve the antenna characteristics, and mimimise array phase errors, which is necessary to enhance the system performance.**

Keywords: **Suppression mutual coupling, metamaterial bulkhead, waveguide slot array antennas, multiple-input multiple-output (MIMO) systems, array structures.**

I. INTRODUCTION

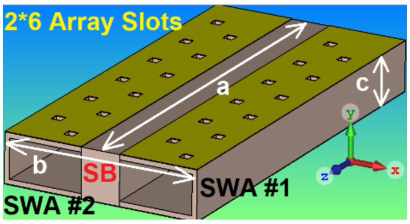
Waveguide slot array (WSA) antennas offer desirable features that include low-loss, moderate cost, and high power-handling capability [1]. However, the main drawback of WSA structure is the mutual coupling between the slot antennas, which degrades the antenna gain, bandwidth and distorts the radiation pattern. For application of WSA antennas in next generation MIMO systems requires a high degree of isolation and low envelope correlation coefficient [2]. Various approaches have been used to reduce mutual coupling, examples include using (i) a coplanar strip wall between two antennas has been reported in [3]; (ii) a metasurface corrugations [4]; and a frequency selective surface in [5]. However, these techniques degrade the antenna radiation pattern. This is due to the fact that a frequency selective surface wall or a coplanar strip wall is not matched. As a result, the radiation pattern is distorted due to reflected waves from the embedded wall between the antennas.

In this paper a new approached is presented to enhance insolation between WSA antennas. The method essentially involves placeing a metasurface between the waveguide slot antennas. The proposed technique is shown to improve isolation by 16.5 dB and enhance the gain and operational bandwidth by 14.66% and ~10%, respectively. The proposed technique is simple to implement and effective.

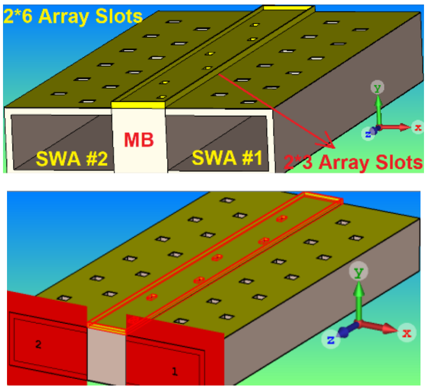
II. METASURFACE BULKHEAD

To enhance isolation between the radiation elements of waveguide slot array antennas a metasurface was placed between the WSA structure. Dimensions of each slot are 1×1×0.55 mm^3. To demonstrates the effectiveness of the proposed approach two WSA antennas were employed, where one of them was a used as a reference antenna with no metasurface and the other was WSA antennas with metasurface. The metasurface is constituted from a dielectric substrate where the outer metallisation surface is embedded with a 2×6 slot array. Dimensions of each slot are 1×0.5×0.05 mm^3, which were obtained through simulation analysis. In the structure the slot arrays essentially play the role of series left-handed capacitance (C_L), and the structure induces loops in the surface currents, resulting in series right-handed inductance (L_R). The shunt right-handed capacitance (C_R) is created by the gap between the surface of the waveguide and ground-plane. Proof-of-concept in this study is evaluated using 3D full-wave commercially available electromagnetic tool. The proposed technique is simply to implement in practice.

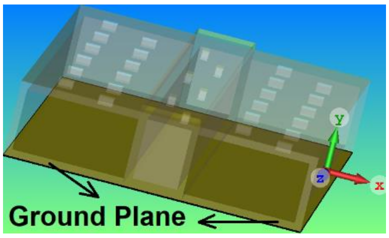
The experimental two WSA antennas were constructed using Rogers RT5880 lossy substrate with dielectric constant of 2.2 and tanδ=0.0009. The reference waveguides, shown in Fig. 1(a), were isolated from each other with a dielectric bulkhead of dimensions 40×4×5 mm^3. Total dimensions of the WSA antennas are 40×20×5 mm^3.



(a) WSA antennas with simple bulkhead (SB) of RT5880.



(b) WSA antennas with metasurface bulkhead (MB)



(c) 3-D view of the WSA with MB

Fig.1. Configuration of the reference and proposed waveguide slot array (WSA).

S-parameter performance of the reference WSA antennas is shown in Fig. 2 and the salient features summarized in Table I. This structure operates over L- and S-bands covering a frequency range from 1.7 GHz to 3.66 GHz. Minimum, average, and maximum isolation level between the radiation elements without metasurface are -13.5 dB, -20 dB, and -27 dB, respectively.

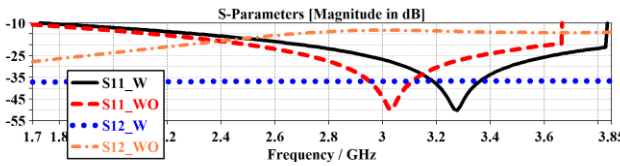


Fig.2. Reflection and transmission coefficients of the reference and proposed WSA antennas without (WO) and with (W) metasurface bulkhead.

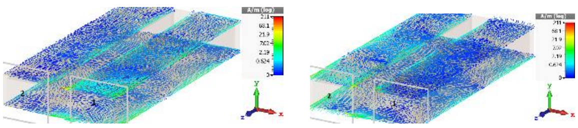
To reduce the mutual coupling between the two WSA antennas a metasurface bulkhead was applied, as shown in Fig. 1(b). Reflection and transition coefficient response of the structure is shown in Fig. 2 and the results are summarised in Table I. With metasurface bulkhead (MB) the antennas cover a frequency range from 1.7 GHz to 3.85 GHz, and the frequency range is extended by 190 MHz with no change in dimensions. For $|S_{11}| \leq -10\ dB$, the minimum, average, and maximum isolation levels obtained with MB are -36 dB, -36.5 dB, and -37 dB, respectively.

