4th Iranian Conference on Electrical and Electronics Engineering
(ICEEE2012)
Islamic Azad University, Gonabad-Branch
28-29-30 August 2012

Design, Optimization and Improvement of an Aperture Coupled Stack Microstrip Antenna Array using an Electromagnetic Band Gap Structure

Kiarash Malekzadeh
Department of Electrical Engineering
Iran University of Science and Technology
Tehran, Iran
Malekzadeh_kiarash@yahoo.com

Mohamad Soleimani
Department of Electrical Engineering
Iran University of Science and Technology
Tehran, Iran
Soleimani@iust.ac.ir

Abstract— In this paper an aperture coupled stacked microstrip antenna array is designed to have proper characteristics and an electromagnetic band gap structure is used to reduce the mutual coupling of the antenna array configuration. An H-shaped aperture and a composite substrate are utilized to maximize the impedance band width. Using a mushroom-like EBG structure the mutual coupling has been reduced as much as 10 dB and the impedance band width is 20%. Simulations provide the results to confirm the design.

Keywords-component; EBG; Microstrip Antenna Array; Mutual Coupling; Aperture Coupled; Stacked Patch

INTRODUCTION

Periodic structures have recently shown a lot of interesting characteristics. They were first proposed in optic areas as photonic band gap structures (PBG) [1] and they were realized by periodic structures such as dielectric rods, etched holes, metal patches, polymers, etc. Then these periodic structures entered the area of electromagnetic field and the terminology of EBG was used [2]. The main reason to use these structures was the great and unique behaviors they could offer such as forbidden band gap and in-phase reflection. Soon the electromagnetic band gap structures found their widespread applications in engineering among which the following items can be mentioned: filters, resonators, power dividers, power amplifiers, high speed circuits, antennas, absorbing screens, air holes in the dielectric substrate or artificial magnetic conductors (AMC) surrounding the antenna. Due to the unwanted effects that surface waves can bring to the arrays, the EBG structures found their position in suppressing the surface waves and entered the world of arrays. In addition, their reflection phase characteristics can vary continuously from 180° to -180° in a frequency band. Unlike the PMC/PEC strip grids which can only operate when they are aligned orthogonally to the direction of propagating waves, EBG structures can show the band gap properties for all directions of wave propagation. The so-called mushroom-like EBG structure was first proposed by Sievenpiper [3] which consists of a periodic array of metallic patches, each one connected to the ground plane by vertical vias. Many other novel EBG structures have been proposed such as uni-planar compact EBG (UC-EBG) [4] and dumbbell shape EBG [5], etc. Their main goal is to achieve compactness, low loss and capability of being integrated with antennas to enhance their gain and reduce the backward radiation by suppressing surface waves and improving efficiency. While most of the mushroom-like EBG structures are square shaped unit cells and the dimensions along the periodic directions are the same, some rectangular EBG structures have also been proposed [6], where the metal patch is rectangular.

The radiation efficiency of different kinds of antennas can be enhanced by eliminating the surface waves using the EBG structures. Since EBG lattices have to be a half-wavelength at the band-gap frequency, it was difficult to implement them in physical dimensions. But the mushroom-like EBG proposed by Sievenpiper solved the problem. High impedance ground plane (HIP) [7] can be formed by mounting the radiating element on top of the EBG structure.

Stacked patches were first studied in 1978 [8] and their effects have been thoroughly investigated after that. The stacked microstrip antennas have a lot of variables which can be adjusted to obtain desirable characteristics. These variables include the patch sizes, the offset between the centers of patches, feed location, substrate thicknesses and dielectric constants.

In this paper an aperture coupled stacked microstrip antenna with good performances such as bandwidth, return loss and gain has been designed, analyzed and simulated. Then it has been put into an array with the spacing of half of a wave length which makes the array as compact as possible. But the surface waves cause the most harm among the array elements in this distance. The mutual coupling affects the suitable behavior of the array due to the surface waves. Thus with the cost of an increase in mutual coupling and the consequences such as scan blindness, the area of the array is reduced. So in order to benefit both the low area occupation and low mutual coupling, a mushroom like EBG has been applied to the proposed structure to decrease the mutual coupling as much as possible, and the results have been investigated. It can be shown that the applied EBG structure has a significant effect on the behavior of the proposed array.

I. APERTURE COUPLED STACKED MICROSTRIP ANTENNA CONFIGURATION

The design procedure of the aperture coupled stacked microstrip antenna is presented here.

