DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

Design of high gain and wide band EBG resonator antenna with dual layers of same dielectric superstrate at X-bands

Tariq Rahim[1](rahim372@gmail.com), Jiadong Xu[1](jdxu@nwpu.edu.cn)
1 School of Electronic and Information Engineering Northwestern Polytechnic University, 710129, Shaanxi, Xian, China.

***Abstract*— A wide band EBG resonator antenna with two layer of dielectric superstrates of the same material is design which is operating in X band. The EBG superstrates act as Partially Reflective Surfaces (PRS) having positive reflection phase curve which are suspended above a double sided dipole patch antenna fed by a coaxial cable pass through ground plane. Thus a resonator cavity is constructed which increases the bandwidth and gain of the feed antenna. The measured results validate the simulation results obtain from Computer Simulation Technology (CST) microwave studio. These results show that the antenna posses a 3 dB gain bandwidth from 8.5 GHz to 11.2 GHz, with a peak gain of 15.3 dBi. Furthermore, the scattering parameter S11 is well within range from 8.6 GHz to 11 GHz.**

***Index Terms*—** Antenna, CST, EBG resonator antenna, superstrate.

I. INTRODUCTION

Electromagnetic Band Gap (EBG) structure is extensively studied in the last decade due to its potential in controlling the electromagnetic wave for various applications. Among these applications wideband and high gain resonator antenna design were studied by different authors [1-5]. Most of the conventional EBG resonator antenna the EBG structure is suspended at a proper height above the feed antenna backed by the ground plane. This type of design configuration drastically reduces the feed losses and also avoids the complex feed structure particularly at higher frequency bands. Different types of feed antennas were used by many authors but we proposed double sided microstrip dipole antenna. With the daily increase in the demands of high gain, low profile and small size antennas for modern radar and communication systems particularly in microwave and millimeter wave bands. Antennas such as reflector antennas, dielectric lens antennas, slotted wave guide antennas, horn antennas, and microstrip patch array antennas are conventionally used to fulfill these requirements. However, these types of antennas exhibits a few disadvantages such as complex structure, high cost, and high aperture size which makes EBG resonator antennas an interesting candidate to overcome these drawbacks [6-12]. Therefore, EBG resonator antennas are extensively under study for the last decade to exploits its simplicity, low aperture size and high gain. The EBG antenna is constructed by placing EBG superstrates (act like Partially Reflecting Surfaces (PRS) at the design frequency) above the ground and feed by a feed antenna at the center to form an air-filled cavity between the EBG

 received 16 Nov 2012; for review 15 Nov 2015; accepted 21 March 2016
  ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

superstrate and ground plane [13-21]. In addition to the feed antenna the major characteristics of the EBG resonator antenna, such as its design frequency, directivity, gain bandwidth and radiation patterns, are determined by the property of the superstrate. The operating frequency depends on the following equation [22],

$$f = \frac{c}{4\pi h}(\varphi_H + \varphi_L - 2N\pi) \qquad N = 0,1,2,.... \qquad (1)$$

Where, φ_H and φ_L are the reflection phases of the superstrate used and the ground plane, respectively, while h is the distance between the superstrate and the ground plane. The boresight gain (G) relative to the feed antenna is given by

$$G = \frac{S}{F^2(\theta)} = \frac{1+\rho}{1-\rho} \qquad (2)$$

In the above relation S is the power pattern, $F(\theta)$ is the element pattern and ρ is the magnitude of the reflection coefficient of the superstrate used. To keep a low profile, normally the first resonance is taken at value N=0. With a perfectly electric conducting (PEC) ground plane $\varphi_L = \pi$, (1) can be rearranged as

$$\varphi_H = \frac{4\pi hf}{c}(2N-1)\pi \qquad N = 0,1,2,.... \qquad (3)$$

The expression given in (3) illustrates that a wideband EBG resonator antenna could be obtained by using a superstrate with a reflection phase of positive slope at the desired frequency. Superstrate with these characteristics can be constructed by 2-D printed metal strips [18] and 1-D dielectric substrates [19], respectively, and used in several antenna designs [20-24].

Different types of feed antenna can be used to excite the cavity. In this manuscript we use a patch based dipole fabricated on a low loss substrate. The feed antenna is also placed at an optimized distance above the ground plane which minimizes the effects of the surface waves. The resonator cavity forms between the PRS and the ground plane have in phase fields in boresight direction which contributes to the enhancement of gain and directivity. Due to the absence of transverse modes at the operating frequency there is no need to fabricate a side wall. Moreover, in addition to the feed antenna gain and bandwidth the design of the EBG superstrates also contribute in the overall gain and bandwidth of the EBG resonator antenna. The PRS placed at a distance h from the ground plane and generate multiple reflections in the cavity. Different types of EBG structures are used as PRSs to form EBG resonator antennas have been design, such as 1-D dielectric slabs [1], 2-D dielectric grids and rods [3], 2-D printed frequency selective surfaces (FSSs) [4], 2-D metallic apertures in a conducting plate [5], and 3-D woodpile structures [6]. Structures based on 1-D dielectric slabs and printed FSSs are preferable because they are simple and easy for fabrication. The EBG antenna exhibits advantages such as high directivity and high radiation efficiency. A mushroom type high impedance surface (HIS) with size-tapered patches and a single layer printed FSS were applied as the ground plane and the PRS, respectively, in the design of a wideband FP resonator antenna [10]. In this work, a wideband EBG resonator antenna having two superstrate whose reflection phase gradient is positive at the required central frequency. The antenna was simulated in Computer Simulation Technology

