A New Waveguide Slot Array Antenna with High Isolation and High Antenna Bandwidth operation on Ku- and K- bands for Radar and MIMO Systems

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***Abstract*- In this paper a novel technique is proposed to reduce the mutual coupling between the radiating elements of a waveguide slot array antenna. This is achieved by inserting slots between the waveguide oval shaped slots. The reference waveguide array antenna used in the study was implemented with an arrangement of 3×5 oval shaped slots. By incorporating linear slots between the radiating oval shaped slots in both horizontal and vertical directions significant reduction in mutual coupling is achieved of 24 dB, 20 dB, and 32 dB in the frequency bands of 12.95-13.75 GHz (Ku-band), 15.45-16.85 GHz (Ku-band), and 18.85-23.0 GHz (K-band), respectively. Edge-to-edge distance between the slot radiators is 0.2λ, which is at least two-fold smaller than conventional array antennas. With the slot isolators the antenna's minimum and maximum gains improve by 53.5% and 25.5%, respectively. In addition, the radiation patterns are unaffected. The proposed method is simple to implement, low cost solution mass production.**

***Keyword*- Waveguide slot array antennas (WSAA), mutual coupling suppression, slot radiators, slot isolators.**

I. INTRODUCTION

Multiple-input multiple-output (MIMO) technology, which uses multiple antennas, is now becoming widespread in next generation of wireless communication systems as it enhances system performance [1]–[3]. For optimal performance there needs to be low correlation between signals received by each of the antennas in MIMO systems. This can only be achieved when there is low mutual coupling between the antenna ports. This is not normally possible when the antennas are closely spaced as in MIMO systems. High mutual coupling results from surface waves that are induced in the ground-plane. The consequence of this is increased received signal correlation that adversely impacts on diversity gain and channel capacity [4].

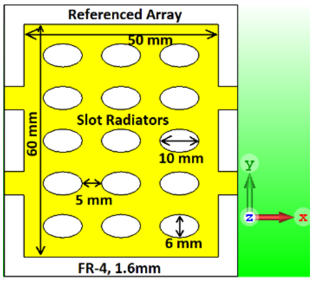
Various techniques have been used to reduce the mutual coupling between the antenna elements including neutralization technique [5], simultaneous matching [6], etching slits in the middle of the ground-plane [7][8] and using EBG substrates [9]-[12]. These techniques require considerable circuit board space. In another approach the isolating slot is etched between the antenna elements. Various slot configurations have been explored including a vertical slot [13], a T-shaped slot [14], or two L-shaped slots [15]. Although these isolating slots minimise the mutual coupling between the radiating antennas, they do not improve system bandwidth.

In this article, a new approach is described to decrease the mutual coupling between the array elements in a waveguide slot antenna for wideband applications. This is achieved by simply incorporating linear slots between the waveguide radiating slots. With this approach high isolation between the radiating elements is achieved. Isolation is improved by 20 dB to 32 dB across Ku- and K-bands.

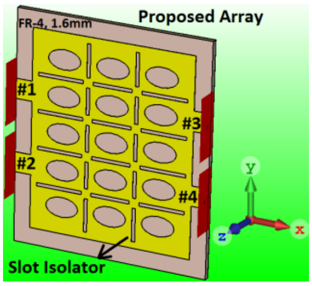
II. PROPOSED WAVEGUIDE SLOT ARRAY ANTENNAS WITH HIGH ISOLATION

The reference waveguide slot antenna consisting of 15 slots is arranged in a 3×5 array, as shown in Fig.1. The oval shaped slots play the role of radiators. The structure was implemented on the FR-4 lossy substrate with dielectric constant of ε_r=4.3, loss-tangent of tanδ=0.025, and thickness of 1.6mm. The antenna's S-parameters (S_{11} and S_{12}) are plotted in Fig.2, where the bandwidth is defined by $|S_{11} \leq 10dB|$.

