Implementation of EBG Configuration for Asymmetric Microstrip Antenna to Improve Radiation Properties

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***Abstract*—The purpose of this paper is to achieve compact microstrip antenna with improved performance using uniform electromagnetic band-gap (EBG) configuration for S-band at 2.45 GHz. The proposed configuration was easy to develop and based on metallic surfaces without implementation of vertical holes (vias) or vertical connections. Initially, simple microstrip antenna of a square shape was designed which operated at 2.42 GHz. The original microstrip antenna was bisected along the vertical axis and optimized with respect to dimensional parameters for 2.45 GHz. Performance characteristics were checked by bisecting original square-shaped microstrip antenna to reduce it to half of its original size. The reduction area of radiating patched up to 52.77% of its original size with the cost gain. After the placement of circular EBG configuration integrated along the two edges of antenna, it retained its best performance characteristics with a simple design. However, the design validation prototype was subjected to experimentation. Results of the presented antenna exhibited better performance compared to the conventional antenna.**

***Index Terms*—Compact; Electromagnetic Band-Gap (EBG) Configuration; Gain; Half Microstrip Antenna.**

I. INTRODUCTION

Microstrip antennas present a smart solution to conformal, compact and low-priced designs for wireless communication. Microstrip antennas are the fairly plain alternative for wireless applications as it has a variety of advantages like compactness, low price and conformal than the other antennas. Their major disadvantages are low gain, contracted bandwidth and not being flexible due to low efficiency [1].

These can easily be mounted on any conformal shape rockets, missiles without major modifications [1]. Single patch antenna gives low gain. There are different methods used to increase the radiation of antenna. The resonance gain method consists of the inclusion of substrate covered by layer over it. The use of a parasitical element or reduction of surface wave helps microstrip antenna gain to be improved [2 - 5]. At the edges of ground plane parasitic, surface waves diffracts causes distortion of the antenna pattern. Sievenpiper EBG structure has its unit cell smaller than other types of EBG configuration. Dan Sievenpiper et. al. have been investigating the high-impedance and various textured surfaces to modify its radio-frequency electromagnetic properties. These metallic surfaces are used in antenna structures as a ground plane to obtain smoother radiation profiles [6]. A span of frequency over which EBG inhibits transmission of electromagnetic (EM) waves is called as band-gap. EBG has the property to reject sharply these propagated waves used in antennas and filter components for several frequency levels and different geometrics like a hexagonal pattern or square pattern on microstrips [7]. These structures have been used in antennas basically for gain and bandwidth improvement. For many different MIC based antennas, this investigation had been done [3, 8 - 9]. An improvement of a roll-off factor in stop-band and pass-band by suppressing the outcome of surface wave and radiation losses in the filter has been passed out with EBG structure [10 - 11]. EBG designs are based on the utilization of vias or vertical connections [12, 13]. The use of via holes and connections put constraints on the fabrication process and limits prospective applicability [14].

In the present paper, we propose a simple circular EBG structure, which is easy to construct on planar layouts without vias to improve antenna performance as compared to the conventional antenna. The initially typical square microstrip antenna is configured at S-band which resonates at 2.42 GHz. There is a need of compact planar antennas that have the capability of better performance characteristics. By keeping this as a need, the aim of this study is to offer a compact microstrip antenna. Miniaturization of the conventional structure by half is obtained by bisecting it along the y-axis. A size reduction about 52.77% as compared with the square antenna is possible. As the size reduces, there is an increase in ohmic losses, which minimizes the antenna performance and gain. So, to improve antenna performance with size reduction, it is planned to modify the patch element of typical square microstrip antenna into half with a circular shape of EBG structure.

