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Mutual Coupling Reduction in Antenna Using EBG on Double Substrate

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Abstract

In this paper, a mutual coupling study is conducted between two-element array antenna on dual substrate. A single patch antenna is firstly designed on dual substrate layer to testify appropriate performance at 2.45 GHz. Subsequently, an array of two element patches on dual substrate are constructed with one of them is incorporated with three EBG unit cell on the bottom substrate. The radiating patch is on the top substrate, while the EBG unit cell is on the bottom substrate. With EBGs in separate layers from the antenna array, the antenna elements are closely separated by a distance of 22 mm with a significant reduced mutual coupling of -26.61 dB. This corresponds to a distance reduction of 34.68%. The proposed structure implemented only three EBG unit cells. Apart from that, the study of overlapped case of EBG with the antenna is also presented.

Keywords: *antenna array, dual substrate, mutual coupling, overlapped distance*

1. Introduction

The metamaterial is a composite material which mimics the unique characteristic of a material not available in nature [1]. The unique charactericstic is achieved by the modification of the material structure rather than the type of the dielectric material used. Metamaterials are often implemented in the periodic or repetitive form of unit cells. There are many types of metamaterial including electromagnetic band gap (EBG), artificial magnetic conductor (AMC), double negative (DNG) or double positive (DPS) material, electric LC (ELC) and split ring resonators (SRRs) [2, 3]. EBG is a resonant metamaterial that able to suppress the propagation of surface wave on the dielectric substrate. The surface waves of frequencies are suppressed if the frequencies are within the band gap region of the EBG. This unique characteristic of EBG can be used to manipulate the electromagnetic behaviour in microwave design.

An array antenna consists of more than 2 antenna elements. Conventionally, to reduce the mutual coupling between elements of an antenna, a given element needs to have a gap of minimum lambda/2 with any other element. If the distance between the antenna element is too close (≤ Lambda/2), the mutual coupling will become greater and so significant that it may degrade the antenna performance [4]. The coupling can cause scan blindness, mismatches between feeding networks and the array elements and loss of bandwidth [5]. In thicker and higher dielectric substrate, the mutual coupling between the antenna elements is higher due to strong excitation of surface wave [6]. However, thicker substrates with higher permittivity are preferred in modern wireless communication requires an antenna that are compact in size such as in MIMO application [7]. Therefore, mutual coupling is an important factor to be considered in designing array antenna. The mutual coupling can be represented by the S21 parameter in two-element array antenna design.

In [8], the author manage to reduce the mutual coupling between antenna elements by implementing three layer substrate which disturbs the power flow between the radiators at the inter-element distance of 0.406 lambda(L), thus reducing mutual coupling to -16.4 dB at 2.4 GHz. However, the reported structure has a high total thickness of 14.78 mm due to three substrate layer used, increase cost due to different substrate used, and antenna with more substrate layer will prone to more misalignment factor in the fabrication stages. In [9], mutual

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coupling reduction with EBG is achieved at 2.52 GHz, whereby the coupling is -17.98 dB as compared to the array antenna without EBG, which is -11.39 dB. However, the spacing between elements is 34 mm and 5 EBG unit cells are required just to reduce mutual coupling by 6.59 dB. Apart from that, the design of EBG which located in between the antenna elements and on the same substrate with the radiating antenna limits the minimum separation distance achievable between the antenna elements. Thus, the overall antenna dimension cannot be minimised further.

In this paper, a dual element array antenna with and without EBG are discussed. The two antenna arrays are designed on the dual substrate layer. The antenna radiating part is located on the top substrate while EBG is located on the bottom substrate layer. The EBG array is consists of only three unit cells. With the use of dual layer design, the antenna element can be placed closer to each other with greater mutual coupling reduction. This is achievable with EBG which is not conventionally located in between and on the same substrate layer with the antenna. Apart from that, this paper also studied on the overlapped case between the antenna elements and EBG. To the best of our knowledge, the case has never been discussed in the previous research.