TABLE I. S-PARAMETER PERFORMANCE OF THE REFERENCE AND PROPOSED WSA WITH SB AND MB

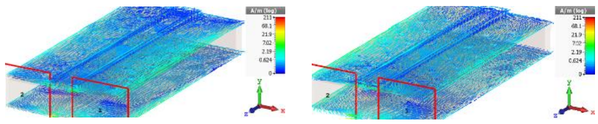
$\lvert S_{11} \leq -10dB \rvert$	with SB: 1.70 – 3.66 GHz (Δf: 1.96 GHz →73.13% *FBW*)
	with MB: 1.70 – 3.85 GHz (Δf: 2.15 GHz →77.47% *FBW*)
Minimum Isolation	without metasurface: -13.5 dB
	with metasurface: -36 dB
Average Isolation	without metasurface: -20 dB
	with metasurface: -36.5 dB
Maximum Isolation	without metasurface: -27 dB
	with metasurface: -37 dB

ISOLATION IMPROVEMENT WITH METASURFACE	
Minimum	10 dB
Average	16.5 dB
Maximum	22.5 dB

Surface current distribution over the reference and proposed WSA antennas without and with metasurface bulkhead at 3.27 GHz is shown in Fig. 3. Plots are shown when the waveguide is excited from each end. The co- and cross-polarized radiation patterns of the reference and proposed WSA antennas at 2.4 GHz and 3.27 GHz are shown in Fig.4. The structure has a bidirectional radiation pattern. It is evident that after applying the metasurface bulkhead the radiation patterns remain virtually the same. Gain of reference WSA antennas, shown in Fig. 5, varies from 4.5 dBi to 7.5 dBi, ut with MB the gain variation improves from 5.75 dBi to 8.6 dBi. These results show with MB the gain improvement variation is 27.77% to 14.66% over the specified frequency range.



(a) Without metasurface bulkhead



(b) With metasurface bulkhead

Fig.3. Surface current distribution over the reference and proposed WSA antennas at 3.27GHz. Left side shows that port #1 excited and port #2 has matched to 50Ω, & the right side illustrates that port#2 excited and port #1 has matched to 50Ω.

The proposed technique is compared with other recent mutual coupling reduction techniques in Table II. The results show that the proposed array antenna operates over a wide bandwidth of more than 2 GHz from 1.7-3.85 GHz

(77.47% fractional bandwidth) to support part of L- and S-bands. The results also reveal with metasurface bulkhead a higher isolation is obtained between WSA antennas, and the radiation pattern remains intact. The proposed method is simple to implement, which can be applied retrospectively to existing planar array antennas.

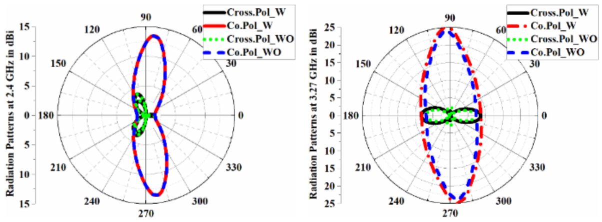


Fig.4. Co. and Cross. polarization radiation patterns at operational frequencies for both cases with no (WO) and with (W) MB.

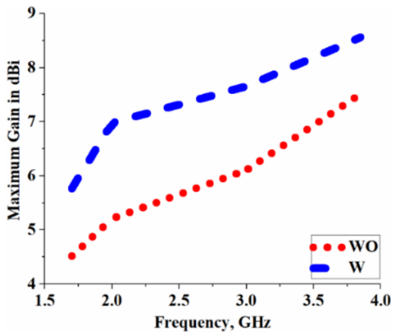


Fig.5. Maximum gain response versus frequency for reference and proposed WSA without (WO) and with (W) metasurface bulkhead.

TABLE II. PROPOSED ARRAY ANTENNA CHARACTERISTICS COMPARED WITH RECENT WORKS

Ref.	Method	Max. isolation improvement	BW	Rad. pattern deterioration
[6]	EBG	4 dB	Narrow	Yes
[7]	UC-EBG	10 dB	Narrow	Yes
[8]	Compact EBG	17 dB	Narrow	Yes
[9]	DGS	17.43 dB	Narrow	Yes
[10]	U-Shaped Resonator	10 dB	Narrow	Yes
[11]	Slotted Meander Line Resonator	16 dB	Narrow	Yes
[12]	I-Shaped Resonator	30 dB	Narrow	Yes
[13]	Slot in Ground plane	40 dB	Narrow	Yes
[14]	SCSRR	10 dB	Narrow	Yes
[15]	SCSSRR	14.6 dB	Narrow	Yes
[16]	W/g MTM	20 dB	Narrow	No
[17]	W/g MTM	18 dB	Narrow	No
[18]	Meander Line Resonator	10 dB	Narrow	No
[19]	Fractal load with DGS	16 dB	Narrow	No
This work	**Metasurface**	**22.5 dB**	**Wide**	**No**

III. CONCLUSION

An effective technique is demonstrated to substantially suppress unwanted coupling between radiation elements in waveguide slot array antennas. This is based on inserted a metasurface bulkhead between the slot array. Average improvement in isolation over the operating band of the antenna is 16.5dB. With the proposed technique the frequency bandwidth is extended by 190 MHz and the radiation gain is enhanced by 14.66%. This technique is simple to implement and is proposed for MIMO systems.

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