II. THE SQUARE MICROSTRIP ANTENNA

Initially, a simple square microstrip antenna is designed. FR4 is taken as the dielectric material due to the advantage of low cost. The substrate has a dielectric constant of 4.4, height 1.6mm and loss tangent 0.02. A metal patch of dimensions $W_p=L_p=29.8$ mm with 50-ohm inset feed was used. The feed used was microstrip line feed, which was 21mm long and 2.4mm wide. Then miniaturization of the same structure was achieved by bisecting it along y-axis such as Half Microstrip antenna (HMA), which gave an asymmetric shape. Figure 1 shows the square microstrip antenna (SMA) geometry and Figure 2 shows the simulation model of SMA. Figure 3 shows the geometry of half microstrip antenna (HMA) and Figure 4 shows the simulation model of HMA. The design and simulation were carried out through HFSS software. The simulated results of return loss are shown in Figure 5 for both antennas. SMA resonated at the frequency 2.42 GHz with a return loss equals to -20.98 dB and HMA resonated at 2.45 GHz with a return loss equals to -24.65dB.

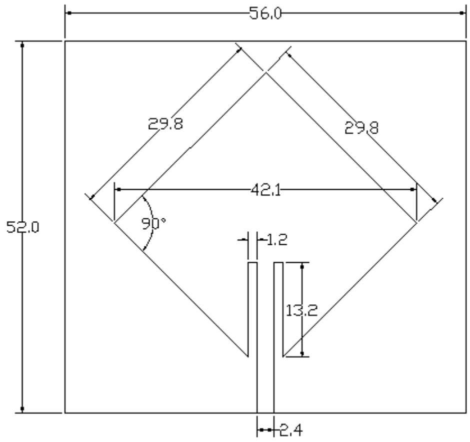


Figure 1: Geometry of square microstrip antenna (all dimensions are in mm)

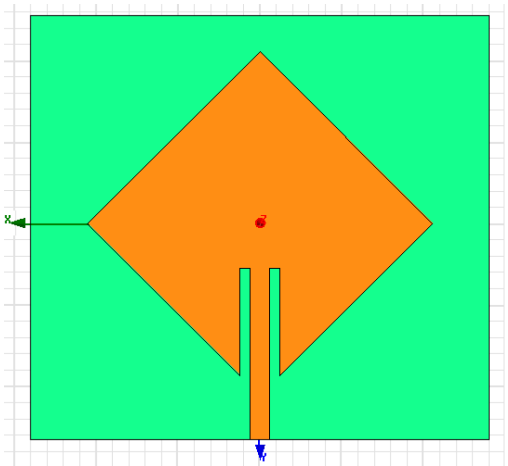


Figure 2: Simulation model of square microstrip antenna (SMA)

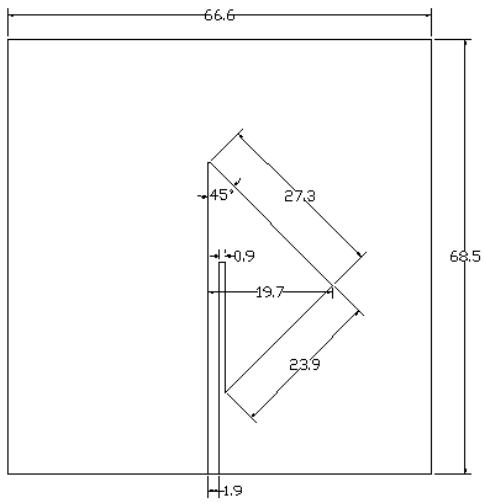


Figure 3: Geometry of half microstrip antenna (HMA) (all dimensions are in mm)

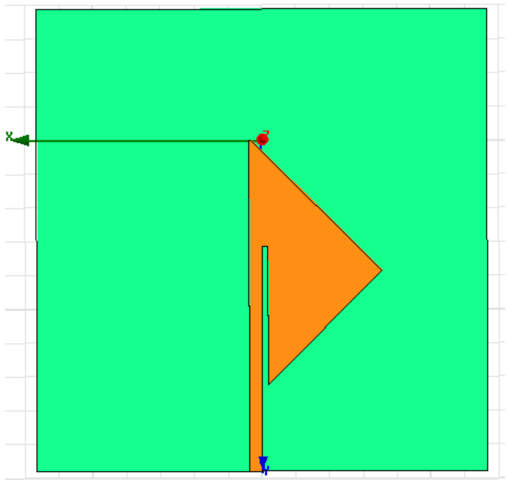


Figure 4: Simulation Model of Half microstrip antenna (HMA)

