Bandwidth Enhancement of A 2×2 Triangular Microstrip Patch Antenna Using Triangular Lattice Ebgs in the Ground Plane

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Abstract:
Triangular lattice Electromagnetic Band-Gap (EBG) Structure in the ground plane is used in the design of a Triangular Microstrip Patch Antenna (TMPA) Array to improve its bandwidth. The patch elements are equilateral triangular in shape. The Equilateral Triangular Microstrip Patch Antenna (ETMPA) Array design has four patch elements in 2×2 form with ground plane having circular cutouts forming triangular lattice EBG. The ETMPA array with EBG provides better antenna gain and bandwidth. The ETMPA Array with EBG gives an impedance bandwidth of 16.76GHz and a percentage bandwidth of 110% while ETMPA Array gives an impedance bandwidth of 2.46GHz and a percentage bandwidth of 17.7%, thus an increment of approximately 500% in impedance bandwidth is observed. The achieved bandwidth of the ETMPA array with EBG extends from 2.7034GHz to 19.4649GHz. The array gain with EBG structure improved to 14.6dBi which is 9.7dBi for ETMPA array without EBG.

Keywords: ETMPA, ETMPA Array, Electromagnetic Band-Gap (EBG), Impedance Bandwidth, Percentage Bandwidth, Triangular Lattice.

1. Introduction

With the increasing utilization of high performance antennas in the wireless communication applications, the popularity of microstrip patch antenna has increased a lot, though it has limitations like narrow bandwidth, low gain, low efficiency, spurious feed radiations etc. Efforts have been made to improve the performance of the microstrip patch antenna using various techniques. Some of these techniques are to increase the substrate height or using aperture coupled feed etc. These techniques increases the bandwidth of the patch antenna to some extent but also increases the surface waves on the substrate causing distortion in the radiation pattern and reducing the gain and directivity of the patch antenna [6]. Arrays is also one of the solution for increasing the gain and directivity of the antenna, though they also have limitations narrow bandwidth, spurious signal feed radiations, low efficiency etc. To overcome above problems Electromagnetic Band- Gap (EBG) substrates and materials have attracted much attention of the researchers in microwave and antenna communities. EBG has many applications in the field of microwaves and millimeter waves device development, as well as antenna designing. EBG material, in general, are periodic structures that forbid the propagation of electromagnetic surface waves within a particular frequency band called the band-gap [8]. In this paper we have designed triangular lattice of circular holes in the ground plane to improve the gain and bandwidth of the ETMPA Array. We have used simulating software HFSS v13 for designing the array and simulating the results. HFSS software works on the Finite Element Method (FEM) in which triangular elements are used for surface meshes and tetrahedron elements for volumetric meshes. For achieving maximum band-gap we have used r/a= 0.45 and a/λ_g= 0.5, where *r* is the radius of circular holes in the ground plane, *a* is the separation between the holes and λ_g is the guided wavelength [7].

2. Design Of An ETMPA Array

Microstrip Patch Antenna in general have a conducting patch on a grounded microwave dielectric substrate and have attractive features like low profile, light weight, easy fabrication and conformability to mounting hosts [3]. But above all these attractive features microstrip patch antenna have one disadvantage that they provide narrow bandwidth and for practical utilization we need to enhance the bandwidth of the patch antenna. Thus to overcome the above problem we can form an assembly of radiating elements in a specific electrical and geometrical configuration, which is referred to as an *array*. An array may have a number of elements in different geometrical configuration; each element is provided with the same magnitude of electric current and is in same phase. To provide very directive patterns, it is essential that the fields from the elements of array should interfere constructively (add) in a desired direction and interfere destructively in the remaining space [1]. Triangular patch is one of a basic patch geometry used in several applications because of being physically smaller than other patch geometries like rectangular and circular patches. The resonance frequency of a triangular patch can be found using the cavity model, in which the triangle is surrounded by a magnetic wall along the periphery. Corresponding to several modes the resonance frequency of an equilateral triangular patch can be given as [2]:

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{(m^2 + mn + n^2)} \quad (1)$$

Where, c is the velocity of light, a is side length of equilateral triangular patch and ε_r is the dielectric constant of the substrate. In the above equation for better results we change the side length a by the effective side length a_e, hence our expression for resonance frequency for TM_{10} mode will become-

$$f_{10} = \frac{2c}{3a_e\sqrt{\varepsilon_r}} \quad (2)$$

Where effective side length of equilateral triangular patch is given as [2]:

$$a_e = a\left[1 + 2.199\frac{h}{a} - 12.853\frac{h}{a\sqrt{\varepsilon_r}} + 16.436\frac{h}{a\varepsilon_r} + 6.182\left(\frac{h}{a}\right)^2 - 9.802\frac{1}{\sqrt{\varepsilon_r}}\left(\frac{h}{a}\right)^2\right] \quad (3)$$

Where h is height of the substrate. Using equations (2) and (3) we can calculate the side length of the equilateral triangular patch for a given operating frequency.

