EM Isolation Enhancement Based on Metamaterial Concept in Antenna Array System to Support Full-Duplex Application

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***Abstract*– This paper proposes EM mechanism to improve the isolation between transmitting and receiving array antennas using metamaterial EM band gap (MTM-EBG). The proposed mechanism can be applied to full-duplex array antenna system with very closely spaced arrays (0.33λ_0) with no degradation in radiation pattern. Using the proposed technique the isolation is shown to improve by >30 dB in an antenna array consisting of three-element microstrip patches designed to operate across 9.7 to 12.3 GHz. Parametric analysis was used to optimise the decoupling arrays performances. The proposed antenna array has physical dimensions of 65×22.5×1.6 mm^3 and an electrical size of 2.16λ_0×0.75λ_0×0.053λ_0, where λ_0 is free space-wavelength at mid-band of 10 GHz.**

***Keywords*– Mutual coupling suppression, metamaterial, electromagnetic band gap, decoupling arrays, isolation enhancement, full-duplex wireless transceivers.**

I. INTRODUCTION

In full-duplex applications mutual coupling between the nearby transmitting and receiving antennas results in correlation between the transmitted/received signals, which can significantly degrade the radiation and efficiency characteristics of the antenna [1]. This is because of excitation of surface wave modes [2] that result in mutual coupling between adjacent E-plane coupled microstrip antennas especially when the gap between the antennas is greater than 0.3λ_0 [3]. Numerous techniques have been proposed to date to reduce the mutual coupling between adjacent nearby antennas including (i) using shorting patches to prevent the excitations of the surface waves [4], (ii) using cavity backed slots [5], and (iii) using parasitic elements isolators [6]. Also, metamaterial insulators for small size antennas have been suggested using negative effective permittivity and permeability [7],[8], or reversal of current through the metamaterial radiators [9]. In [10] a parasitic isolator, which is printed between the two patches, is used to suppress mutual coupling. The parasitic isolator controls the polarization of the coupling field to reduce the antenna coupling. Furthermore, a defected ground structure is employed to suppress the cross-polarization level. The measured results show that, at the resonant frequency, the achieved isolation enhancement is 19.6 dB.

In this paper the effectiveness of using metamaterial EM band gap technique to suppress mutual coupling between array elements is demonstrated. Isolation between three elements of a microstrip antenna array is improved by >30 dB. This is based on combining multiple MTM-EBG decoupling slabs in the array antenna. In addition, by applying this technique size reduction is achieved as the gap between neighbouring antennas can be reduced by ~15%. The three-element antenna array, which was designed to operate across 9.7 to 12.3 GHz, has dimensions of 65×22.5×1.6 mm^3, and can be applied in the implementation of full-duplex radar.

II. ISOLATION ENHANCEMENT BETWEEN ANTENNA ARRAY ELEMENTS

Geometry of the three-element antenna array without MTM-EBG decoupling slab is shown in Fig. 1. The structure was constructed on FR-4 substrate with dielectric constant of ε_r= 4.3, thickness of h = 1.6 mm and tanδ = 0.025. The antenna array is composed of three identical circular patches with radius of 15 mm. The proposed antenna array was designed to operate from 9.7 GHz to 12.3 GHz, which corresponds to a fractional bandwidth of 23.63%. The average isolation between the radiating elements over its operating range is -17 dB.

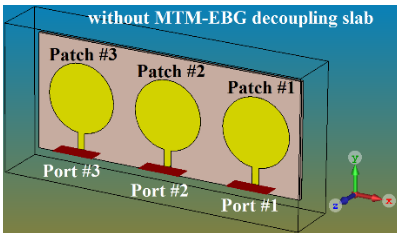
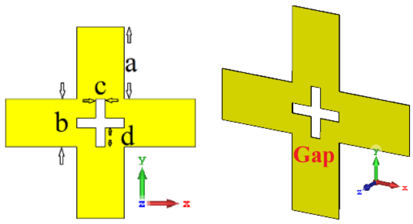


Fig.1. Antenna array constructed with three identical circular patches without MTM-EBG decoupling slab.

To improve the isolation between antenna array elements MTM-EBG decoupling slab is employed. The MTM-EBG is a 'cross' shaped conductor with a cross shaped slot located at its center, as shown in Fig.2. The MTM-EBG decoupling slab is inserted between the circular patches, as depicted in Fig.3.