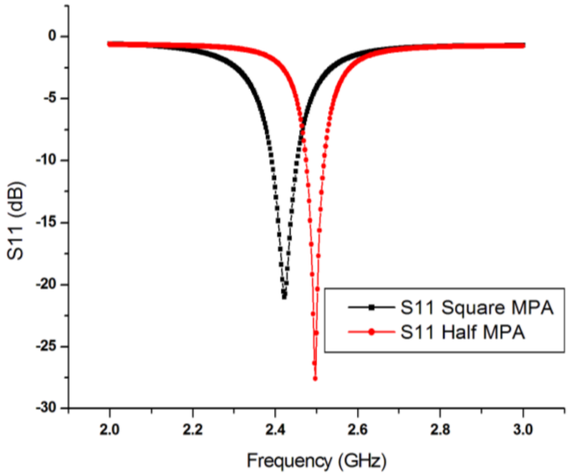


Figure 5: Simulated return loss for square microstrip antenna and Half Microstrip antenna

Generally, it is known that the smaller is the dimension of the antenna for higher resonance frequency, the higher is the dimensions for lower frequency. Though half format of the symmetrical structure is small in size and asymmetric in shape, they have all the necessary features for resonance frequency. [15]. This technique is implemented in this paper to take benefit of miniaturization. The square microstrip antenna was optimized for the best impedance matching, which exhibited the resonance frequency 2.42 GHz with a return loss of -20.98 dB. The square microstrip antenna was bisected to y-axis to obtain the miniaturized antenna. The width of the microstrip line of SMA is 2.4 mm, which was also divided after bisecting. Obliviously, because of the reduction in the width of the microstrip line, impedance gets a mismatch and the return loss was also shifted. For impedance matching, the width of the microstrip line was set to 1.9 mm and depth of slot for inset feed was also modified to 20.5 mm instead of 13.2 mm.

Thus, HMA showed better impedance matching for 50Ω source and resonated at 2.45 GHz with a return loss -24.65 dB.

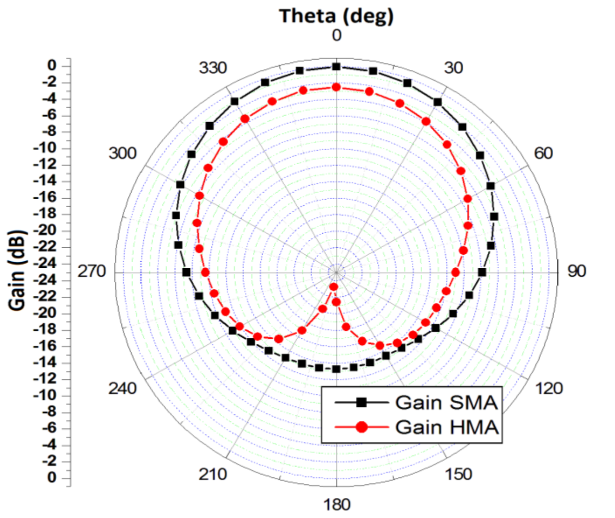


Figure 6: Simulated gain for square microstrip antenna (SMA) and Half Microstrip antenna (HMA)

Radiation properties of the miniaturized antenna have been observed. Figure 6 shows the simulated gain for the antennas with a square and half configuration. The simulated gain for SMA was -0.06 dB and for HMA was -1.66dB *(θ = 0°)*.

The symmetrical structure of antenna has led to a larger antenna structure. The simulated gain of SMA was -0.06 dB. It is observed that due to asymmetrical structure of antenna and size reduction in the radiating element of antenna gain was significantly reduced to - 1.66dB for HMA. As antenna aperture was reduced, it resulted in a decrease in antenna gain [16]. Size scaling down was possible up to 52.77%, but with a decrease in gain. As shown in Figure 4, the size of reducing the radiating patch has been achieved up to 52.77% by simply bisecting the SMA at Y-axis.

