A Low Mutual Coupling MIMO Antenna Using Periodic Multi-Layered Electromagnetic Band Gap Structures

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Abstract **─** A multi-layered electromagnetic band gap (EBG) structure is proposed and incorporated into a MIMO antenna to reduce unexpected mutual coupling between antenna elements. The proposed multi-layered EBG (ML-EBG) structure is comprised of an improved EBG and three loading patches with a same distance. The proposed ML-EBG structure is designed at 2.55 GHz and it is utilized in a MIMO antenna array with an edge-to-edge distance of 0.13λ to reduce the mutual couplings. The simulated and measured results have been put forward to prove that the mutual coupling has been reduced by 30 dB between the antenna elements compared to the MIMO antenna without the ML-EBG structure.

Index Terms **─** MIMO antenna, multi-layered electromagnetic band gap, mutual coupling reduction.

I. INTRODUTION

Mictrostrip antennas have been becoming an useful technology and a hot topic in wireless communication systems in the past decades [1-4] since they are small, light and low profile. Moreover, the microstrip antennas are easy to incorporate into a practical application to form a conformal antenna and they can be implemented to create multi-band antenna and circular polarization antennas [5-8]. In particular, the microstrip antennas are easy to integrate into a unified component with active devices and microwave circuits [9-10], rendering them suitable for various wireless communication applications.

With the development of the wireless communication techniques, MIMO techniques have been attracting much more attention for next-generation applications [11-12]. MIMO antennas are to use in the future portable devices. Since the space of the portable device is limited, the configuration of the multiple antennas is difficult [13-14] to install in such a limited device. As a MIMO antenna aimed to use in wireless portable terminal, the distances between the antenna elements are narrow. Thus, the mutual coupling between the array elements is high [15-18]. After that, the mutual coupling reduction technology is urgent to be boosted. In recent years, a great number of techniques have been presented to reduce the mutual coupling between MIMO antenna elements, such as orthogonal structure [19], electromagnetic band gap (EBG) [20-26]. However, some of them have large array element distances, while others have high mutual coupling between array elements. Several amazing techniques have been reported to reduce the mutual coupling of a MIMO antenna. In [20], a double-layer EBG structure has been introduced into a MIMO antenna to achieve a low mutual coupling. In [21], a slit-patch EBG structure has been presented, which provides a significant mutual coupling reduction between a wide band UWB antennas. Then, miniaturized convoluted direction opening conversed slits have been proposed for reducing the mutual coupling between PIFA antenna elements. The size of each convoluted slit is about one-quarter wavelength and the convoluted direction opening conversed slits give strong effects on the mutual coupling between the PIFA antenna elements. In [22-23], split-ring structured EBGs have been investigated for MIMO antenna coupling reduction. However, the antenna sizes are large. Then, a soft surface has been designed for antenna array decoupling [24]. The coupling has been reduced by about 9 dB with a large antenna size and three stripes. In [25], a multi-layers EBGs have been proposed with a coupling reduction of 24dB at the center frequency. Then, an improved EBG structure has been resented in [26] for a mutual coupling reduction of 26 dB. We can see that the coupling reductions of these antenna arrays are limited and some of them have large sizes. Additionally, a conformal antenna with a coupling reduction has been reduced by using slots. However, it is an un-planar antenna which is difficult to integrate into a portable terminal [27].

In this paper, a multi-layered electromagnetic band gap (ML-EBG) structure is proposed and it is integrated

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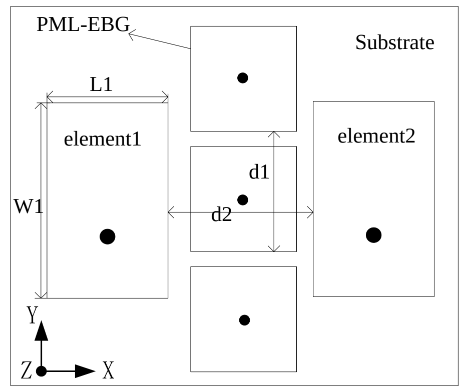
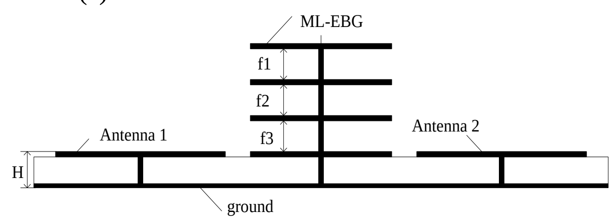
into a two-element MIMO antenna array to verify its effectiveness for array mutual coupling reduction. First, the MIMO antenna supported by two same rectangle patch antennas are presented with an edge-to-edge distance of 0.13λ. Next, a periodic ML-EBG structure is placed in the center of the MIMO antenna array. The ML-EBG is designed to be four layers and each layer is connected via a shorted pin. The proposed MIMO antenna with ML-EBG is created and simulated by using the HFSS, fabricated and measured in a chamber. The simulated and measured results have been put forward to verify that the isolation has been improved by 30 dB between the adjacent antenna elements compared to the MIMO antenna without the ML-EBG structures.