(a) (b)

Fig.2. Single symmetrical metamaterial electromagnetic band gap (MTM-EBG) decupling slab, a) top view, and b) isometric view.

The average EM isolation between the antenna array elements with MTM-EBG decoupling slab is -27 dB over its operating range. By inserting MTM-EGB in the antenna array the isolation between the neighbouring radiating elements improved by 59%.

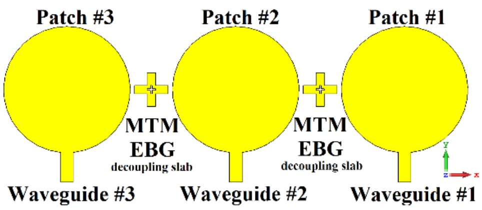
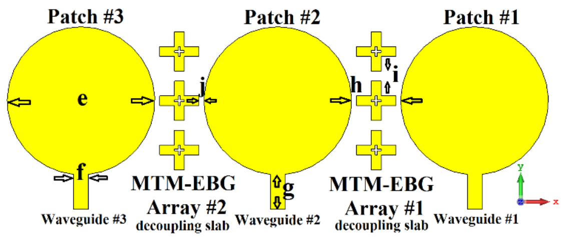
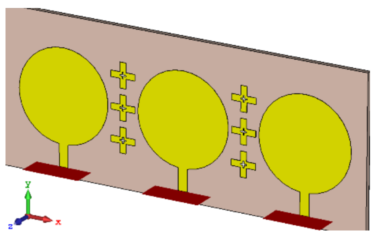


Fig.3. Antenna array with MTM-EBG decoupling slabs located between the radiating elements.

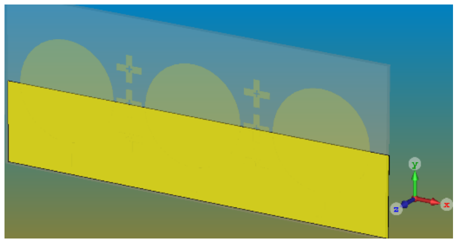
The effect of increasing the number of MTM-EBG was also investigated. Fig.4 shows MTM-EBG was increased to three. The dimensions of the antenna array and MTM-EBG decoupling slab are given in Table I. Fig.5 shows how the S-parameter performance of the antenna array is effect by the number of MTM-EBG. In all cases the antenna array operates over a frequency range from 9.7 to 12.3 GHz. In addition, the antenna match is optimum at f_{r_1}=10.0 GHz and f_{r_1}=11.6 GHz with reflection coefficient of -25 dB and -37 dB, respectively. Average mutual coupling reduction is -17 dB with three MTM-EBG, which is an improvement by 20 dB with a single MTM-EBG. The minimum and maximum isolation between radiation patches in this case are -25 dB and -45 dB, respectively.



(a) Top view



(b) Isometric View

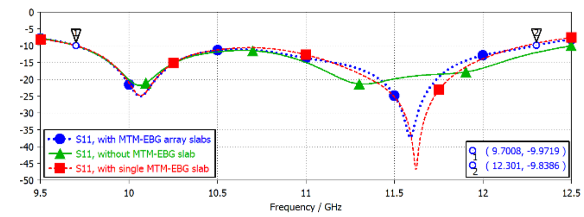


(c) Antenna array's ground plane

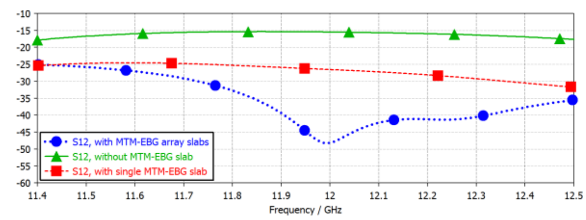
Fig.4. Proposed antenna array constructed using three identical circular radiating patches with MTM-EBG decoupling slabs.

TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA ARRAY (Dimension are in millimetres).