As the purpose of our work is to miniaturize antenna as HMA without degradation of antenna performance i.e. enhancement in gain, the technique of integration of circular EBG configuration was adopted.

III. Design of Half Microstrip Antenna (HMA) with Circular Shape EBG Configuration

Most of the high performance and compact microwave components are designed using EBG configuration and defected ground structure (DGS) [17, 18]. There are many types of EBG structures. The author has selected the fundamental and common shape of the EBG i. e. circular one. A circular shaped EBG has a versatile use. The features of EBG help to get a better performance of the antenna. Many of the investigators have made efforts to enhance the performance of the structure using the EBG structures with vias. However, via and its connections put constraints in the process of fabrication and its potential applicability. Uniplanar EBG implementation on a single dielectric layer makes an extensive use of gaps between the metal pads. The advantages of uniplanar EBG are low loss, moderate impedance. The nonexistence of vertical vias and common features of the use of gap and metal surfaces exhibits inductive and capacitive behavior. On arrangement of circular EBG, the field between adjacent circular metal patch through the gap provides the capacitance. The flow of current through metals patch results in the inductance. Thus, inductance and capacitance, which are in parallel result in resonance circuit. This parallel resonance circuit gives high impedance and exhibits the band gap at the resonance frequency [14].

The planned EBG configuration is a circular shape, planar layout, without vias. Circular shape EBG configuration is implemented along two edges of HMA. The two common features of EBG configuration are the suppression of or control of the surface waves and its function as an artificial magnetic conductor (AMC). The performance of EBG configuration is based on photonic band-gap (PBG) phenomenon. EBG configuration has attracted a lot of interest in antenna engineering. Different EBG configuration plays the same role and same characteristics of control of surface waves, diminution of mutual coupling and used for compact design.

In this work, circular shape EBG structure has been embedded along edges of HMA to prevent the spread over of the bounded surface waves to interface between free space and metal. Thus, the surface waves can be reduced to improve the radiation of an antenna.

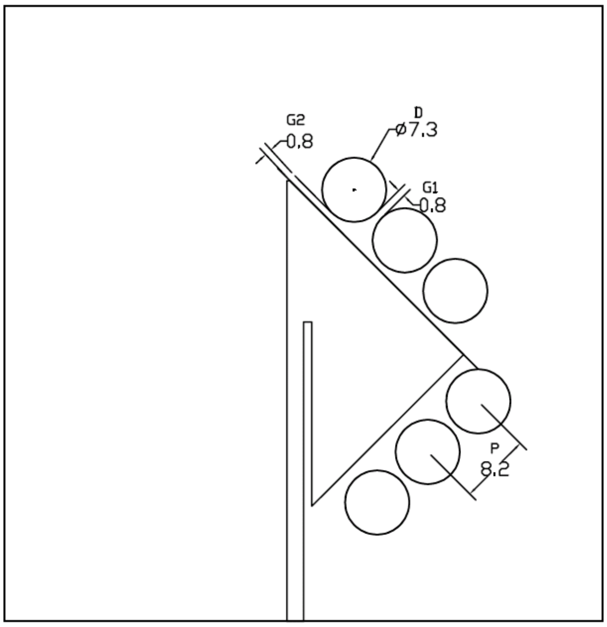


Figure 7: Numerical parameters of HMA with EBG (all dimensions are in mm)

Figure 7 shows the numerical parameter of HMA with EBG, G1 is the gap between adjacent circular EBG configuration, G2 is the gap between patch edge and circular EBG configuration, D is the diameter of circular EBG configuration and P is the pitch of circular EBG configuration.