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

(CST) Microwave Studio 2012. The simulated results obtain from CST are validated by the measured results.

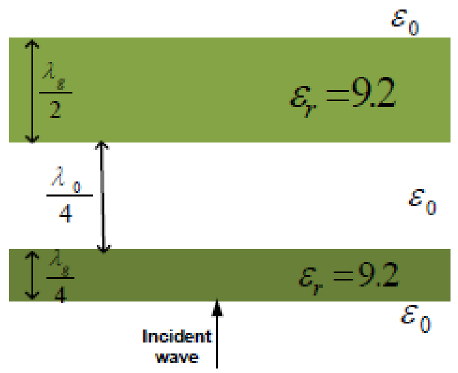

Fig. Structure of the proposed EBG act as superstrate

II. GEOMETRY OF THE PROPOSED EBG STRUCTURE

In this manuscripts different conventional electromagnetic band gap (EBG) structures are used for the improvement of gain of EBG resonator antennas [9-11]. However, the narrow bandwidth limitation makes the final antenna having small bandwidth. This problem is address by design of PRS having positive reflection phase gradient, which makes these antenna wideband. Therefore a double layer superstrate is proposed whose reflective phase gradient is positive. The design parameters of the proposed EBG structure used for the wideband antenna are depicted in Fig. 1, which contains two dielectric substrates having the same dielectric constant. The dielectric substrates are made of Rogers TMM 10 substrate having dielectric constant value (ε_r=9.2), and loss tangent value 0.0022. The thickness of lower substrate is approximately 2.49 mm at central frequency 10 GHz. The upper dielectric substrate thickness is approximately 4.98 mm. The distance between these two dielectric substrates is approximately equal to 7.5mm.

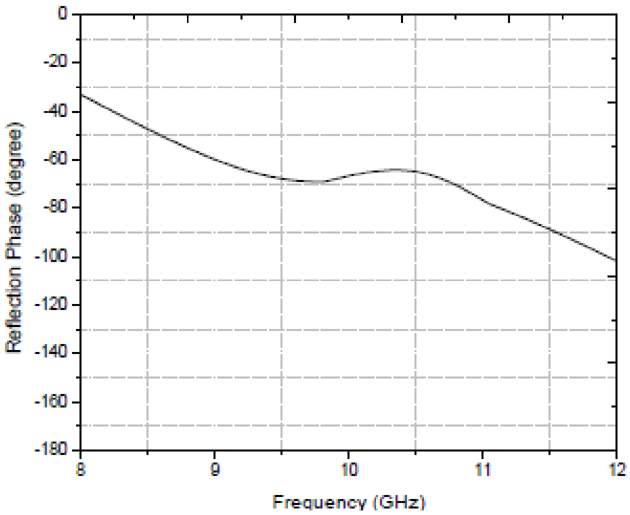

Fig. 2. Plot of the reflection coefficient phase

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

Fig. 2 illustrates the reflection coefficient phase and magnitude which can be calculated by transmission line theory. A positive phase gradient around 10 GHz is observed for the proposed EBG structure due to the dual layer configuration shown in Fig.1. Most of the conventional EBG structure have negative phase gradient which exhibits relatively small bandwidth. The reflection magnitudes shown in Fig. 3 have a minimum value of 0.55 at 9.55 GHz. The detail analysis of the same type of EBG superstrate is done in [25] using transmission line model. The structure is modeled using equivalent cascade transmission line network and analyzed using smith chart.

