Mutual-Coupling Reduction in Metamaterial SIW Slotted Antenna Arrays Using Metal Fence Isolators for SAR and MIMO Applications

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Abstract*- A new type of mutual coupling reduction technique is applied to metamaterial substrate integrated waveguide (SIW) slotted antennas array. The circular shaped reference SIW antenna is constructed from Alumina substrate with dimensions of 40×5×1.5 mm^3. Embedded in the reference antenna is an array of 38 slots with dimensions of 2×1×1.5 mm^3. The reference SIW antenna covers six frequency bands from X- to Ku-bands with maximum and average isolation between the radiation slots of approximately -20 dB and -10 dB, respectively. Isolation was increased by inserting metal fences between the radiation slots, which also improves the antenna's impedance matching properties. Maximum, minimum, and average suppression on mutual coupling between radiation slots after application of the metal fences are 20 dB, 8 dB, and 13 dB, respectively. The proposed metal fence isolators (MFI) improve the radiation patterns without degrading the antenna's performance. With MFI the maximum gain achieved improves by ~10%. The technique is simple to implement and proposed for synthetic aperture radar (SAR) and multiple input multiple output (MIMO) applications.

Keywords*- Substrate integrated waveguide (SIW), mutual coupling reduction, metamaterial, slotted antenna arrays, metal fences isolators (MFI), circular waveguide.

I. INTRODUCTION

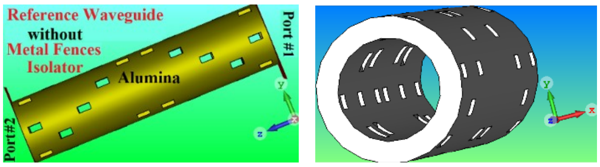
Substrate integrated waveguide (SIW) is becoming popular in cavity-backed slot antenna designs as it has advantages of low cost, low-loss, easy fabrication and integration with planar circuits [1],[2]. SIW based array antenna have been shown to achieve high gains [3]. This is because (i) SIW cavities functioning as slot radiators eliminate the need of feed network [4]; (ii) feed networks based on SIW have lower loss than those built using microstrips [5]; and (iii) isolation between array elements is improved with the closed-form SIW structure [6]. These attributes significantly reducing the complexity of array synthesis. Compared with other forms of antennas like bow-tie antennas, the limitation of slot antennas is their narrow bandwidth [7]-[12].

To overcome the bandwidth limitation and increase the isolation between the radiation slots, a SIW slotted antenna arrays (SIWSAA) design is proposed in this paper which is based on metamaterial technology [13]-[15]. The left-handed capacitance is shown to increase the bandwidth of SIWSAA without inflating the dimensions of the antenna [16],[17]. Furthermore, a novel technique is proposed to suppress the mutual coupling between the radiation elements with inclusion of metal fence isolators between the radiation elements.

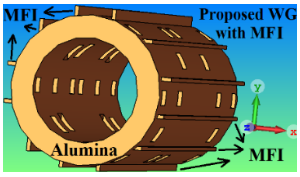
II. HIGH ISOLATION METAMATERIAL SIW SLOTTED ANTENNA ARRAY

The referenced metamaterial SIW slotted antenna array is shown in Fig. 1. The slots as a main part of radiation play the role of the left-handed capacitive (C_L) and inductive (L_L) properties with no need for metallic via-holes. Series right-handed inductor (L_R) and shunt right-handed capacitors (C_R) create unwanted currents that flow in the waveguide structure that result in voltage potential difference between the waveguide and the ground-plane. The reference slotted antenna is a circular waveguide that was constructed with Alumina substrate with a high dielectric constant (ε_r) of 9.9. The slotted circular waveguide antenna structure was embedded with 38 radiation slots. The dimensions of the substrate integrated circular waveguide slotted antenna array (SICWSAA) and the radiation slots are: 40×5×1.5 mm^3 and 2×1×1.5 mm^3, respectively.

S-parameter characteristics, reflection and transmission coefficients, of the reference SIWSAA are shown in Fig. 2. It is evident from these results the antenna can cover six frequency bands from X- to Ku-bands with a maximum and average isolation between the radiation slots of approximately -20 dB and -10 dB, respectively. To increasing the isolation between the radiation elements, metal fences were inserted between the radiation slots. This approach is shown to significantly improve reduction in mutual coupling between the radiation elements. The maximum, minimum, and average improvement in the isolation with MFI are 20 dB, 8 dB, and 13 dB, respectively. Details of the results are listed in the Tables in Fig. 2.