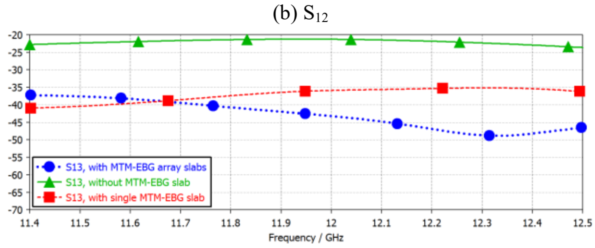
a	b	c	d	e	f	g	h	i	J
3	2	0.4	0.75	15	3	7.5	10	2	1



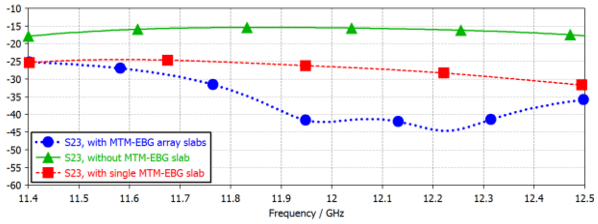
(a) S_{11}



(b) S_{12}



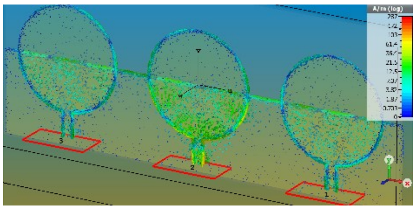
(c) S_{13}



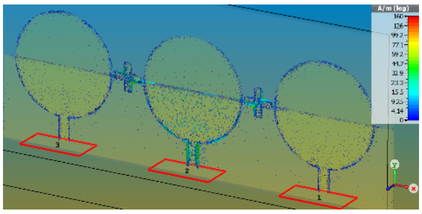
(d) S_{23}

Fig.5. S-parameters performance of the antenna array with three MTM-EBG.

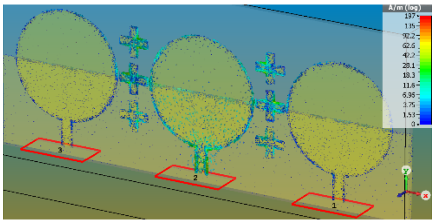
The overall dimensions of the antenna array with MTM-EBG decoupling slab is 65×22.5×1.6 mm^3 corresponding to the electrical size of $2.16\lambda_0 \times 0.75\lambda_0 \times 0.053\lambda_0$, where λ_0 is free space-wavelength at mid-band of 10 GHz.



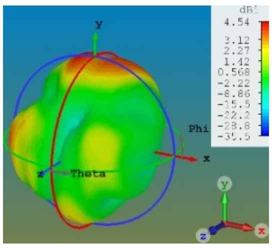
(a)



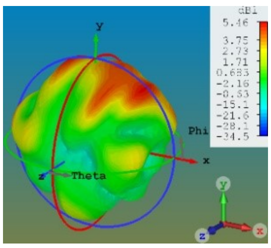
(b)



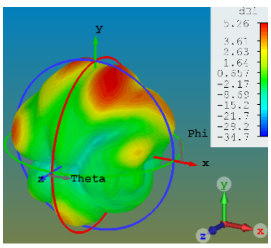
(c)



(d)



(e)



(f)

Fig.6. Antenna array's distributed surface currents and 3-D radiation patterns at resonance frequency of 10 GHz, a) distributed surface current without MTM-EBG decoupling slab, b) distributed surface current with single MTM-EBG decoupling slab, c) distributed surface current with array of MTM-EBG decoupling slabs, d) 3-D radiation pattern without MTM-EBG decoupling slab, e) 3-D radiation pattern with single MTM-EBG decoupling slab, and f) 3-D radiation pattern with array of MTM-EBG decoupling slabs.

For greater insight, the simulated E-field magnitude profile before and after applying the MTM-EBG decoupling structure are shown in Figs. 6 (a–c). This shows the propagating E-field is not allowed to be coupled to the nearby antennas, which confirms the effectiveness of the proposed technique in mitigating surface waves. The antenna radiation pattern is enhanced by applying this technique as is evident in Figs. 6 (d–f). 3-D radiation pattern shows greater directivity and efficient behaviour after applying the proposed MTM-EBG decoupling structure. In particular, the maximum gain increased from 2.7 dBi to 6.5 dBi. The antenna array was analysed using full wave Microwave CST studio.

III. Conclusion

Isolation between nearby antenna can be substantially improved (>3 dB) by simply incorporating an arrangement of metamaterial EM band gap (MTM-EBG) decoupling slab between the radiating elements. This is because the proposed MTM-EBG can effectively suppress surface wave modes created on the microstrip antenna. The proposed technique can be applied in the implementation of full-duplex radar as well as in phased array antennas.

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