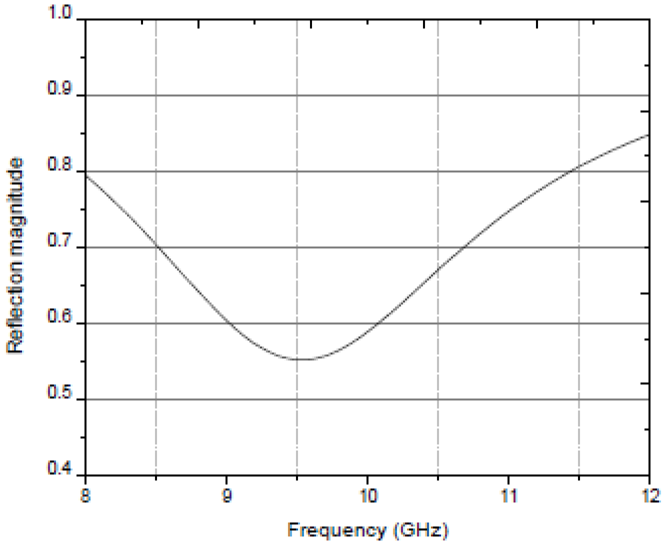

Fig. 3. Plot of the magnitude of the reflection coefficient

III. FEED ANTENNA

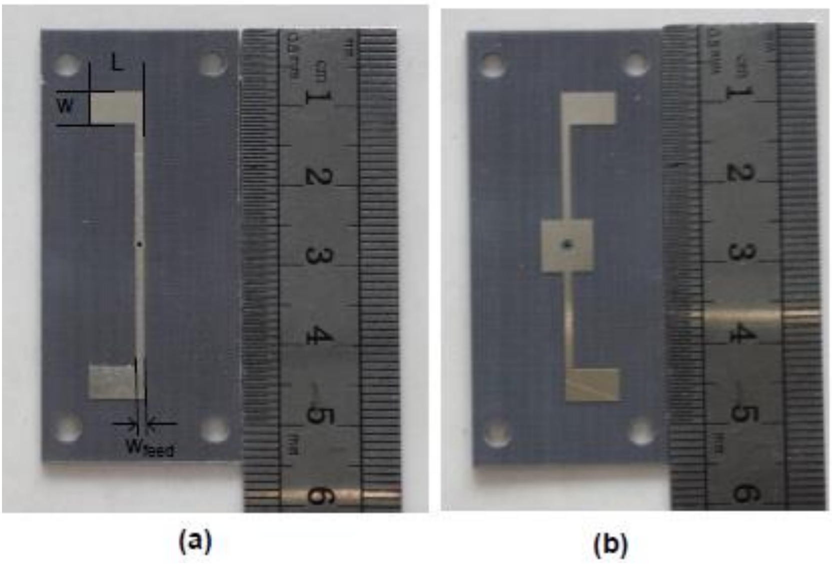

Fig. 4. The fabricated model (a) Top view of fabricated dipole with dimensions (b) Bottom view of the fabricated dipole

In addition to the proper design of the EBG structure the feed antenna also play an important role in

ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

the design of EBG resonator antenna. Different type of antennas are used as a feed antenna for the EBG resonator antennas such as waveguide aperture in the ground plane [19], probe-fed patch antenna [20], monopole antenna [21], slot coupled patch antenna [22].

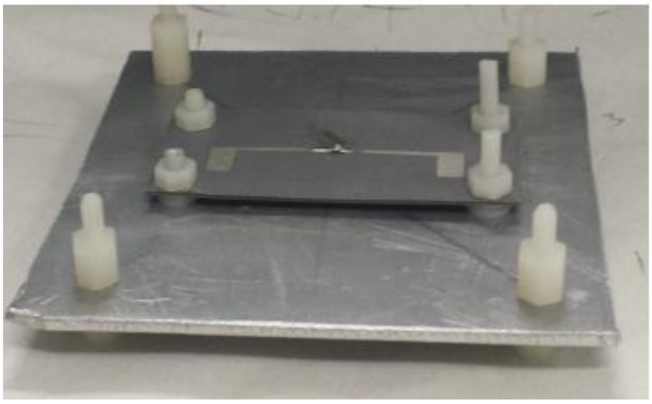

Fig. 5. Fabricated assembled feed dipole antenna

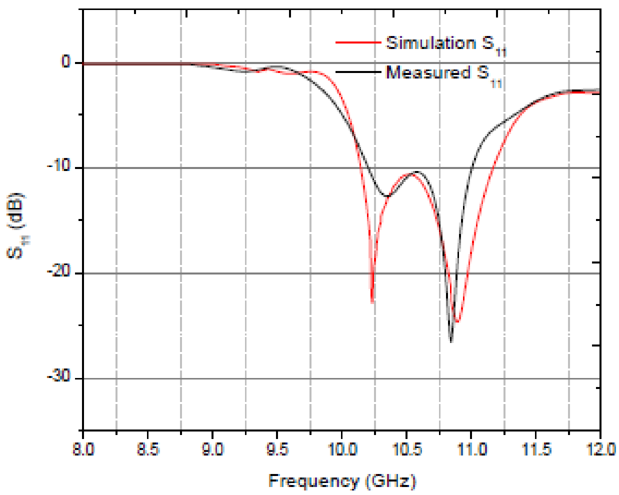

Fig. 6. The plot of the simulated and measured scattering parameter S_{11} for the feed dipole antenna