In the case of conventional microwave antennas, characteristics such as high gain, beam scanning, or steering capability are possible only when discrete radiators are combined to form arrays. The elements of an array may be spatially distributed to form a linear, planar, or volume array. A linear array consists of elements located finite distances apart along a straight line. Similarly, a planar array has elements distributed on a plane and a volume array has elements that are distributed in three dimensions [5, 9]. In the design of an array one of the most essential factor is the feed technique, generally, it is divided in two broad categories, parallel feed technique and series feed technique. In parallel or corporate feed technique there are single input port and multiple feed lines in parallel constituting the output ports. Each of these feed lines is terminated at an individual radiating element. Series feed consists of a continuous transmission line from which small proportion of energy are progressively coupled into the individual element disposed along the line by various means including proximity coupling, direct coupling, probe coupling, or aperture coupling [2]. In designing of an ETMPA Array we have taken parallel feed technique in utilization. The feed is taken such that each element receives equal input impedance. The feed works as the 2:1 power divider, i.e. power is divided equally in both the arms from the common feed [11]. Rogers RT/ Duroid 6010 substrate is used having dielectric constant 10.2 and dielectric loss tangent tan δ= 0.0023 with dimensions equal to 60×60mm^2 and thickness of substrate as 2.5mm. The patch element side length is 10.7mm; common feed is of 3mm and arms feed is of 1.5mm. The separation between the patch elements is taken as $0.5\lambda_0$ and operating frequency used is 5.2GHz.

The model of an ETMPA Array designed in HFSS simulating software is shown as below:

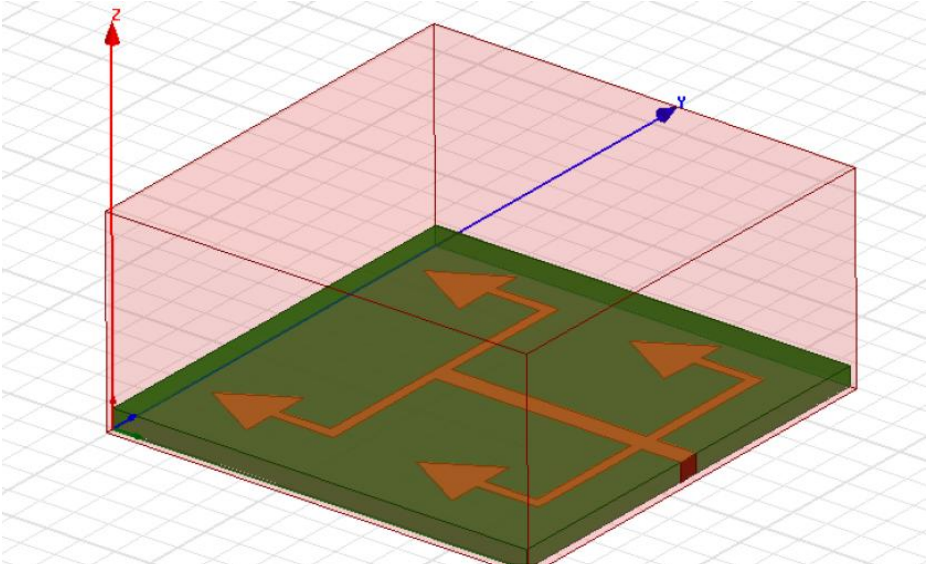


Figure 1: ETMPA array model designed in HFSS

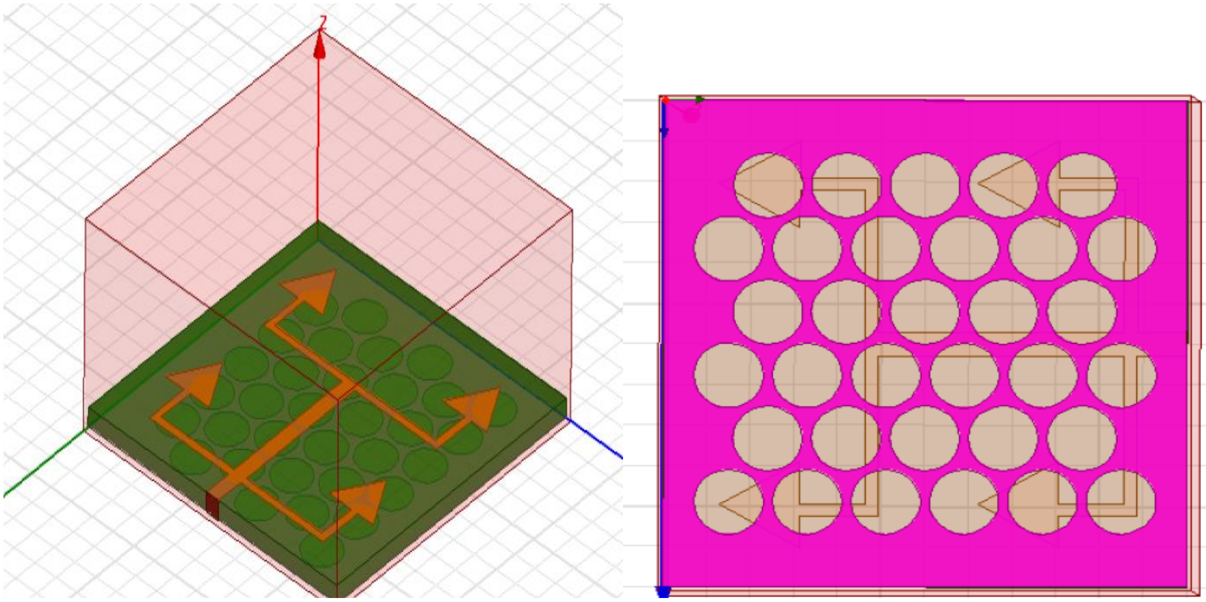
3. Design Of An ETMPA Array Using Triangular Lattice Ebgs In The Ground Plane

Electromagnetic band-gap structures are defined as artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states. EBG structures are usually realized by periodic arrangement of dielectric materials and metallic conductors [4]. The 2-D EBG surfaces have the advantages of low profile, light weight, and low fabrication cost. Surface waves are by-products in many antenna designs. Directing electromagnetic wave propagation along the ground plane instead of radiation into free space, the surface waves reduce the antenna efficiency and gain. The diffraction of surface waves increases the back lobe radiations, which may deteriorate the signal to noise ratio in wireless communication systems such as GPS receivers. The band gap feature of EBG structures has found useful applications in suppressing the surface waves in various antenna designs. When the incident wave is a surface wave the EBG structures show a frequency band gap through which the surface wave cannot propagate for any incident angles and polarization states. Thus reducing the surface waves and increasing the gain and directivity of the antenna design [10].Electromagnetic band-gap substrates (EBGs) have produced a wide variety of design alternatives for researchers working in the area of microwaves and photonics. 2-D EBGs in the ground plane have been introduced by Itoh. Triangular lattice has been chosen because triangular lattice EBGs can give rise to a complete band-gap for both transverse electric (TE) and transverse magnetic (TM) polarizations. It has been observed that for maximum band-gap [7]:

$$\frac{r}{a} = 0.45 \quad \text{and} \quad \frac{a}{\lambda g} = 0.5 \qquad (4)$$

Where r is the radius of circular holes in the ground plane, a is the separation between the holes and λ_g is the guided wavelength defined as $\lambda_g = \lambda/\sqrt{\varepsilon_r}$, where λ is free space wavelength and ε_r is the dielectric constant of the substrate.

Using equation (4) the radius of the circular holes in the ground plane is calculated as 4mm and the separation between the holes as 9mm. Hence the HFSS modeled design of the ETMPA Array with triangular lattice EBGs in the ground plane is -



(a) (b)

Figure 2: ETMPA array with triangular lattice EBGs (a) Top view, (b) Back view

4. Simulations And Results

Designing and simulating the 2×2 ETMPA Array using Triangular Lattice EBGs in ground plane in HFSS simulating software, it has been observed that an impedance bandwidth of 16.76GHz is obtained i.e. a percentage bandwidth of 110%, while for ETMPA Array without EBG an impedance bandwidth of 2.46GHz and a percentage bandwidth of 17.7% are obtained. Thus an increment of approximately 500% in impedance bandwidth is observed. The return loss value for the ETMPA Array with EBG is -32.2801 at the resonance frequency of 15.2405GHz. The S parameter results for both the design are shown in figure 3 and VSWR results in figure 4. The VSWR for the ETMPA array with EBG is 1.0499.