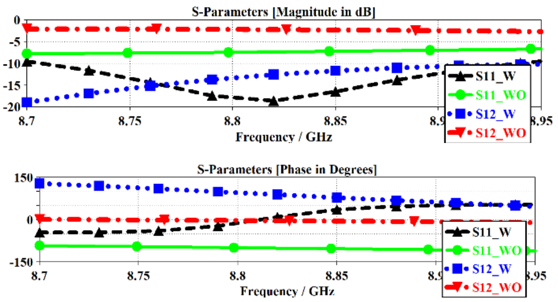


(a) Reference SIWSAA without MFI (top and front views)



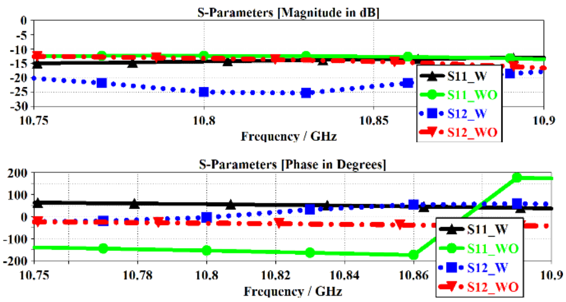
(b) Proposed SIWSAA with MFI

Fig. 1. Configurations of the reference SIWSAA and the proposed SIWSAA with MFI.



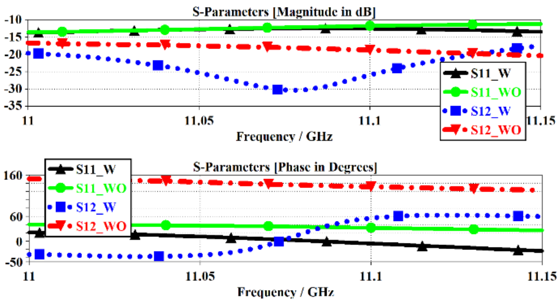
$\lvert S_{11}\rvert \leq -10dB$: 8.7-8.95 GHz, Δf=250 MHz, FBW=2.83%	
Max. Suppression (S_{12}) with MFI	18 dB @ 8.7 GHz
Min. Suppression (S_{12}) with MFI	7 dB @ 8.95 GHz
Ave. Suppression (S_{12}) with MFI	13 dB

(a) First band



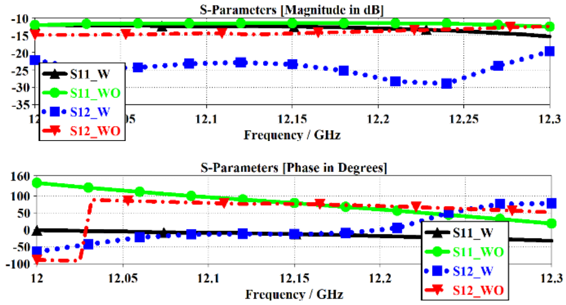
$\lvert S_{11}\rvert \leq -10dB$: 10.75-10.9 GHz, Δf=150 MHz, FBW=1.38%	
Max. Suppression (S_{12}) with MFI	12 dB @10.82 GHz
Min. Suppression (S_{12}) with MFI	8 dB @ 10.75 GHz
Ave. Suppression (S_{12}) with MFI	10 dB

(b) Second band



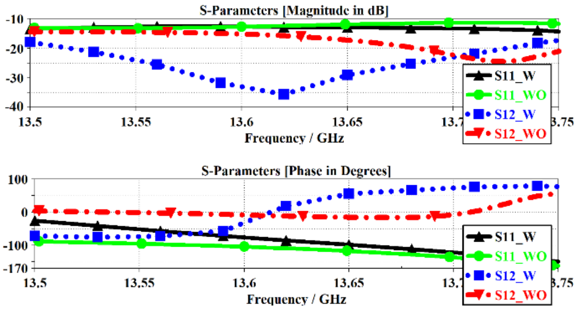
$\lvert S_{11}\rvert \leq -10dB$: 11-11.15 GHz, Δf=150 MHz, FBW=1.35%	
Max. Suppression (S_{12}) with MFI	14 dB @ 11.07 GHz
Min. Suppression (S_{12}) with MFI	4 dB @ 11 GHz
Ave. Suppression (S_{12}) with MFI	9 dB

(c) Third band



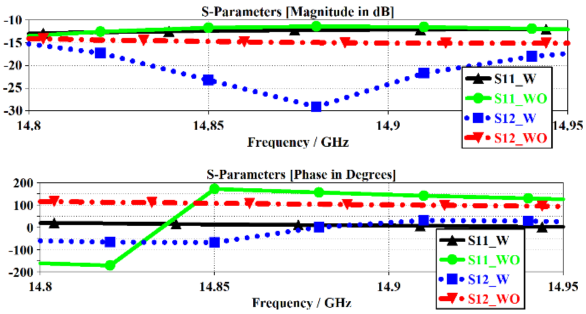
$\lvert S_{11}\rvert \leq -10dB$: 12-12.3 GHz, Δf=300 MHz, FBW=2.47%	
Max. Suppression (S_{12}) with MFI	16 dB @ 12.24 GHz
Min. Suppression (S_{12}) with MFI	8 dB @ 12.3 GHz
Ave. Suppression (S_{12}) with MFI	12 dB

(d) Fourth band



$\lvert S_{11}\rvert \leq -10dB$: 13.5-13.75 GHz, Δf=250 MHz, FBW=1.83%	
Max. Suppression (S_{12}) with MFI	20 dB @ 13.63 GHz
Min. Suppression (S_{12}) with MFI	6 dB @ 13.5 GHz
Ave. Suppression (S_{12}) with MFI	13 dB

(e) Fifth band



$\lvert S_{11}\rvert \leq -10dB$: 14.8-14.95 GHz, Δf=150 MHz, FBW=1.00%	
Max. Suppression (S_{12}) with MFI	15 dB @ 14.88 GHz
Min. Suppression (S_{12}) with MFI	3 dB @ 14.95 GHz
Ave. Suppression (S_{12}) with MFI	9 dB

(f) Sixth band

Fig. 2. S-parameter response of the reference and proposed substrate integrated circular waveguide slotted antenna array before and after applying MFI.