2. EBG Unit Cell and Antenna Designs

The design of square EBG unit cell and the antenna incorporated with EBG are simulated using the full wave simulation in Computer Simulation Technology (CST) 2015. Fr4 with permittivity 4.5, thickness 1.6 mm and copper thickness 0.035 mm is used as the substrate. The approximation of λ/2 is used as the initial dimension of the EBG unit cells in the simulation. The design of EBG unit cells is shown in Figure 1(a). The suspended transmission line method with 3 EBG unit cells, as shown in Figure 1(b), is used to examine the bandgap characteristics, S21 of the EBG unit cells. The suspended transmission line method consists of two substrate layers which the 50 Ω transmission lines is positioned on the top substrate layer, with each end are connected to the Subminiature Version A (SMA) port, namely Port 1 and Port 2. The bottom layer consists of three EBG unit cells, with each via connected the cells to the ground at the back side of the bottom substrate layer. There is no air gap in between the two layers of the substrate. Figure 1(c) shows the S21 and S11 of the EBG unit cells in the suspended transmission line method. The EBG have a -20 dB band gap from 2.37 GHz to 2.69 GHz with -26.18 dB at 2.45 GHz. At this band gap, the propagation of surface wave at 2.45 GHz will be suppressed and these properties will be used in the mutual coupling reduction in between the antenna elements.

A single element antenna on dual substrate layer is designed as shown in Figure 2(a) and Figure 2(b). The antenna is matched with the feeding line using inset feed technique. Unlike conventional antenna which is designed on the single substrate layer, the proposed antenna design is consists of the dual substrate layer with ground located on the back side of the bottom substrate layer. The air gap, G of 0.035 mm in between of the top and bottom substrate layer, which is equivalent to the thickness of the EBG unit cells that will be used in the later studies. The air gap value is kept constant for all the subsequent design. At this stage, the single antenna design is done to ensure the single element antenna is working at 2.45 GHz based on the bandwidth and radiation pattern characteristics.

Next, the single antenna is used as a basis for the two-element antenna on dual substrate layer as shown in Figure 3(a) and 3(b). The antenna elements in both figures are separated with one another by a distance of D mm. The distance, D in Figure 3(a) and Figure 3(b) are varied to three values to observe the mutual coupling S21 of both array antenna design. The two-chosen value of D is 33.68 mm which are equivalent to $\lambda g/2$ = 33.68 mm and 22 mm. $\lambda g/2$ is chosen as it is the minimum distance so that the antenna element will not be affected significantly by mutual coupling. Reduction distance of D, 22 mm is chosen as the width of the square EBG cell is 21 mm. Therefore, each of the antenna elements in Figure 3(b) are separated by 0.5 mm in X-axis from the EBG located underneath of the antenna. The third value of D is 18.0 mm in which the antenna elements in Figure 3(b) is the overlapped case by a distance of *d* with the EBG unit cells in X-axis as shown in Figure 3(c). A negative value of d corresponds to the movement of the radiating element towards the EBG in term of -X axis and vice versa.