In this work a double side patch dipole antenna fabricated on both side low loss substrate as shown in the Fig. 4. Fig. 4 (a) shows the top view and one pole of each dipole can be seen. The other pole of each dipole element is etched on the bottom of the dielectric substrate as shown in Fig. 4 (b). The antenna is design on a low loss dielectric substrate with a thickness of 0.8mm and having dielectric constant of *2.65*. The dipole patch antenna is spaced from the ground plane by 2.5mm air gap with Teflon spacers at all corners of the substrate. These dielectric spacers are also included in the design of antenna in the CST. The air gap drastically reduces the surface wave and thus gives us good impedance matching at the desired frequency bands. The dimensions of the ground plane is $2.4\lambda_0$ x $2.4\lambda_0$ at *10* GHz. The dimension of the antenna and their feed are $L = 6.85\ mm$, $W = 4.6\ mm$, and $W_{feed} = 1mm$. This feeding antenna is designed using CST Microwave Studio 2012 and then fabricated

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

using etching technique. The simulated S_{11} of the antenna is validated by the measured S_{11} as shown in the Fig. 5. There is some difference in both the results which may be associated with the fabrication tolerances and poor performance of the SMA connector at high frequencies. The polar plot for the radiation pattern of the antenna in the E-plane (yoz) and H-plane (xoz) at *10* GHz are shown in Fig. 6. The fabricated feed antenna is shown in Fig. 7. This antenna is feed from the bottom which is easy to handle in comparison to side feed antennas [22-26]. This antenna is used as a feed antenna for the design of wide band EBG antenna discussed in the next section.

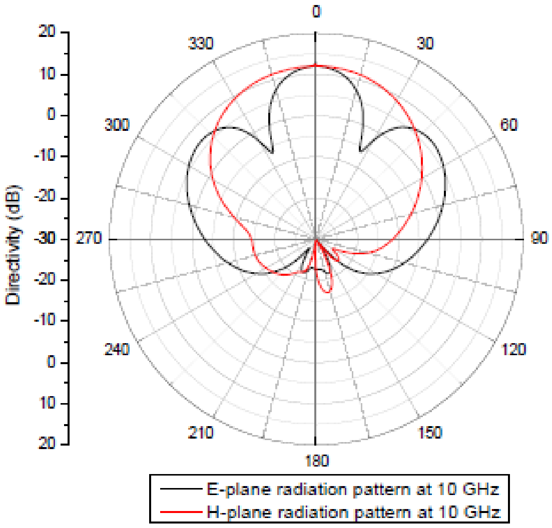

Fig. 7. The simulated radiation pattern of the feed dipole in E-plane and H-plane

IV. EBG RESONATOR ANTENNA DESIGN

The wideband EBG resonator antenna is design using the EBG superstrates and the wideband feed dipole antenna describe in the previous sections. The EBG structure is suspended at a height *h* above the aluminum ground plane with the help of pillars made of low loss dielectric materials Teflon as shown in Fig. 8.