A. Design

In order to design the aperture coupled structure, an H-shaped aperture has been used which has the following admittance:

$$Y_{ap} = j2Y_{0s}\left(\frac{\left(-\frac{Y_{0s}}{2}\right)\cot\left(\frac{\beta_s L_b}{2}\right)+Y_{0s}\tan\left(\frac{\beta_s L_a}{2}\right)}{Y_{0s}+\left(\frac{Y_{0s}}{2}\right)\cot\left(\frac{\beta_s L_b}{2}\right)\tan\left(\frac{\beta_s L_a}{2}\right)}\right) \quad (1)$$

For the feed substrate an RO3010 with $\varepsilon_r = 10.2$ with the thickness of 0.25mm is used. The feed conductor is under this substrate and its width is 0.25mm. A ground plane is mounted above this substrate and an H shaped aperture is etched on the ground plane. The dimensions of this aperture are: a=0.6mm, b=5mm, H=2mm, W=0.2mm. The configuration of this aperture is shown in figure 1.

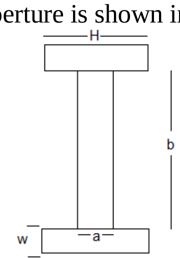

Figure 1. H-shaped Aperture

Figure 2 shows the equivalent circuit of the aperture coupled antenna as seen by the microstrip line.

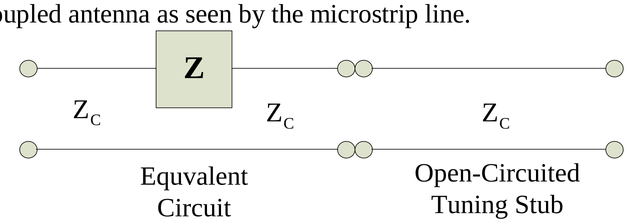

Figure 2. The equivalent circuit of the aperture coupled antenna as seen by the microstrip line

There is 1mm of air above the ground plane and an RT5880 substrate with $\varepsilon_r = 2.2$ and thickness of 1.57mm is placed above it to produce a composite substrate for the first patch. The first patch is located on this substrate with a dimension of 6.5×7 mm^2. Another RT5880 substrate with the same thickness and dielectric constant is put on the first patch. The second patch is on top of this structure with a dimension of 2.8× 2.8 mm^2. In order to design an array out of this antenna a configuration like figure 3 has been designed. Figure 3 shows an exploded view of the proposed structure for better understanding. It is notable to say that an open stub with the length of 0.375mm has been placed at the end of each feed to help the matching process.

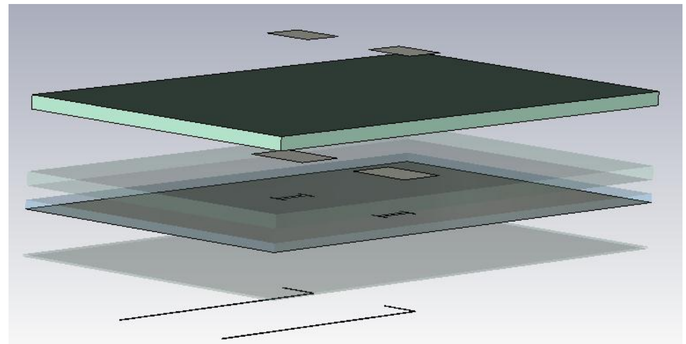

Figure 3. An Exploded View of the Proposed Configuration of the aperture coupled stack microstrip array

The feed configuration is depicted in figure 4.

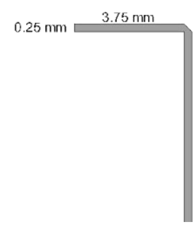

Figure 4. Feed Configuration

B. Simulation

In order to optimize the structure in the best way, first of all the single element antenna configuration has been designed and simulated. The following results are obtained from the simulations with CST STUDIO SUITE software.

Figure 5 shows the input VSWR of the designed structure. As can be seen the impedance bandwidth of around 2 GHz or 20% is obtained with the criteria of VSWR≤ 2.

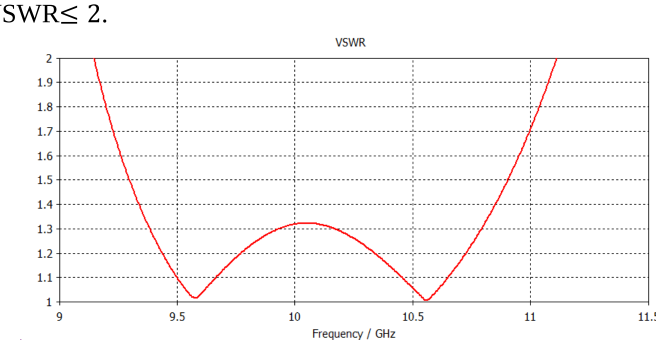

Figure 5. Input VSWR of the Single Eelement Aperture Coupled Stacked Microstrip Antenna

Figure 6 shows the gain of the designed single element aperture coupled stacked microstrip antenna which is above 6.8 dB in the operation range of frequency of the antenna and varies from 6.8 to 7.4 dB.