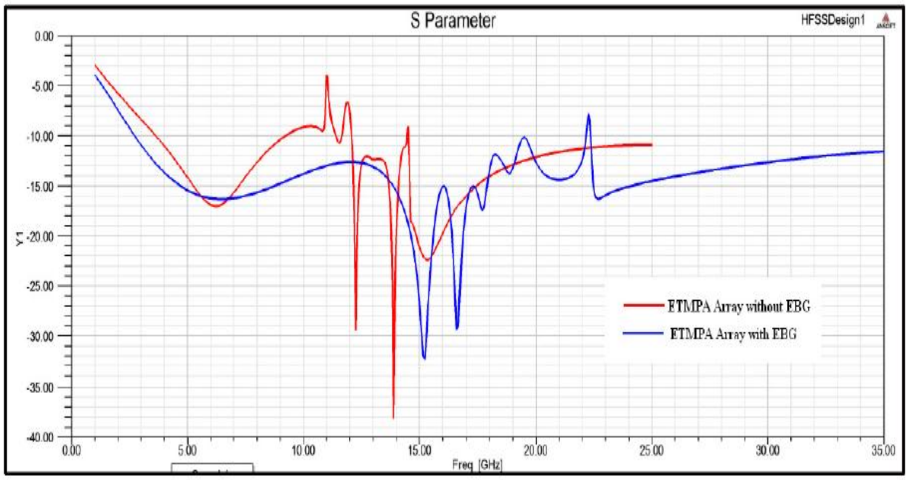


Figure 3: S parameter result for both the designs

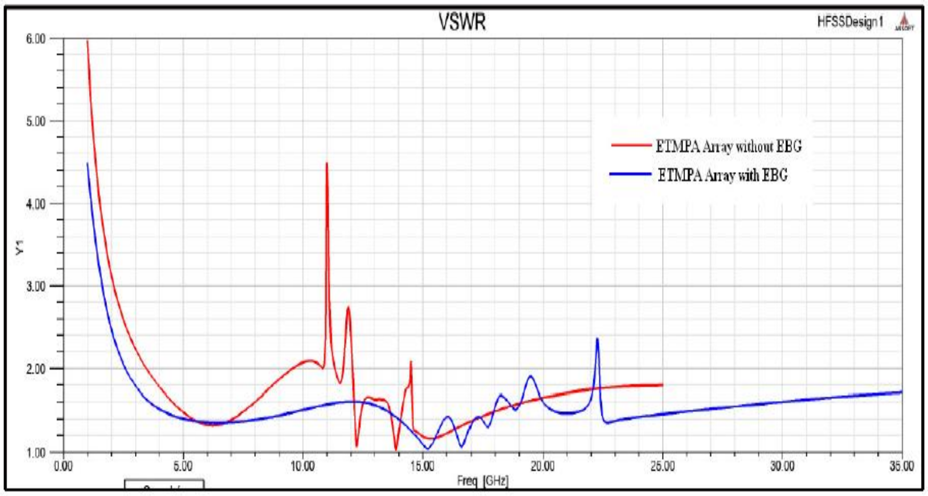


Figure 4: VSWR result for both the designs

ETMPA Array with EBG has a gain of 14.6dBi whereas the gain value of ETMPA Array without EBG is 9.7dBi. The impedance bandwidth and the radiation bandwidth for an ETMPA design are determined using:

$$\text{Impedance Bandwidth} = f_H - f_L \quad (4)$$

And,

$$\text{Percentage Bandwidth} = \frac{f_H - f_L}{f_c} \times 100\% \quad (5)$$

Where f_H and f_L are the start and end point of the S parameter curve where minimum return loss is obtained, however both the frequency point must lie on -10dB line and f_C is the center frequency.

5. Conclusion

From full wave simulations of both the designs i.e. ETMPA Array without EBG and ETMPA Array with triangular lattice EBGs in ground plane for same dielectric constant substrate and same operating frequency, it has been observed that using EBG structure there is an increment of approximately 500% in impedance bandwidth of the array. ETMPA Array with EBG gives an impedance bandwidth of 16.76GHz and a percentage bandwidth of 110%. Its gain has also increased up to 14.6dBi. The results of the ETMPA Array with EBG not only cover the whole Ultra wide band spectrum but also can be used for X band RADAR applications.

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