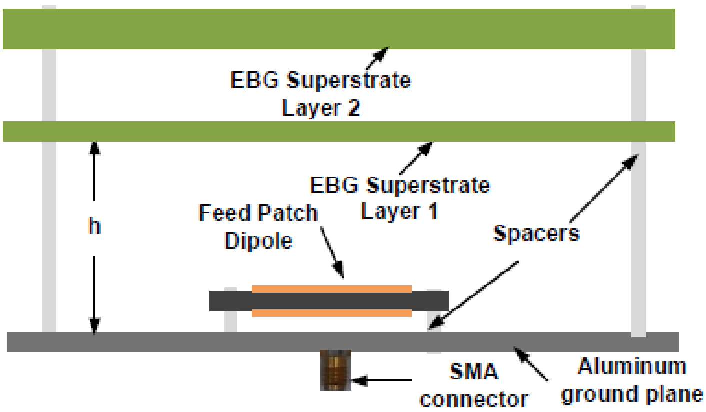

Fig. 8. The model structure of the proposed EBG resonator antenna

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

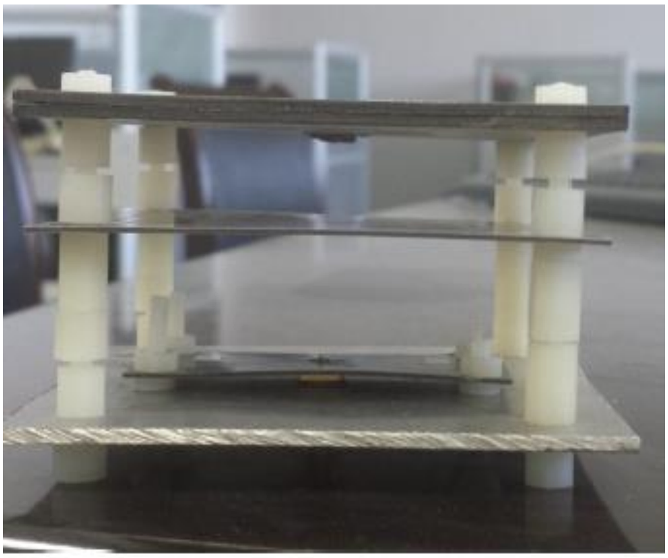

Fig. 9. The fabricated prototype of the proposed EBG antenna

These Teflon spacers with diameter *2.5mm* and having a dielectric constant of *2.1* is also modeled in CST to make their electromagnetic effect also into account. The antenna is feed at the center with the help of feed antenna describe in the previous section decreases the diffractions at the edge. Furthermore, as the EBG structure design was based on the excitation of plane wave and all the design parameters of the antenna cannot be varied. However, the distance between the EBG and the ground plane *h* is adjustable, which is optimized to *15.5* mm to get the satisfactory results. The final optimized dimensions of the antenna are *72mm* x *72mm* x *36mm*. The fabricated prototype antenna is shown in the Fig. 9.

V. RESULTS AND DISCUSSIONS

The simulation and measured reflection coefficient (S_{11}) of the proposed EBG antenna is illustrated in Fig. 10. The simulation results are obtain from CST 2012 using full wave analysis which are validated with the help of measured results which are obtain with the help of an Agilent Vector Network Analyzer (VNA) E8363B. The simulated impedance bandwidth for S_{11} < -10dB is equal to 2.65 GHz ranging from 8.65 GHz to 11.3 GHz. However, the measured impedance bandwidth for S_{11} <-10dB is equal to 2.55 GHz ranging from 8.7 GHz to 11.25 GHz. These few discrepancies may be due to fabrication and assembling tolerances. It is also observed that the bandwidth of proposed EBG antenna drastically increases in comparison to the feed antenna mostly towards the lower frequencies. The gain and radiation pattern of the antenna were measured in an anechoic chamber with the help of Agilent VNA E8363B and standard gain horn antennas. The simulated and measured radiation patterns at 8.7 GHz, 10 GHz, and 11 GHz in E-plane are shown in Fig. 11, Fig. 12, Fig. 13 respectively. The simulated and measured radiation patterns are shown in Fig. 14, Fig. 15, Fig. 16 respectively.

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

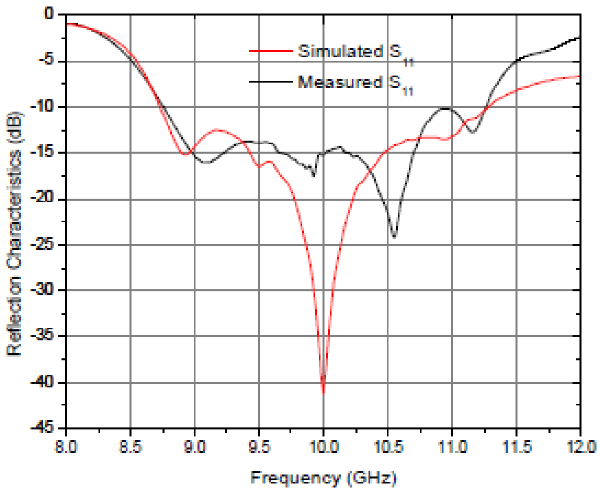

Fig. 10. The plot of simulated and measured reflection spectra of the proposed EBG resonator antenna

The simulated radiation pattern obtained from the CST is validated by the measured results in general, particularly in the boresight. The measured gain is slightly lesser from simulated one due to the fabrications and measuring tolerances. The sidelobes levels are more different in simulation and measured results. This may be due to the radiation of the cable, SMA connector and fabrication tolerances. The gain versus frequency plot is plotted in the Fig. 17, which depicts a 3dB bandwidth of about 2.5 GHz ranging from 8.5 GHz to 11 GHz. As compared to the results given in [22], the gain of the antenna is higher by about 3 dB.

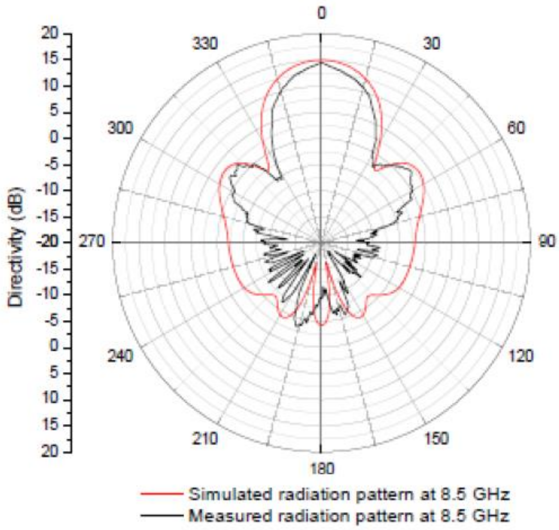

Fig. 11. Polar plot of the simulated and measured radiation pattern in E-plane at 8.5 GHz