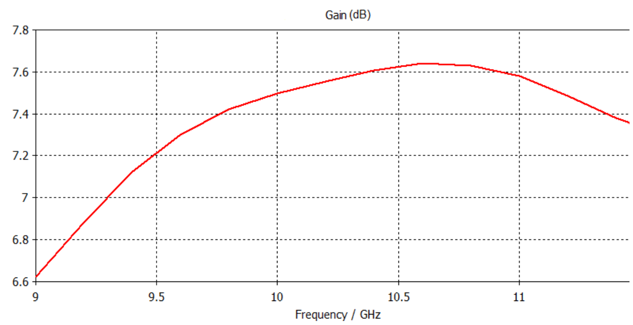

Figure 6. Gain of the Single Eelement Aperture Coupled Stacked Microstrip Antenna

Now the array configuration of the antenna which is shown in figure 3 is designed and simulated to observe its behavior. In order to make an array, two patches can be placed next to each other with the spacing from $\lambda/2$ to λ. When this spacing moves toward λ the mutual coupling would naturally decrease, but some other troubles may show up such as the larger area needed for the array and the level of grating lobes which begins to increase. Thus in order to reduce the grating lobes and make the array smaller, the spacing between two patches should tend to $\lambda/2$. But another problem may occur that can affect the performance of the array. That problem is the mutual coupling which is higher when the distance between two patches is smaller. So the EBG structures can play an important role here. Hence the spacing is set to $\lambda/2$ and the array is simulated.

The following results are obtained from the simulations of the designed array with no EBG structure. Figure 7 shows the S_{21} parameter of the array which indicates the high level of mutual coupling. As can be seen the value of S_{21} varies from -13 dB to around -15 dB. Figure 8 depicts the array gain obtained from the simulations.

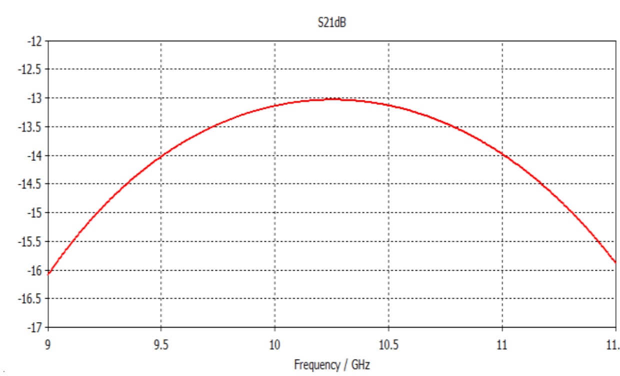

Figure 7. S_{21} of the array without an EBG Structure

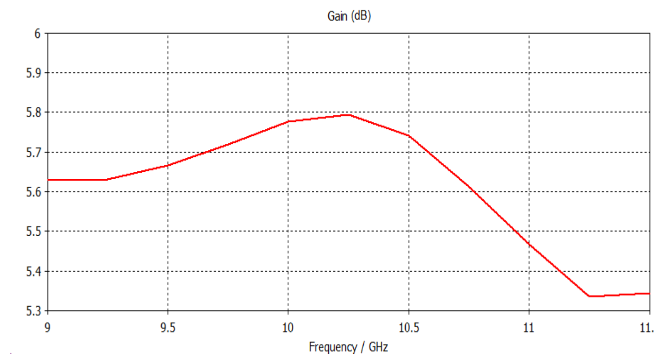

Figure 8. Gain of the Array with no EBG

Figure 8 illustrates the fact that the gain of the array has decreased due to the effects of mutual coupling and varies from 5.6 dB to 5.8 dB.

II. EBG Design

The proposed structure suffers from surface waves which can affect the desired gain and bandwidth of the antenna and the mutual coupling between the two elements. In this paper an Electromagnetic Band Gap (EBG) structure has been designed and used to improve the performance of the antenna and stop the surface waves. When the incident wave is a surface wave ($k_x^2+k_y^2 \leq k_0^2$, k_z is purely imaginary), the EBG structure shows a frequency band gap through which the surface wave cannot propagate for any incident angles and polarization states [9]. Among many different EBG structures, the mushroom like one has been utilized because a lower frequency and a wide bandwidth can be obtained and at a given frequency, its size is smaller than the uni-planar EBG design [9]. In order to design a mushroom like EBG, some parameters are of great importance. These parameters are the width and length of the metal patches of EBG, the height and radius of connecting vias, the gap between two adjacent metal sheets, and the way the unit cells are located in the structure.