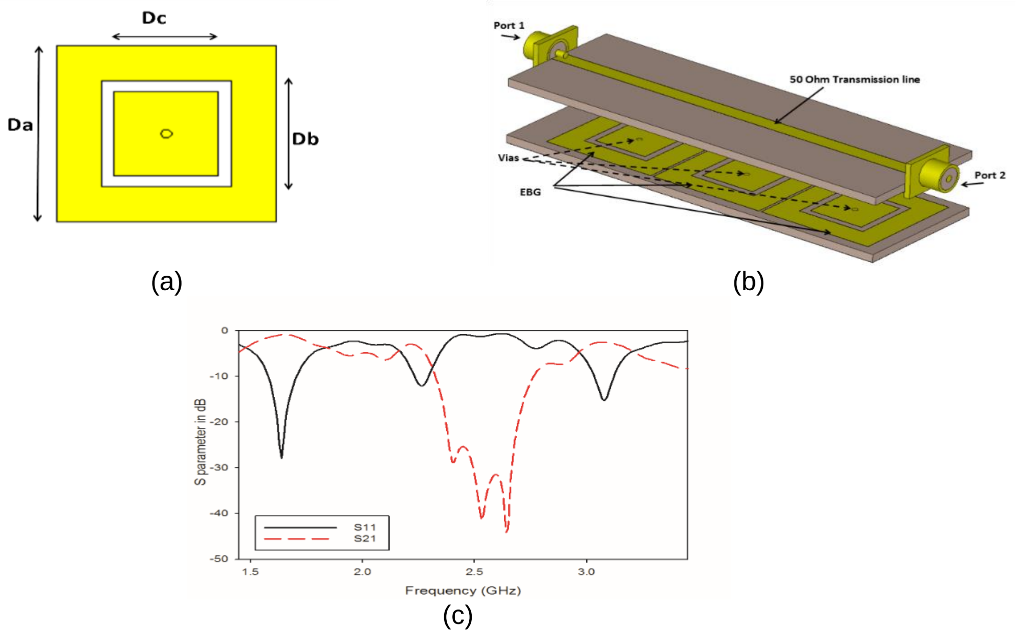


Figure 1. (a) EBG unit cells with shorting pin vias, (b) Supended transmission line method to observe the band gap (S21) characteristics of the EBG unit cells and (c) the simulated S11 and S21 of the EBG unit cells. Da = 21.0 mm, Db = 12.5 mm and Dc = 10 mm.

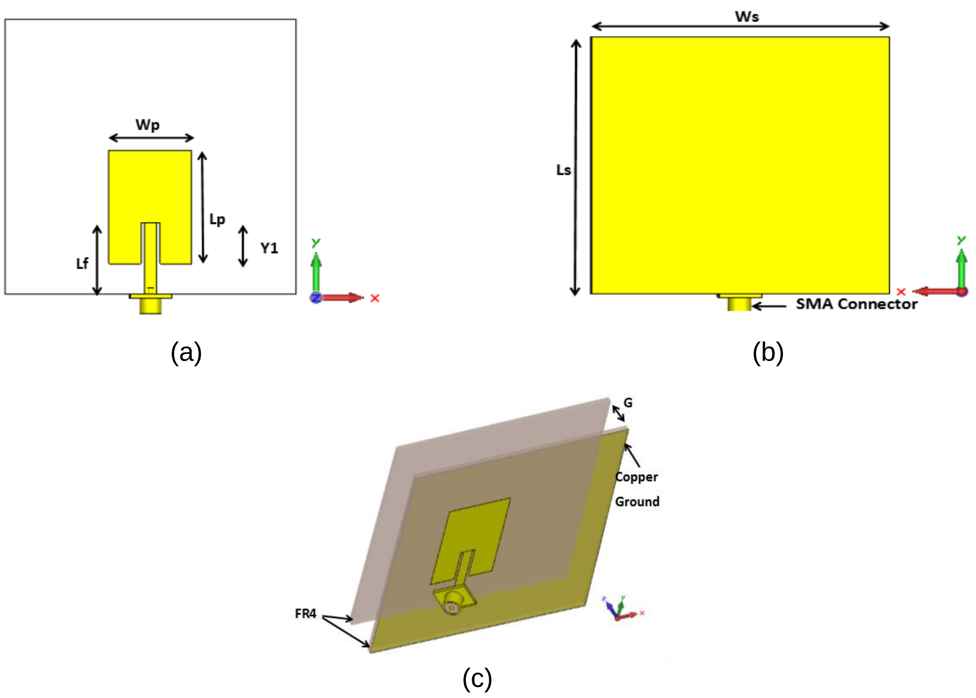


Figure 2. (a) The front and (b) back view of the single patch antenna. (c) The 3-dimensional exploded single patch antenna on dual substrate layer. Air gap, G = 0.035 mm Lf = 18.27 mm, Lp = 28.90 mm, Ls = 70.00 mm, Wp = 20.00 mm, Ws = 70.00 mm, Y1 = 10.50 mm