II. ANTENNA DESIGN

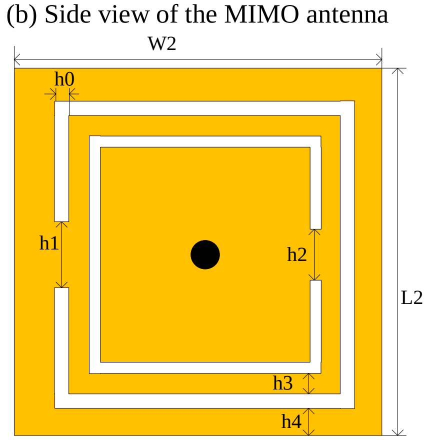
A ML-EBG structure is proposed and utilized in a MIMO antenna to reduce the mutual coupling between the MIMO antenna elements. The proposed ML-EBG is a 3-D structure. The first layer of the proposed ML-EBG together with the two rectangle patches are printed on a substrate with a permittivity is 4.4, loss tangent is 0.02, and the thickness of 1.6 mm. The other three layers are loaded on the first layer with a uniform distance of 1.6 mm. All the four layers are connected from the upper layer to the bottom layer via a shorted pin which is connected with the ground plane of the MIMO antenna. A great number of works has been done to optimize the number of the layers and the distance between each layer by using the HFSS. The numbers of the layers and the distance are chosen based on the lowest coupling between the antenna elements with respect to S21. The proposed MIMO antenna with ML-EBG is shown in Fig. 1. It is found that the ML-EBG and the two identical patch antennas are installed on the top of the substrate, while there is a ground plane on the bottom of the substrate. The distance between the edge-to-edges of the two identical patch antennas is 0.13λ. Furthermore, three identical ML-EBG cells are installed on the middle of the two-element MIMO antenna array. In this paper, the MIMO antenna array is operated at 2.55 GHz. The initial patch antenna element is obtained from the results [28] and the two patch antenna elements are symmetrically placed on each side of the ML-EBG structures. The ML-EBG can provide a band gap characteristic on the same frequency of the operating band of the MIMO array. It is worth noting that the upper of the ML-EBG is a general rectangle patch, while the other three layers are rectangle patch with split-ring slots shown in Fig. 1 (c), which is to enhance the performance of the proposed coupling reduction structure. The proposed MIMO with ML-EBG is optimized and the related parameters are: L1=28.3mm, W1=15.5mm, d1=15.5mm, d2=15.5mm, f1=f2=f3=H=1.6mm, L2=W2=14mm, h0=1mm, h1=3mm, h2=2mm, h3=0.4mm, h4=1.4mm.



(a) MIMO antenna with ML-EBG structure



(b) Side view of the MIMO antenna



(c) The layers except top of ML-EBG

Fig. 1. Configuration of the proposed MIMO antenna with ML-EBG structures.

III. PERFORMANCE OF THE MIMO ANTENNA WITH ML-EBG STRUCTURES

A. Dispersion diagram of the proposed ML-EBG

Since EBG structure has an ability to suppress surface wave, it can be regarded as an obstacle for special frequency band. Thus, the EBG structure has been used in the middle of a MIMO antenna for coupling reduction applications because the current from one antenna to another antenna will be blocked. The electromagnetic band gap characteristic of the ML-EBG structure shown in Fig. 2 is obtained by the HFSS. T, X and M are the symmetric points in the irreducible Brillouin zone, which can be seen in [28-30]. It can be seen that the frequency band from 2.25 GHz to 3.0 GHz is a band gap which is to suppress the expected surface current.