Considering two adjacent metal sheets, a fringing capacitor can be obtained as follows [10]:

$$C_g = \frac{W\varepsilon_0(1+\varepsilon_r)}{\pi} cosh^{-1}\left(\frac{W+g}{g}\right) \quad (2)$$

Where W is the width of the metal patches of EBG, g is the gap between two patches of EBG and ε_r is the relative dielectric constant surrounding the EBG structure. Considering two EBG unit cells next to each other, the current flowing through the metal sheets and vias and the ground connecting them, an inductance can be derived [9]:

$$L = \mu h \quad (3)$$

Where h is the height of vias. So for the equivalent circuit model of an EBG with the capacitance and inductance of C and L respectively, the resonant frequency is given by:

$$\omega = 1/\sqrt{LC} \tag{4}$$

Using these parameters and considering the desired frequency of operation for the EBG structure, the optimum values are derived and used in simulations.

III. Simulation and Results

For the proposed structure of the aperture coupled microstrip antenna the frequency range is around 9 to 11.5 GHz. So according to (2), (3), and (4) the design parameters of the EBG are as follows:

The height of via is H_v=1mm. The radius of via is V_r=0.5mm. The metal sheets are square and their lengths are 1.25mm. The gap between to metal sheets is g=0.2mm.

Figure 9 illustrates the way the EBG structure is placed between two patches.

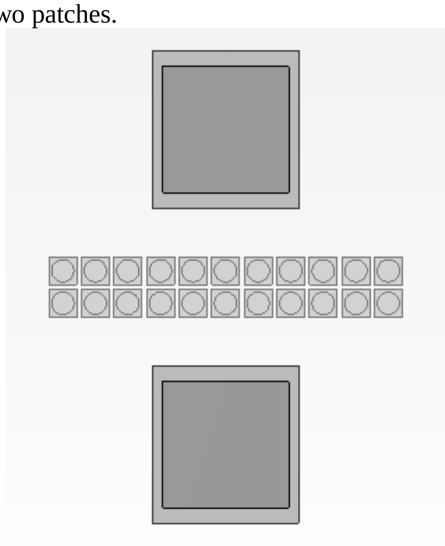

Figure 9. EBG Rows Placed between Patches

The EBG structure has a stop band which is at the same frqquency of the surface wave propagation. So it can prevent the surface waves propagating between the adjacent patches which results in the reduction of the mutual coupling. Simualtions of the structure using one, two and three rows of EBG have been done and the results are stated bellow. Using only one row of the mushroom like EBG reduces the value of S_{21} parameter which can be seen in figure 10.

It is obvious that the value of S_{21} has decreased about 5 dB with just on row of the EBG structure.

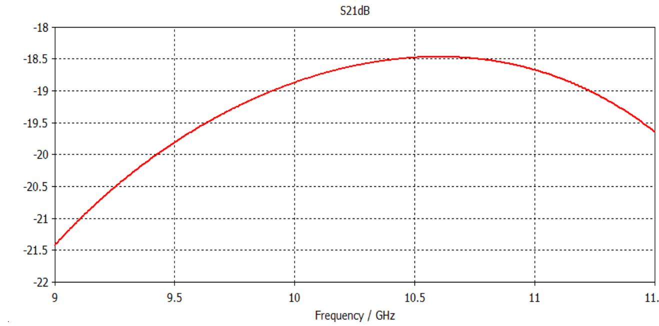

Figure 10. Values of S_{21} for one row of EBG Implemented in the Structure

Now two rows of EBG structure are implemented in the designed structure and the effect of the EBG structure has been investigated by simulation. Figure 11 shows the values of S_{21} parameter. It can be seen that using two rows of EBG makes the value of S_{21} decrease about 3 dB compared to the structure with one rows of EBG and 8 dB compared to the structure without EBG.