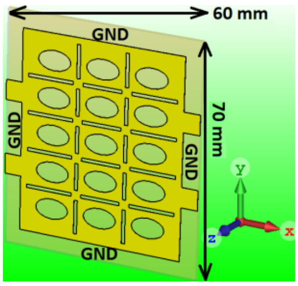
To increase isolation between the waveguide slot radiators, we have inserted linear slots between the radiators to suppression surface currents, as shown in Fig.2. S-parameters of the reference waveguide antenna without (WO) the slot isolator and with (W) linear slot isolator are shown in Fig.2. These results show the proposed antenna with slot isolator covers three frequency bands of 12.95 GHz – 13.75 GHz, 15.45 GHz – 16.85 GHz, and 18.85 GHz – 23.0 GHz over Ku- and K-bands. The maximum suppression in mutual coupling with the proposed method is 24 dB @ 13.75 GHz in first band, 20 dB @ 16.2 GHz in second band, and 32 dB @ 22.5 GHz in the third band. The results are summarised in Table I.



(a) Reference slot array antenna

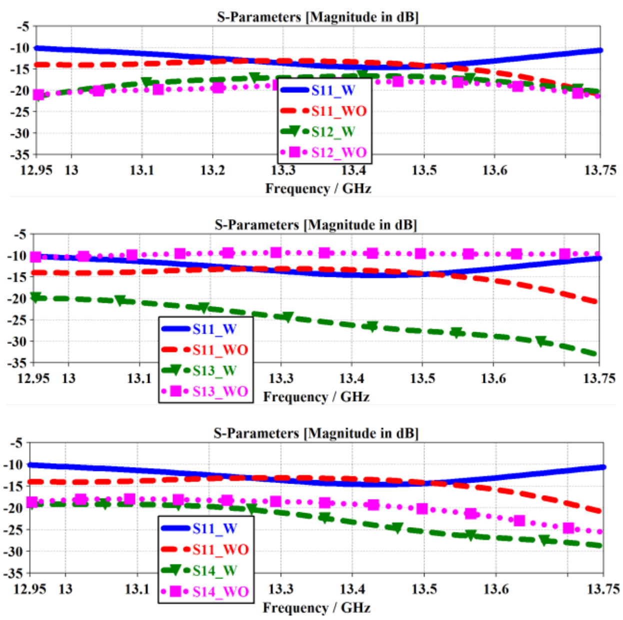


(b) Proposed waveguide slot array antenna

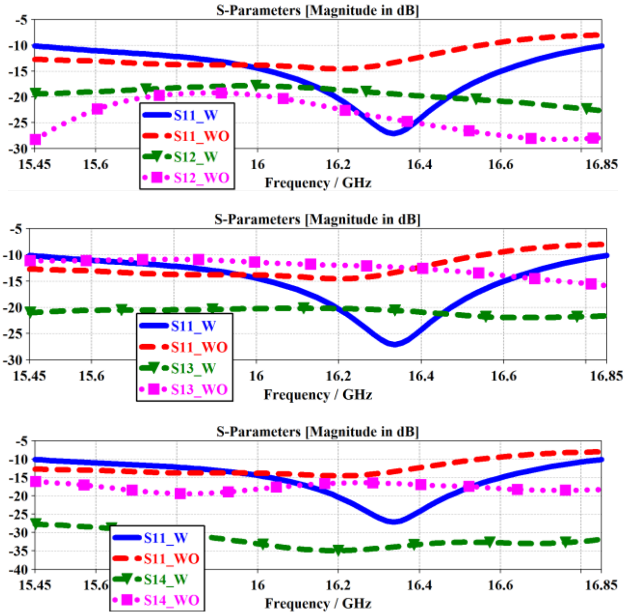


(c) Ground plane for both reference and proposed arrays

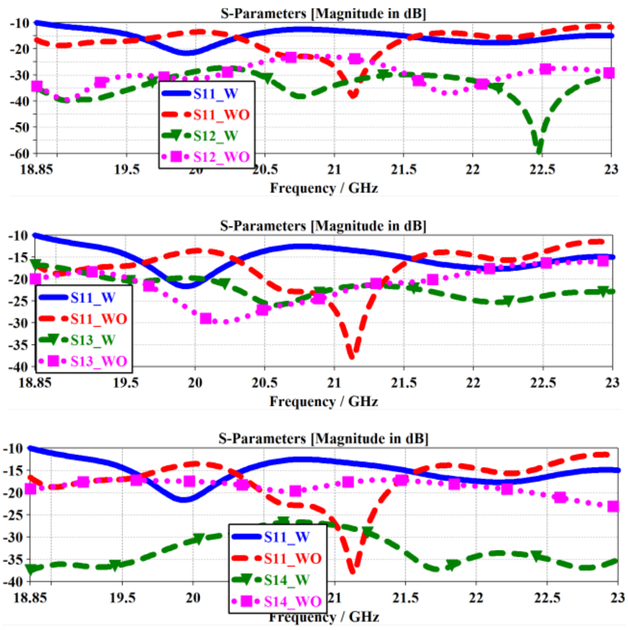
Fig.1. Configuration of the proposed waveguide slot array antenna