An evaluation of the HMA with circular EBG has been carried out by keeping the numerical dimensions of the patch and circular EBG constant. Various gap sizes were selected considering that the selected gaps are relatively small to increase the value of capacitance. In view, the selected gap should not be complicated to fabricate. The parameters related to the design of the EBG have been chosen accordingly to the desired frequency. The diameter of EBG unit cell (D) was 0.04λ to 0.20λ, pitch of circular EBG configuration (distance between center of EBG unit cell) P was 0.05λ to 0.1λ and gap between patch edge and EBG unit cell G2 was ≤ 0.01λ. During the evaluation, different gap sizes were considered ranging from 0.5mm to

1.5mm. Observation was recorded by changing the gap between the edge of the HMA and the circular EBG are given in Table 1.

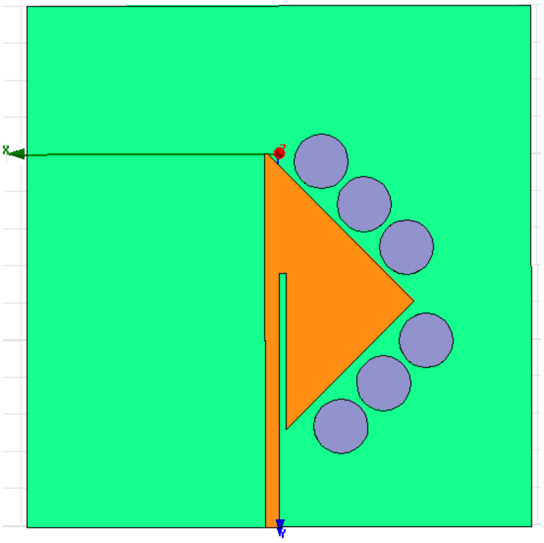


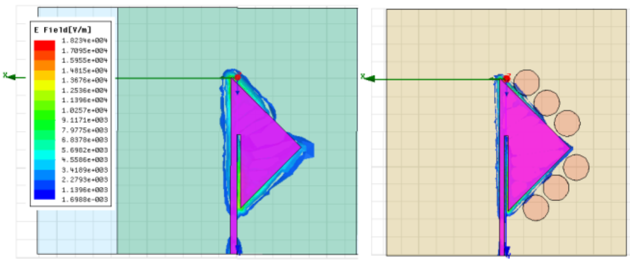
Figure 8 Simulation model of HMA with circular shape EBG

Table 1
Analysis of simulated results for variation in distance between edge of HMA and circular EBG

Distance (mm)(G2)	Resonance Frequency (GHz)	Return Loss (dB)	Gain (dB)
0.5	2.455	-12.42	4.528
0.8	2.467	-11.60	4.665
1.0	2.470	-11.07	4.650
1.5	2.472	-11.49	4.610

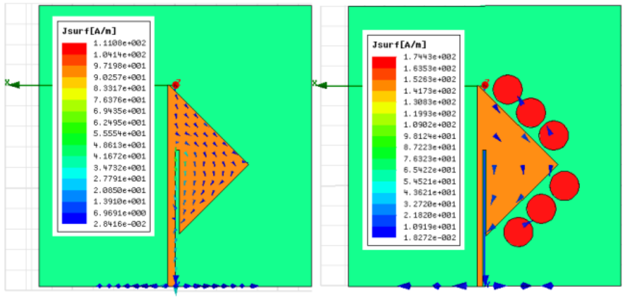
As the gap (G2) between the edge of the HMA and circular EBG varies from 0.5mm to 0.8mm, the gain increases. But if we increase the gap furthermore, the gain continues to decrease. Changes are also observed in the frequency and simulated return loss by varying the distance between circular EBG and the edges of the patch without changing physical dimensions of HMA. The best performance was obtained when the gap was G2 = 0.8 mm. The gain obtained at G2=0.8mm is 4.665dB.

Circular EBG of diameter 7.35 mm along the edges of HMA at 0.8mm distance parallel to respective edge was finalized by above parametric study which shows the better performance. It was observed that the gain improved by 6.325 dB with the introduction of circular EBG. Integrating EBG configuration in HMA showed 4.665 dB gain *(at θ = -20°)*. EBG configuration reduced scattering of the wave along the edges by controlling the surface waves and improved the gain.