Maximum gain and phase response for the reference and proposed cases are shown in Fig. 3. The radiation characteristics of the proposed structure with and without MFI are shown in Fig. 4. The 2- and 3-Dimensional radiation patterns are at 8.7 GHz, 11.1 GHz, and 13.6 GHz. It is evident that the metal fence isolators greatly improve the radiation gain with negligible effect on the E- and H-plane radiation characteristics.

The above results show that the proposed substrate integrated circular waveguide slotted antenna array exhibits high isolation and operates over a large bandwidth covering X- to Ku-bands. This type of antenna is suitable for synthetic aperture radar (SAR) applications and multiple input multiple output (MIMO) systems.

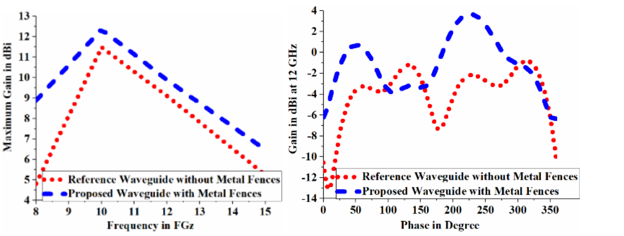
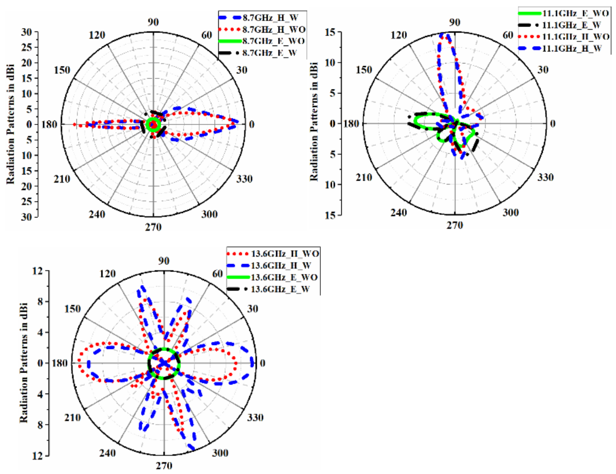
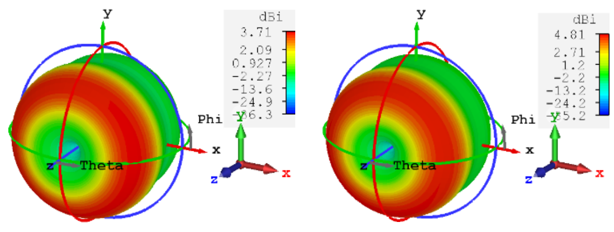


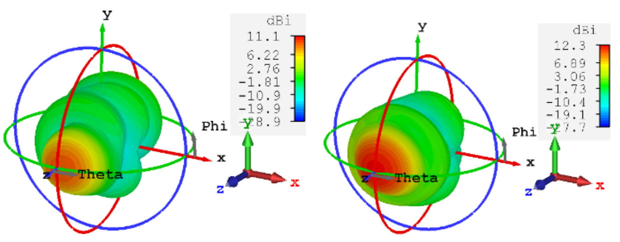
Fig. 3. (a) Maximum gain over frequency, and (b) phase response at 12 GHz.



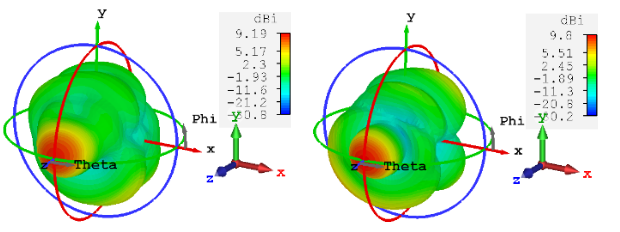
2-Dimensional radiation patterns



with no MFI @ 8.7GHz with MFI



with no MFI @ 11.1 GHz with MFI



with no MFI @ 13.6 GHz with MFI

3-Dimensional radiation patterns

Fig. 4. 2-D and 3-D radiation patterns.

III. Conclusion

It is demonstrated that metamaterial substrate integrated waveguide (SIW) slotted antennas array can operate over a very large frequency range (X- to Ku-band), and with application of metal fence isolators between the slots the mutual coupling between the slots is significantly reduced. Average reduction in isolation over its operating frequency range is approximately -20 dB.

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