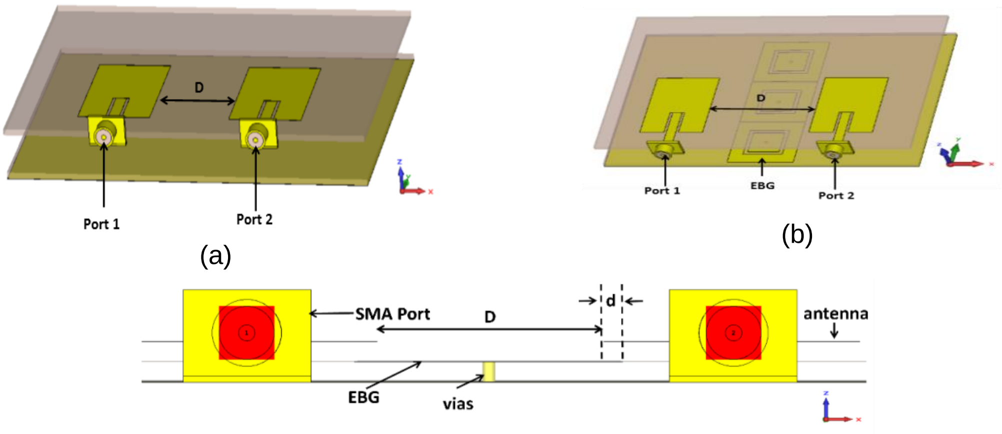


Figure 3. (a) the array antenna with two elements separated by a distance D on dual substrate layer while (b) is another similar design with EBG unit cells incorporated in the bottom substrate layer. (c) D = varying distance in between antenna elements, while d is the overlapped distance between the antenna and the EBG unit cells in term of X-axis. +d represents the overlapped distance while -d represents the distance EBG away from the antenna

3. Results and Discussion

Figure 4(a) shows the reflection coefficient of the single element antenna on the dual substrate layer. It can be observed that the antenna successfully operates at 2.45 GHz with bandwidth from 2.40 GHz to 2.50 GHz. The antenna has a realised gain of 2.54 dB and the 3-dimensional radiation pattern is shown in Figure 4(b). The E-field and H-field are shown in Figure 4(c) and Figure 4(d) respectively. The corresponding antenna exhibits directional radiation pattern with a realised gain of 2.54 dB. It has been proven that the antenna is functioning at the frequency of interest and will be used in subsequent array antenna design.

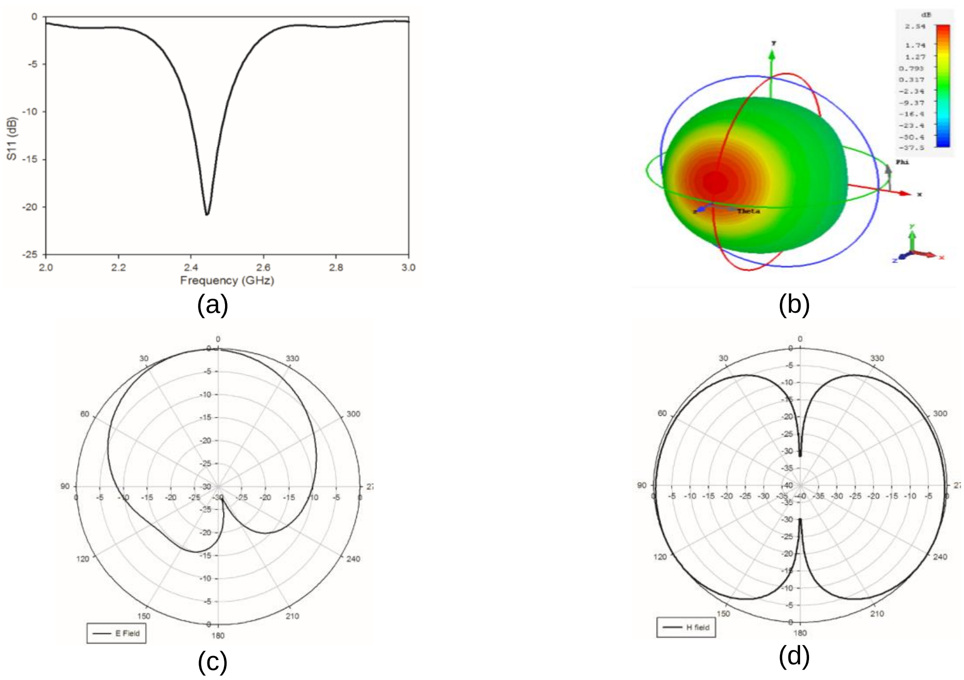
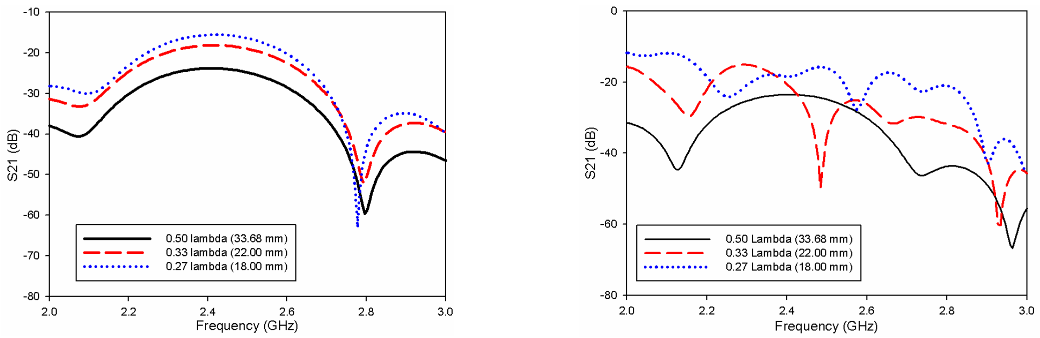