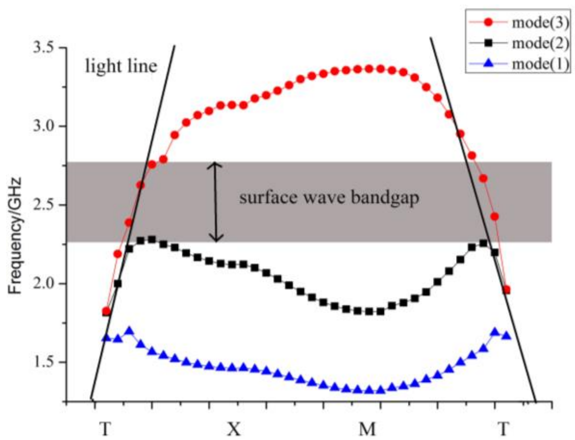


Fig. 2. Characteristic of the proposed ML-EBG.

B. Effects of the ML-EBG

From the characteristic analysis of the proposed ML-EBG, a MIMO antenna is designed, which integrated three ML-EBG cells between the two antennas. Figure 3 illustrates the performance of the MIMO antenna with ML-EBG cells. For the sake of comparison, the MIMO antenna without the designated ML-EBG is also investigated by using the HFSS. The reflection coefficients of both the MIMO antennas with or without the ML-EBG are almost same. It is also found that the bandwidth of the MIMO antenna with ML-EBG cells becomes slightly narrow. However, the mutual coupling of the MIMO antenna with ML-EBG cells between the two antenna elements is reduced according to the S21. It can be seen that the coupling is reduced from -15 dB to -45 dB, which means the isolation of the two-element MIMO antenna achieves an isolation improvement of 30 dB. Thus, the proposed MIMO antenna can provide a high isolation without effects on its bandwidth.

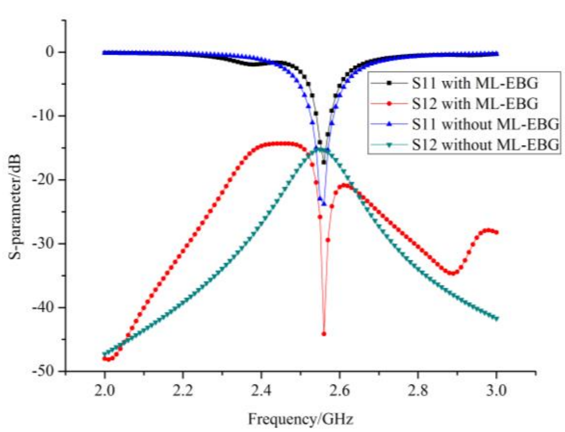


Fig. 3. The MIMO antenna with ML-EBG.

To understand the effects of the ML-EBG, parameter h0,h1,L2 are used for evaluating the performance of the isolation of the MIMO antenna. Figure 4 shows the effects on the isolation with various h0. It is found that the characteristic of the ML-EBG is changed. As h0 ranges from 1.2 mm to 2.0 mm, the band gap rejection frequency moves to high frequency. This is because the h0 changes the resonance characteristics of the split-ring resonator, which results in the band gap frequency shifts to higher frequency from 2.52 GHz to 2.61 GHz. The effects of h1 on the isolation of the MIMO antenna are discussed in Fig. 5. We can also see that the center frequency of rejection band gap frequency band shifts to high frequency. Figure 6 gives the effect of parameter L2 which is the width of the ML-EBG structure. It is observed that the rejection center frequency shifts from high frequency to low frequency with an increment of L2, which is opposite to the shift direction of the h0 and h1. Thus, the ML-EBG can provide a flexible band rejection characteristic to implement the mutual coupling reduction in MIMO antenna array.

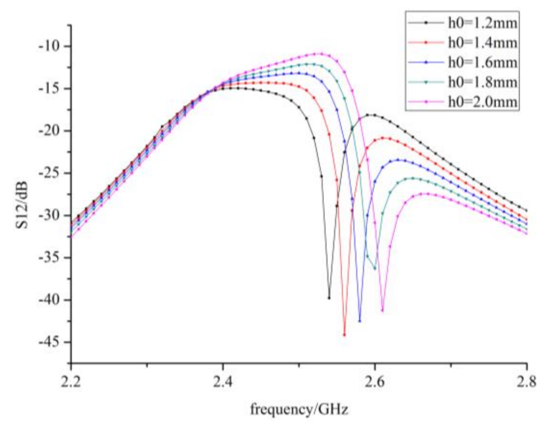


Fig. 4. Effects on the isolation of the MIMO antenna with various h0.