(a) (b)

Figure 9: E-Field distribution of (a) HMA without circular EBG & (b) HMA with circular EBG



(a) (b)

Figure 10: Current distribution of (a) HMA without circular EBG & (b) HMA with circular EBG

E-field and current distribution mechanism over the simulated structure of antenna were studied. Figure 9 (a) and (b) show the e-field of HMA before and after insertion of the EBG configuration. It shows that the electric field distribution and E-Field intensity were between and around the antenna. From Figure 9, it is indirectly showed that energy gets attenuated within the EBG cell. Figure 10 (a) and (b) shows the current distribution of HMA before and after insertion of EBG configuration. It is observed that in HMA without EBG large surface current existed over the patch and feed line. The amount of surface current along the feed line was also minimized, but the negligible amount remained. In order to suppress undesired surface waves, patch should be surrounded by the EBG structure [13, 19]. Here, we implemented the EBG structure along the edges of the patch and the surface current was effectively suppressed. Thus, EBG acts as a blocking wall for the surface wave propagation. Further, to improve surface wave reduction, a row of the EBG structure can be inserted along the microstrip line.

Table 2
Simulated result comparison of conventional square microstrip antenna, HMA without EBG and HMA with EBG

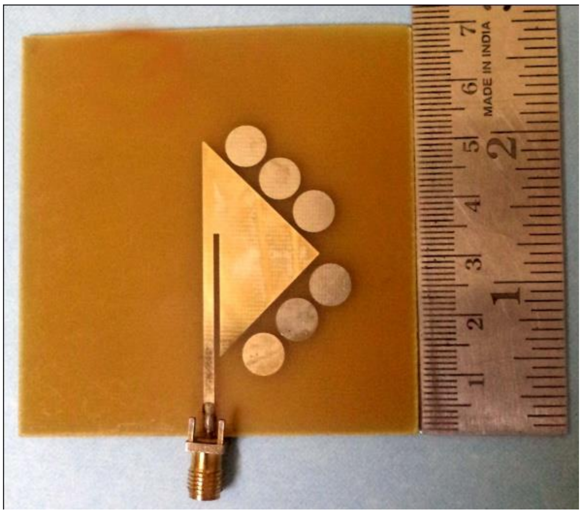
Parameter	Conventional Square MA	HMA without EBG	HMA with EBG
Frequency (GHz)	2.42	2.45	2.46
S11 (dB)	-20.981	-25.085	-11.603
Gain (dB)	-0.069	-1.660	4.665
Bandwidth(MHz)	63	42.5	25
Patch Area (mm^2)	819.06	386.79	641.37
% size reduction by with respect SMA	100%	52.77%	21.69%

Table 2 shows HMA without EBG, which provides miniaturization with a reduction of gain by -1.729dB. To improve gain parameter, EBG configuration was integrated by keeping the physical volume of HMA constant. Improvement in the radiation properties was observed after the implementation of circular EBG along the edges. The simulated gain obtained was 2.398 dB *(at θ = 0°)* and 4.665 dB *(at θ = -20°)*.

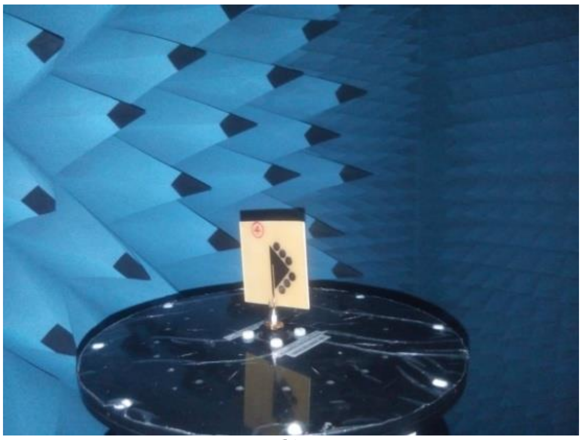
IV. Results and Discussion

A prototype of HMA with EBG was fabricated using FR4 Epoxy substrate with dielectric constant of 4.4 and loss tangent 0.02 having a thickness of 1.6mm. The front profile and test setup of a fabricated prototype of HMA with EBG are shown in Figure 11 (a) and (b) respectively. The prototype was tested for return loss and VSWR by using

Agilent E5071C ENA series Network Analyzer and the radiation pattern was measured in an anechoic chamber.