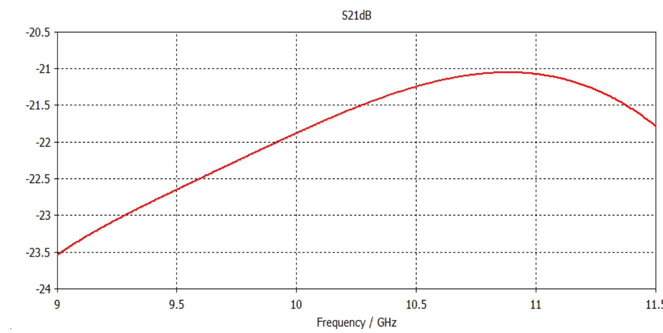

Figure 11. Values of S_{21} for two rows of EBG Implemented in the Structure

Using three rows of the EBG structure causes S_{21} to decrease as much as 10 dB compared to the structure having no EBG structures implemented in, which is shown in figure 12.

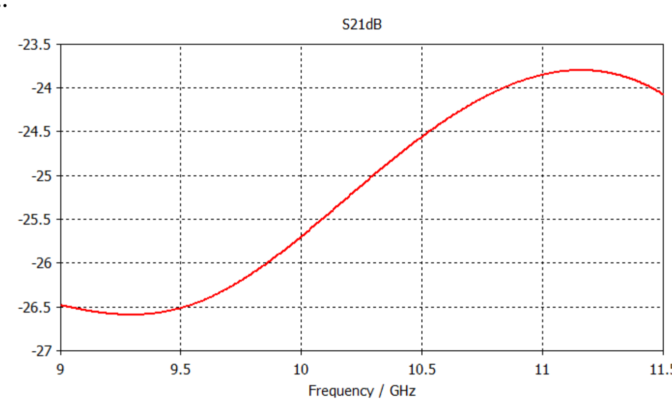

Figure 12. Values of S_{21} for three rows of EBG Implemented in the Structure

Figure 13 shows the side view of the structure containing rows of EBG.

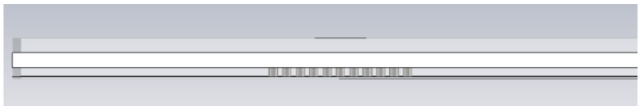

Figure 13. Side View of the Structure with Implemented Rows of EBG

Simulations show that using more than 3 rows of an EBG structure has no remarkable effect compared to 3 rows and is not need to be implemented. So using 3 rows of a mushroom-like EBG structure can reduce the mutual coupling around 10 dB.

CONCLUSION

The designed aperture coupled stacked microstrip antenna has proper characteristics such as impedance band width and gain, but when it is implemented into an array, the performance of the arrays suffers from the surface waves and the mutual coupling between the patches. So in order to overcome this problem a mushroom like EBG structure has been designed and implemented in the array. The band gap behavior of the EBG structure prevents the surface wave to propagate along the array. So the mutual coupling is reduced significantly. The value of S_{21} has decreased more than 10 dB.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to ITRC (Iran Research Institute for ICT) for their support.

REFERENCES

[1] E.Yablonovitch, "Inhibited spontaneous emission in solid-state physics and electronics," Phys. Rev. Lett., vol. 58, 2059–63, 1987.

[2] Y. Rahmat-Samii and H. Mosallaei, "Electromagnetic band-gap structures: classification, characterization and applications," Proceedings of IEE-ICAP symposium, pp. 560–4, April 2001.

[3] D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolus, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," IEEE Trans. Microwave Theory Tech., vol. 47, 2059–74, 1999.

[4] F.-R.Yang, K.-P. Ma,Y. Qian, and T. Itoh, "A uniplanar compact photonic-bandgap (UC-PBG) structure and its applications for microwave circuit," IEEE Trans. Microwave Theory Tech., vol. 47, 1509–14, 1999.

[5] A. Yu and X. Zhang, "A novel 2-D electromagnetic band-gap structure and its application in micro-strip antenna arrays," Proceedings of ICMMT 2002, pp. 580–3, 17–19 August 2002.

[6] H. Boutayeb, T. A. Denidni, A. Sebak, and L. Talbi, "Metallic EBG structures for directive antennas using rectangular, cylindrical and elliptical shapes," IEEE APS Int. Symp. Dig., vol. 1A, pp. 762–5, July 2005.

[7] S. Tse, B. S. Izquierdo, J. C. Batchelor, and R. J. Langley, "Reduced sized cells for high impedance (HIP) ground planes," Proceedings of 2003 ICAP, vol. 2, pp. 473–6, 2003.

[8] Long, S. A., and M. D. Walton, " A Dual-Frequency, Stacked Circular Disc Antenna." IEEE Antennas and Propagation Symp. Digest, 1978, pp. 75-76.

[9] Fan Yang and Yahya Rahmat-Samii, Electromagnetic Band Gap Structures in Antenna Enginnering,The Cmbridge RF and Microwave Engineering Series.