(a) First band from 12.95 to 13.75 GHz (Ku-band)



(b) Second band from 15.45 to 16.85 GHz (Ku-band)



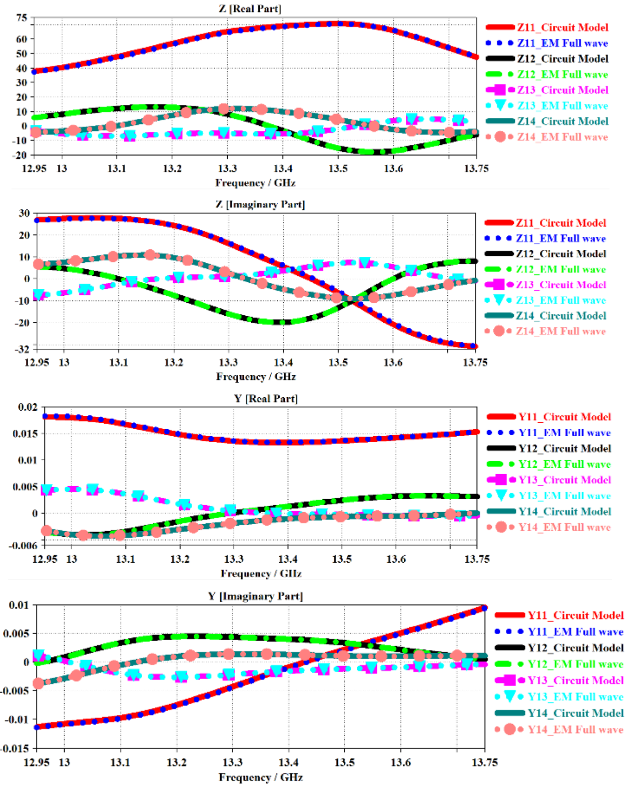
(c) Third band from 18.85 to 23 GHz (K-band)

Fig.2. S-parameters of the referenced and proposed waveguide slot array antennas without (WO) and with (W) linear slot isolators.

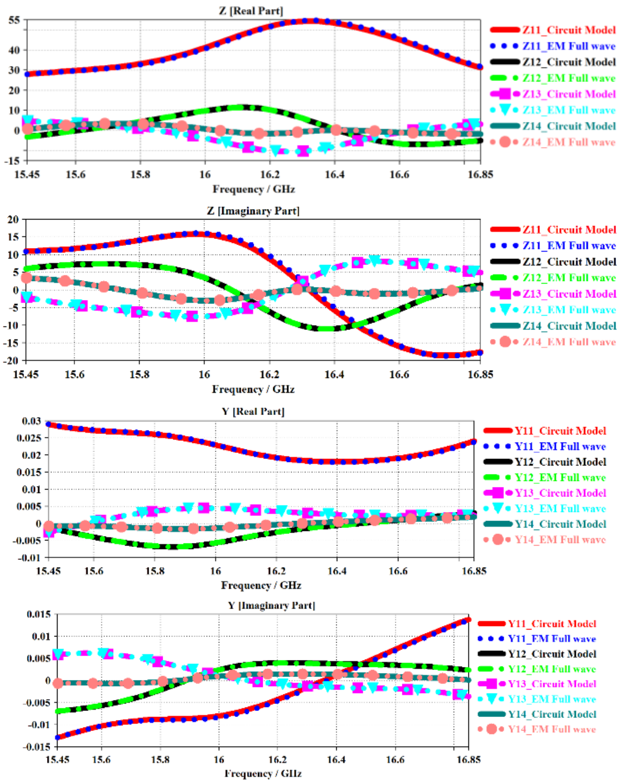
TABLE I. S-PARAMETRS OF THE SLOT ARRAY ANTENNAS