(a)



(b)

Figure 11 (a) Fabricated prototype of HMA with circular EBG and (b) its Test set up

Figure 12 shows the measured and simulated return loss of prototype antenna. Antenna with EBG structure operates (return loss <-10 dB) from 2.46 to 2.52 GHz. It indicates the bandwidth of 60 MHz. Measured return loss was -18.168 dB and VSWR was 1.25 for the frequency of 2.49 GHz. Figure 13 shows the simulated and measured radiation pattern for gain. The pPrototype of half microstrip antenna with EBG configuration exhibits good radiation pattern with gain 3.18 dB *(at* $\theta = 0°$*)* and 4.45 *(at* $\theta = -20°$*)*. The inclusion of EBG configuration improved the radiation properties of the antenna.

V. Conclusion

In this paper, successful implementation of the circular EBG configuration along the edges of miniaturized half microstrip antenna has been achieved. It can be concluded that EBG design is possible with ease of fabrication and planar configuration. Overall size reduction was obtained by 52.77% without EBG configuration and 21.69% with EBG configuration. The feeding of Antenna was matched for operation frequency with S11 <-10 dB. It was also observed that size reduction affects the gain, which was recovered and enhanced with the EBG configuration implementation. This suppressed the propagating surface waves. Proposed method improved the measured gain of the miniaturized antenna by about 4.45 dB at 2.49 GHz with a bandwidth of 60 MHz.

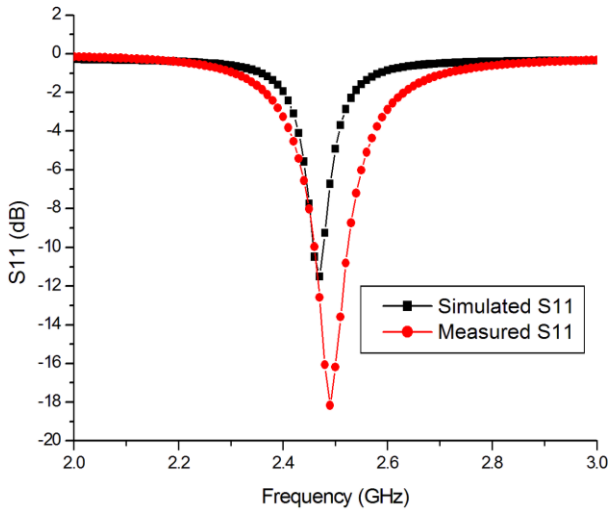


Figure 12: Simulated and measured return loss of HMA with EBG.

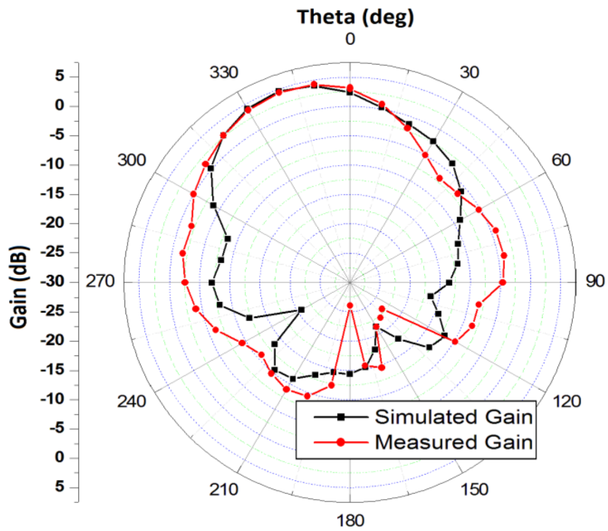


Figure 13: Simulated and measured Gain of HMA with EBG.

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