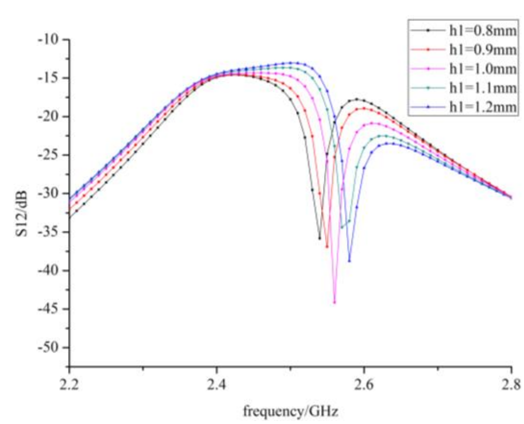


Fig. 5. Effects on the isolation of the MIMO antenna with various h1.

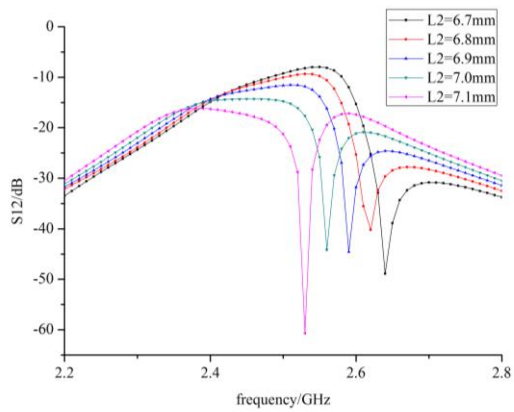
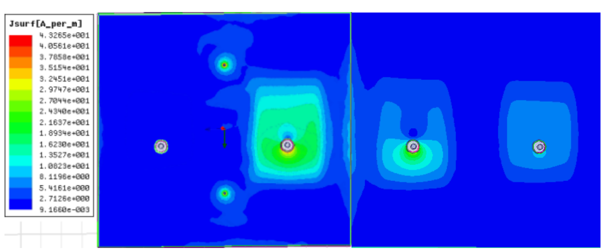


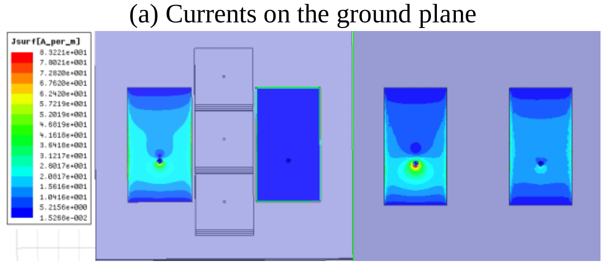
Fig. 6. Effects on the isolation of the MIMO antenna with various L2.

C. Current distribution

The current distributions on the patch antenna of the ground plane and MIMO antenna are shown in Figs. 7 (a) and (b), respectively. Figure 7 (a) shows the current distribution on the ground plane mainly focuses on the left antenna when the MIMO antenna has ML-EBG cells. The current distribution on the ground plane of the MIMO antenna without the ML-EBG flows along the feedings of the two patch antennas. Similarly, the current on the patch antenna concentrates on only one antenna, while the current on the other is very small. However, the currents on the patch antennas of the MIMO antenna without ML-EBG distribute on both antennas. Thus, we can say that the ML-EBG structure effectively suppresses the surface current on the common ground plane of the designed MIMO antenna, and hence, the isolation of the proposed MIMO antenna is significantly improved.



(a) Currents on the ground plane

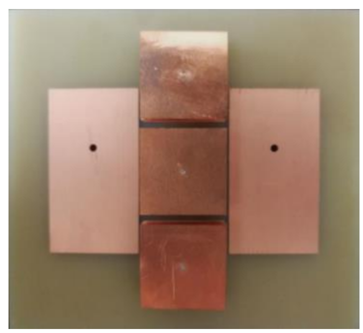


(b) Currents on the patch antennas

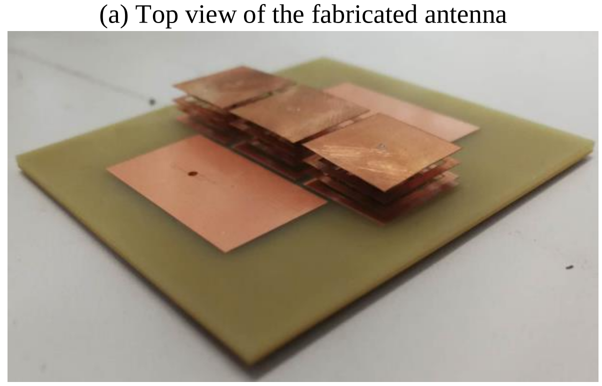
Fig. 7. Current distributions of the proposed MIMO antenna.