First band: 12.95 – 13.75 GHz (Ku-band), Δf=800 MHz, FBW=~6%	
Max. Suppression on S_{12}	-
Max. Suppression on S_{13}	24 dB @ 13.75 GHz
Max. Suppression on S_{14}	6 dB @ 13.5 GHz
Second band: 15.45 – 16.85 GHz (Ku-band), Δf=1.4 GHz, FBW=~9%	
Max. Suppression on S_{12}	-
Max. Suppression on S_{13}	10 dB @ 15.45 GHz & 15.8 GHz
Max. Suppression on S_{14}	20 dB @ 16.2 GHz
Third band: 18.85 – 23.0 GHz (K-band), Δf=4.15 GHz, FBW=~20%	
Max. Suppression on S_{12}	32 dB @ 22.5 GHz
Max. Suppression on S_{13}	7 dB @ 22.25 GHz
Max. Suppression on S_{14}	20 dB @ 21.7 GHz

The input impedance and admittance of the proposed waveguide slot antenna was analysed using circuit model and CST Microwave Studio in Fig.3. These results show very good correlation in input impedance and admittance responses between the circuit model and CST Microwave Studio.



(a) First Band



(b) Second Band

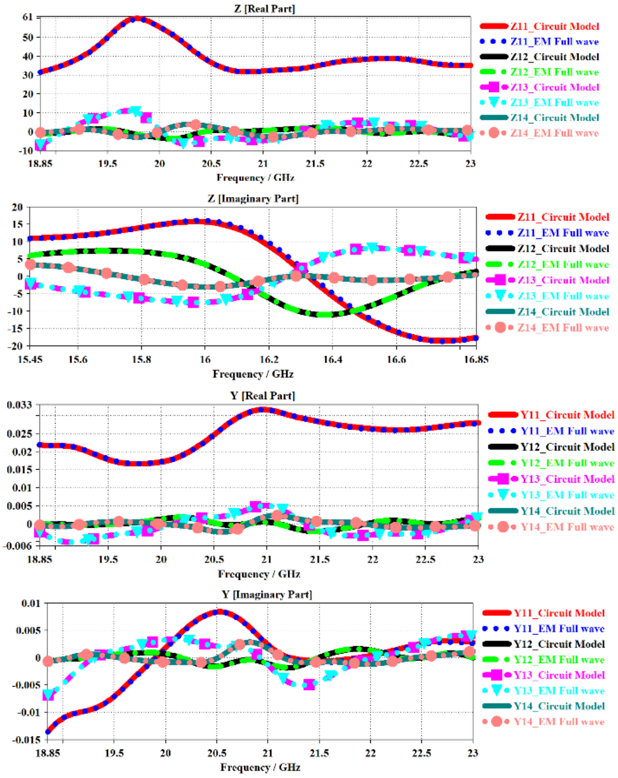


Fig. 3. Input impedance (Ω) & admittance (1/Ω) of the proposed slotted array antenna.

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.