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

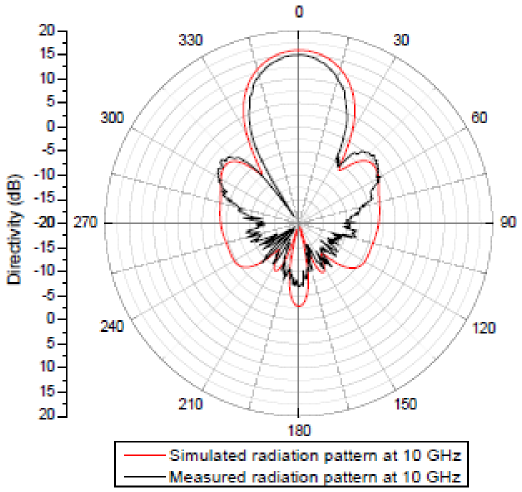

Fig. 12. Polar plot of the simulated and measured radiation pattern in E-plane at 10 GHz

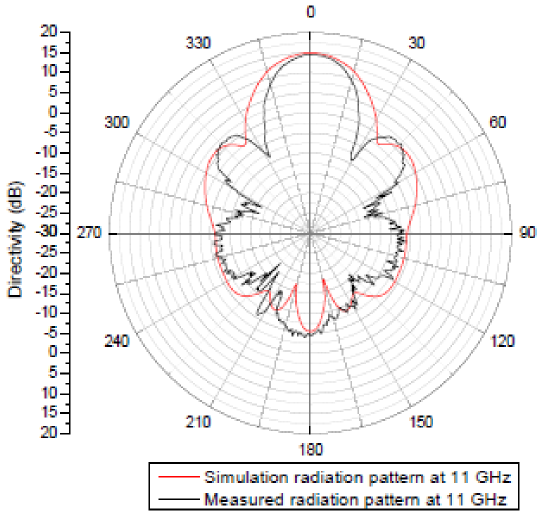

Fig. 13. Polar plot of the simulated and measured radiation pattern in E-plane at 11 GHz

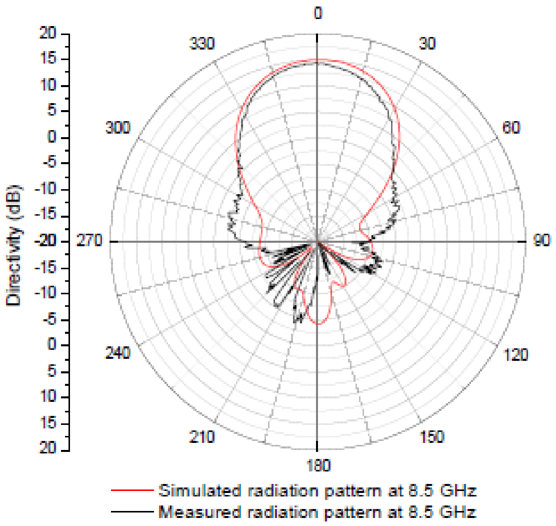

Fig. 14. Polar plot of the simulated and measured radiation pattern in H-plane at 8.5 GHz

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

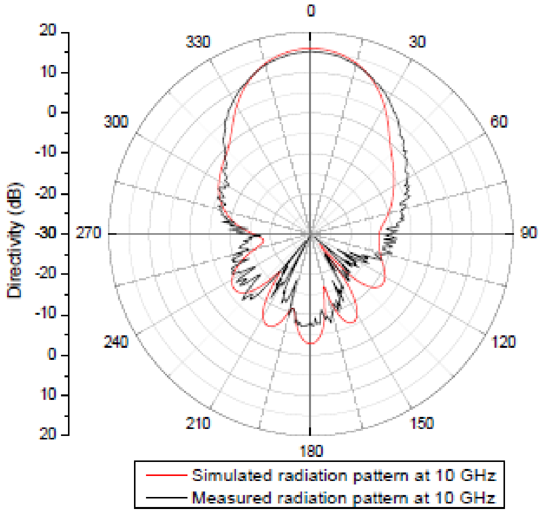

Fig. 15. Polar plot of the simulated and measured radiation pattern in H-plane at 10 GHz

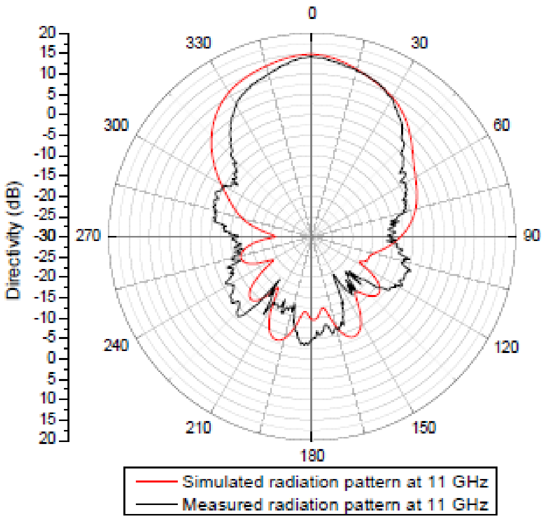

Fig. 16. Polar plot of the simulated and measured radiation pattern in H-plane at 11 GHz