IV. SIMULATION AND MEASUREMENT RESULTS

In order to fully understand the ML-EBG-based mutual coupling reduction in the MIMO antenna, the optimized MIMO antenna is fabricated and measured in a chamber. The fabricated MIMO antenna integrated with the ML-EBG cells are given in Fig. 8. The results are obtained by using a HP8510C vector network analyzer and the radiation patterns are gotten in a chamber, of the ML-EBG cells. Additionally, the effects of the return loss shift and the radiation patterns may come from the EBGs which affect the wave propagation. In this paper, although the return loss has little effects on the coupling between the two antenna elements has been significantly reduced. The radiation patterns of the proposed MIMO antenna with ML-EBG structure has been measured and shown in Fig. 10. In the measurement, one antenna is excited while the other one is terminated with a 50-Ohm load. It can be seen that the proposed MIMO antenna has independent directional radiation pattern in both E- and H-plane (XOZ- and YOZ- plane). Thus, our proposed antenna is suitable for portable terminal applications.



(a) Top view of the fabricated antenna



(b) Side view of the fabricated antenna

Fig. 8. Fabricated MIMO antenna with ML-EBG decoupling structures.

The size of the MIMO antenna array and the decoupling effects with different EBGs are compared in Table 1. We can see that the proposed antenna has a smallest edge-to-edge distance of 0.13λ, which is same as that of the referred antenna in [26]. Although the proposed antenna is a little higher than the referred antenna in [26], the proposed antenna has a coupling reduction of 6 dB in comparison with the antenna in [26]. Moreover, the proposed ML-EBG provides the highest isolation for decoupling in a MIMO antenna.

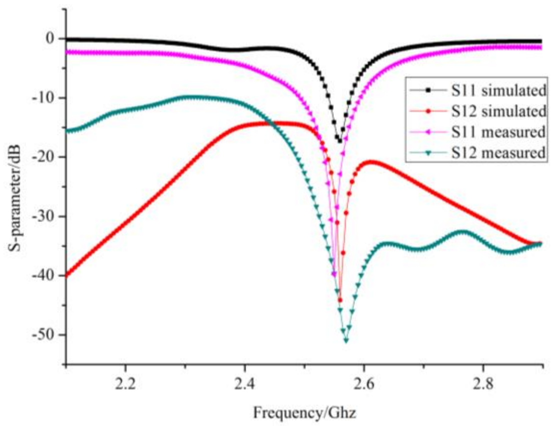


Fig. 9. Measured reflection coefficients and isolation of the proposed MIMO antenna with ML-EBG.

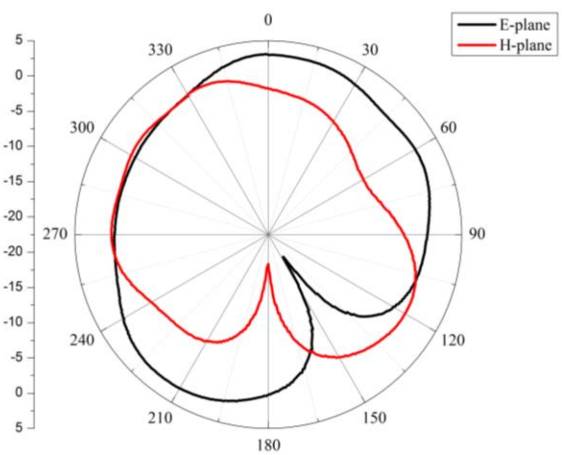


Fig. 10. Radiation patterns of the proposed MIMO antenna with ML-EBG.

Table 1: Comparisons of the decoupling structure with different EBGs

Article	Distance Between Antennas (λ)	Central Frequency (GHz)	Decoupling (dB)
[22]	0.25	5	15
[23]	0.8	13	20
[24]	0.6	1.92	12
[25]	0.47	5.1	20
[26]	0.13	2.55	26
This paper	0.13	2.55	31

V. CONCLUSION

A ML-EBG structure has been proposed and incorporated into a MIMO antenna to verify its performance in surface wave suppression. The band gap characteristics and the key parameters for controlling the ML-EBG has been presented and investigated in detail. The numerical and experimental results have been put forward to verify the effectiveness of the ML-EBG decoupling structure in a two-element MIMO antenna array. The results showed that the two-element MIMO antenna array with an edge-to-edge distance of 0.13λ achieved an isolation of 30 dB by using the proposed ML-EBGs, which means that the mutual coupling reduction is about -30 dB by using the ML-EBG cells. Thus, the proposed antenna can be used for indoor small mobile terminal applications.

ACKNOWLEDGEMENT

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