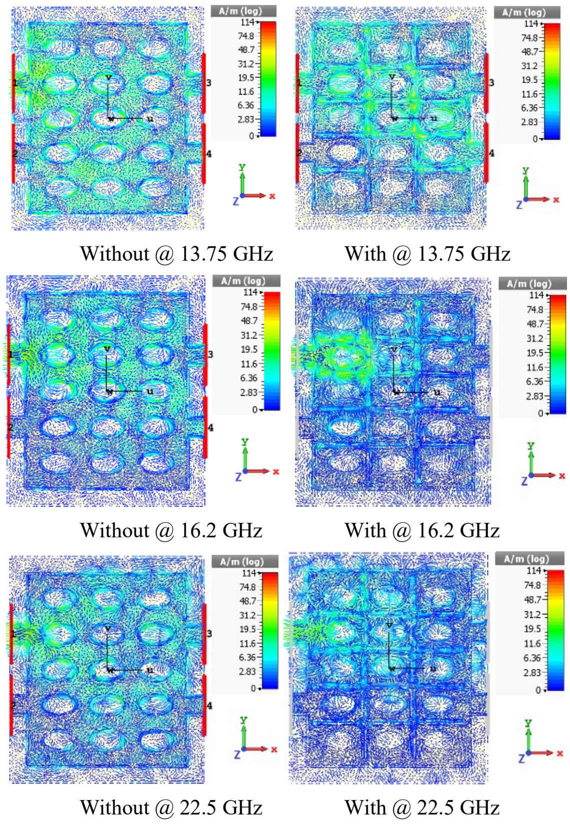


Fig. 4. Surface current distribution over the reference and slotted arrays.

Radiation patterns of the reference and proposed waveguide slot antenna arrays in the horizontal (H) and vertical (V) planes are shown in Fig. 5. After applying the proposed isolation slots to the waveguide antenna array the radiation pattern in the H-plane shows significant improvement in gain. Gain for the reference antenna varies from 4.3 dBi to 8.45 dBi, and with the slot isolators the gain varies from 6.6 dBi to 10.6 dBi. With application of slot isolators, the minimum and maximum gains improve by 53.5% and 25.5%, respectively.

The performance of the proposed technique is compared with other mutual coupling reduction mechanisms in Table II. 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. The proposed method offers a maximum isolation between radiating antennas of more than >30 dB, which is better than other techniques. The advantage of the proposed technique is its simplicity.

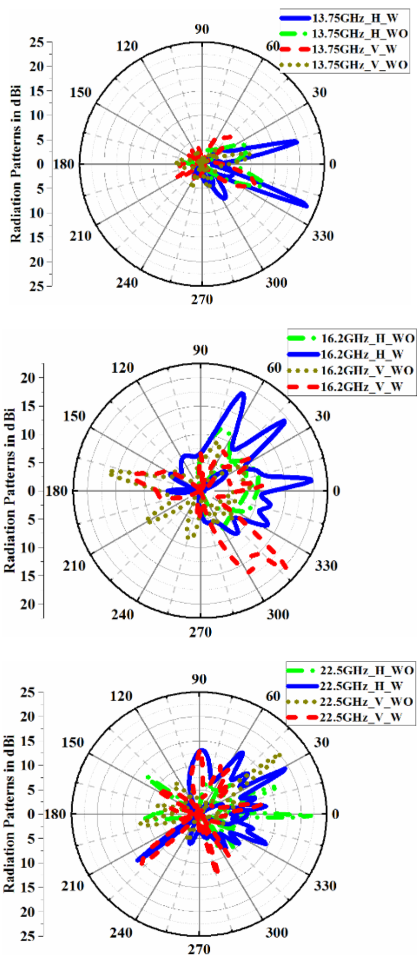


Fig. 5. Radiation patterns of the simple reference and proposed slot array antennas without (WO) and with (W) the proposed slot isolator in the horizontal (H) and vertical (V) planes at 13.75GHz, 16.2GHz, and 22.5 GHz.

TABLE II. COMPARISON BETWEEN THE PROPOSED ARRAY WITH RECENT WORKS

Ref.	Method	Max. isolation **improvement**	BW	Rad. pattern deterioration	Isolator
[16]	EBG isolator	8.8 dB	Narrow	-	Used
[17]	EBG isolator	10 dB	Narrow	Yes	Used
[18]	EBG isolator	10 dB	Narrow	Yes	Used
[19]	EBG isolator	4 dB	Narrow	Yes	Used
[20]	UC-EBG isolator	10 dB	Narrow	Yes	Used
[21]	U-shaped resonator decoupling slab	10 dB	Narrow	Yes	Used
[22]	Slotted meander-line resonator decoupling slab	16 dB	Narrow	Yes	Used
This Work	Slots	>30 dB	Wide (~20%)	No	Don't used

III. CONCLUSION

It is shown by introducing a linear slot between neighbouring waveguide slot antennas the mutual coupling between the array elements is significantly attenuated, in the case presented by 20 dB to 32 dB across Ku- and K-bands. In addition, the gain performance is significantly improved too. The proposed technique is simple to implement and should find application in MIMO wireless systems.

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