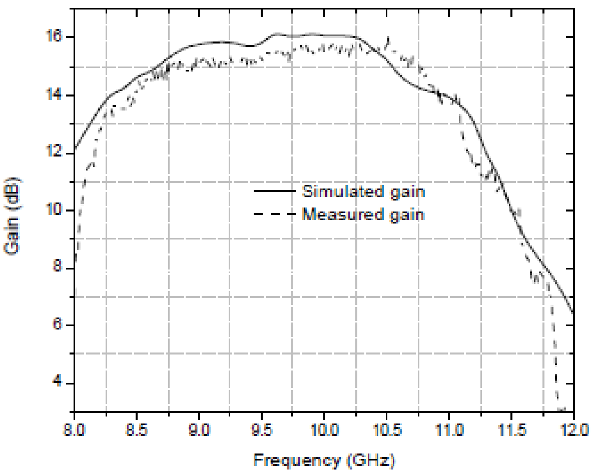

Fig. 17. The gain VS frequency plot of the prototype antenna at X-band

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

VI. CONCLUSIONS

The EBG resonator antenna with high gain and large bandwidth feed by a double sided dipole patch antenna was proposed. An EBG superstrate composed of double layer dielectric sheets of same materials with different thickness which exhibit positive reflection phase gradient at the desired operating frequency band. This positive phase gradient contributes to the widening of bandwidth. A prototype EBG resonator antenna was design and fabricated at X-band. The simulation results obtained from CST microwave 2012 were compared with measured results obtain with the help of VNA and anechoic chamber system and were found matching at the desire frequency band. The proposed design can be extended to different frequencies by properly adjusting the dimensions of the EBG antenna.

REFERENCES

[1] Zeb, B. A., Y. Ge, K. P. Esselle, Z. Sun, and M. E. Tobar, A simple dual band electromagnetic band gap resonator antenna based on inverted reflection phase gradient, IEEE Transactions on Antennas and Propagation, Vol. 60, No. 10, 4522-4529, Oct. 2012.

[2] B.A. Zeb, K.P. Esselle and R.M. Hashmi Computational Models for Bandwidth Enhancement of Electromagnetic Bandgap (EBG) Resonator Antennas and their Limitations 2015 IEEE International Conference on Computational Electromagnetics, p 19-21, March 2, 2015.

[3] Y. J. Lee, J. Yeo, R. Mittra, and S. P. Wee, Application of electromagnetic bandgap (EBG) superstrates with controllable defects for a class of patch antennas as spatial angular filters, IEEE Trans. Antennas Propag., vol. 53, no. 1, pp. 224-235, Jan. 2005.

[4] A. R. Vaidya, R. K. Gupta, S. K.Mishra, and J.Mukherjee, High-gain low side lobe level Fabry Perot cavity antenna with feed patch array, Progr. Electromagn. Res., vol. 28, pp. 223-238, 2012.

[5] J. R. Kelly, T. Kokkinos, and A. P. Feresidis, Analysis and design of sub wavelength resonant cavity type 2-D leaky-wave antennas, IEEE Trans. Antennas Propag., vol. 56, no. 9, pp. 2817-2825, Sep. 2008.

[6] Y. Lee, X. Lu, Y. Hao, S. Yang, J. Evans, and C. G. Parini, Low-profile directive millimeter-wave antennas using free-formed three-dimensional (3-D) electromagnetic bandgap structures, IEEE Trans. Antennas Propag. vol. 57, no. 10, pp. 2893-2903, Oct. 2009.

[7] R. M. Hashmi, B. A. Zeb, and K. P. Esselle, Wideband High-Gain EBG Resonator Antennas With Small Footprints and All-Dielectric Superstructures, IEEE Transactions on Antennas and Propagation, vol. 62, pp. 2970-2977, 2014.

[8] K. Konstantinidis, A. Feresidis, and P. S. Hall, Multi-layer Partially Reflective Surfaces for Broadband Fabry-Perot Cavity Antennas, IEEE Transactions on Antennas and Propagation, 2014.

[9] H. Vettikalladi, O. Lafond, and M. Himdi, High-efficient and high gain superstrate antenna for 60-GHz indoor communication, IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 1422-1425, 2009.

[10] Z. H. Wu and W. X. Zhang, Broadband printed compound air-fed array antennas, IEEE Antennas Wireless Propag. Lett., vol. 9, pp. 187-190, 2010.