Figure 4 (a) the reflection coefficient S11 of the single patch antenna on dual substrate layer; The (b) E field and (c) H field of antenna. (d) The 3D radiation pattern

The simulated S21 of array antenna without EBG and array antenna with EBG is shown in Figure 5(a) and Figure 5(b) respectively. From Figure 5(a) it can be observed that antenna element separation distance of 0.50 λg gives the minimum mutual coupling. The mutual coupling is significantly greater as the elements are closer to one another from 0.50 λg to 0.33 λg and 0.27 λg. In contrast, with EBG incorporation to the antenna, the mutual coupling is greatly reduced although the elements are closer to one another by a distance of 0.33 λg. The mutual coupling is significantly reduced at 2.48 where the mutual coupling is - 49.65 dB. Table 1 summarises the mutual coupling in the three different cases of separation distance D with the corresponding distance reduction. It can be seen that, in the cases of overlapped distance between the EBG and antenna, the mutual coupling is relatively similar to the antenna with and without the EBG incorporation. It can be deduced that the separation distance between elements is limited by the EBG underneath the antenna. However, by incorporating of EBG on the separate layer with the antenna radiating part, the separation distance can be greatly reduced.



(a) (b)

Figure 5. (a) The S21 of the design in Figure 3(a) while (b) is the S21 of the design in Figure 3(b)

Table 1. Mutual coupling with respect to varying distance between antenna elements

Case	D (mm)	d (mm)	S21 at 2.45 GHz Antenan array without EBG (dB)	S21 at 2.45 GHz Antenan array without EBG (dB)	Distance reduction (%)
A	33.68 = λg/2	+ 6.45	- 24.02	- 23.63	-
B	22.00 = 0.33 λg	+ 0.62	- 18.29	- 26.61	34.68
C	18.00 = 0.27 λg	- 1.38	- 15.68	- 15.52	46.56

% Distance between elements = [(New distance – Initial distance)/ Initial distance] x 100%
= - *X*

Where the Initial distance is 33.68 mm which equivalent to λg/2. Negative value of *X* represents distance reduction with respect to the initial distance between antenna elements.

4. Conclusion

An array antenna with EBG on dual substrate layer has been designed and studied. The array antenna is compared to two cases, with and without EBG. With EBG on dual substrate layer, significant minimum mutual coupling of -26.61 dB is achieved at 2.45 GHz with shorter distance of 22.00 mm (0.33 λg) between the antenna elements as compared to the case of the antenna without EBG where the relative mutual coupling of -24.02 dB is achieved with greater distance between the antenna elements of 33.68 mm (λg/2). The use of EBG on dual substrate layer, reduces the distance between the antenna elements by 34.68%. This reduction can benefit in achieving overall compact antenna design. In the overlapped case of the array antenna, the use of EBG and without EBG to the array antenna system does not affect the mutual coupling between the antenna elements.

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