[11] Moustafa, L. and B. Jecko, EBG structure with wide defect band for broadband cavity antenna applications, IEEE Antennas and Wireless Propagation Letters, Vol. 7, 693-696, 2008.

[12] Leger, L., C. Serier, R. Chantalat, M. Thevenot, T. Monediere, and B.Jecko, 1D dielectric electromagnetic band gap (EBG) resonator antenna design, Annales des Telecommunications, Vol. 59, No. 34, 242-260, Mar.Apr. 2004.

[13] Costa, F. and A. Monorchio, Design of subwavelength tunable and steerable Fabry-Perot or leaky wave antennas, Progress In Electromagnetics Research, Vol. 111, 467-481, 2011.

[14] Pirhadi, A., F. Keshmiri, M. Hakkak, and M. Tayarani, Analysis and design of dual band high directive EBG resonator antenna using square loop FSS as superstrate layer, Progress In Electromagnetics Research, Vol. 70, 1-20, 2007.

[15] Feresidis, A. P., G. Goussetis, S. Wang, and J. C. Vardaxoglou, Artificial magnetic conductor surfaces and their application to low-profile highgain planar antennas, IEEE Transactions on Antennas and Propagation, Vol. 53, No. 1, 209-215, Jan. 2005.

[16] Rodes, E., M. Diblanc, E. Arnaud, T. Monediere, and B. Jecko, Dual band EBG resonator antenna using a single-layer FSS, IEEE Antennas and Wireless Propagation Letters, Vol. 6, 368- 371, 2007.

[17] Leger, L., T. Monediere, and B. Jecko, Enhancement of gain and radiation bandwidth for a planar 1-D EBG antenna, IEEE Microwave and Wireless Components Letters, Vol. 15, No. 9, 573- 575, Sep. 2005.

[18] Moustafa, L. and B. Jecko, Design of a wideband highly directive EBG antenna using double-layer frequency selective surfaces and multifeed technique for application in the Ku-band, IEEE Antennas and Wireless Propagation Letters, Vol. 9, 342-346, 2010.

[19] Feresidis, A. P. and J. C. Vardaxoglou, High gain planar antenna using optimized partially reflective surfaces, IEE Proceedings on Microwaves, Antennas and Propagation, Vol. 148, No. 6, 345-350, Dec. 2001.

[20] Moustafa, L. and B. Jecko, Design and realization of a wide- band EBG antenna based on FSS and operating in the Ku-band, International Journal of Antennas and Propagation, Vol. 2010, 8 pages, Article ID 139069, 2010.

[21] Ge, Y., K. P. Esselle, and T. S. Bird, The use of simple thin partially reflective surfaces with positive reflection phase gradients to design wideband, low-profile EBG resonator antennas, IEEE Transactions on Antennas and Propagation, Vol. 60, No. 2, 743- 750, Feb. 2012.

DOI: http://dx.doi.org/10.1590/2179-10742016v15i2558

[22] Naizhi W, Qiang Liu, Changying Wu, Larbi Talbi, Qingsheng Zeng, and Jiadong Xu, Wideband Fabry-Perot Resonator Antenna with two Complementary FSS Layers, IEEE Transactions on Antennas and Propagation, Vol. 62, No. 5, 2463-2471, May. 2014.

[23] N. Wang, L. Talbi, Q. Zeng and J. Xu, Wideband High Gain 1-D EBG Resonator Antenna, IEEE International Wireless Symposium, IWS 2013.

[24] N. Wang, J. Xu, and Q. Zeng Broadband EBG resonator antenna using a combination of different dielectric substrates, IEEE Antennas and Propagation Society International Symposium, APSURSI 2013.

[25] N. Wang, C. Zhang, Q. Zeng, N. Wang, and Jiadong Xu New Dielectric 1-D EBG Structure for the Design of Wideband Resonator Antennas, Progress In Electromagnetics Research, Vol. 141, 233-248, 2013.

[26] N. Wang, L. Talbi, Q. Zeng and J. Xu, Impacts of Surface Waves on performance of an EBG Resonator Antenna, IEEE International Wireless Symposium, IWS 2013.

[27] Feresidis, A. P. and J. C. Vardaxoglou, A broadband high gain resonant cavity antenna with single feed, First European Conference on Antennas and Propagation, EuCAP 2006, 1-5, Nov. 2006.

[28] E. Rodes, M. Diblanc, E. Arnaud, T. Monediere, and B. Jecko, Dualband EBG resonator antenna using a single-layer FSS, IEEE Antennas Wireless Propag. Lett., vol. 6, pp. 368371, 2007.

[29] A. Weily, K. P. Esselle, T. S. Bird, and B. C. Sanders, Dual resonator 1-D EBG antenna with slot array feed for improved radiation bandwidth, IET Microwaves, Antennas Propag., vol. 1, no. 1, pp. 198-203, Feb. 2007.