AN ARRAY OF ELECTROMAGNETIC BANDGAP RESONATOR ANTENNAS FOR V-BAND BACKHAUL APPLICATIONS

[1]A. LALBAKHSH, [2]M. U. AFZAL, [3]K. P. ESSELLE, [4]S. L. SMITH

[1,4]CSIRO Astronomy and Space Science, P. O. Box 76, Epping, NSW 1710, Australia
[1,2,3]School of Engineering, Macquarie University, NSW 2109, Australia
E-mail: [1]ali.lalbakhsh@mq.edu.au

Abstract- This paper presents a wideband Electromagnetic Band Gap (EBG) resonator antenna operating in V-band which can be used in an array configuration to achieve a high gain over a large frequency band. The results of both single element antenna and a 2×2 array are presented, verifying the wideband capability of the proposed structure.

Keywords- Antenna Arrays, Antenna Design, Broadband, Electromagnetic Band Gap (EBG) Resonator Antennas, EBG Structures, Directive Antennas, Satellite Communications, Wideband Antennas.

I. INTRODUCTION

There is an increasing demand for high-gain compact antennas. Such antennas can be used in point to point communication, such as satellite communication. The necessity of large bandwidth has been increased recently with the advancement in data rate in the modern communication systems [1]-[5]. Horn antennas along width reflector antennas have been a solution when high gain is required. In spite of the very good performance of these antennas, they have undesirably large size and heavy weight which make them unfit for some applications. As a result, a new generation of high gain antennas are required which do not have the above-mentioned limitations [6]-[15]. Electromagnetic band gap (EBG) resonator antennas can be a solution when high-gain and antenna size matter. The conventional EBG resonator antenna is composed of a single slab of a dielectric placed at a distance of $\lambda_0 2/$ from a ground plan, where $\lambda_0$is the free-space wavelength at the operating frequency. The presence of the metal ground plane and a dielectric slab creates a cavity, which can be excited by a simple antenna placed in the centre of the ground. Due to the partially reflecting nature of the dielectric slab, also known as superstructure, there are numerous reflections inside the cavity which can create a constructive interference above the antenna. Apart from the desired planar structure of the conventional EBG resonator antennas, they have a very small 3dB directivity bandwidth [6]-[7]. To address this deficiency and achieve a larger bandwidth that satisfies today's modern communication systems requirements, several methods have been proposed. The application of multiple dielectric surfaces as opposed to a single layer was one of the initial methods for enlarging bandwidth [9]. Despite, success in extending the bandwidth, this technique increases the antenna size, due to the additional airgaps between the multiple layers and the thickness of dielectrics. Recently frequency selective surfaces (FSS) have been proposed to be used in RCA configuration for a variety of purposes, such as phase correction, and bandwidth improvement [10]-[17]. Other applications of FSS can be found in artificial magnetic conductor (AMC), bandpass filters, and beam-steering [18]-[23].

II. DESIGN

In this paper we investigate the performance of an array of high-gain EBG resonator antenna for V-band applications. Here, we use radial permittivity variation in the PRS structure to achieve high gain and wideband characteristics. Four concentric circular dielectric materials are used in the configuration of the superstructure, where the greatest and the smallest relative permittivity is used in the central and outer regions of the PRS, as shown in Fig. 1(a). The dielectric materials used in the superstructure and their dimensions are tabulated in Table 1. The thickness of the superstructure in all four regions is 1 mm and calculated using equation (1) which is inspired by the method in [24]. The single antenna element has a slot antenna in the centre of the ground with a size of 1.8 mm × 3.4 mm, while the square metallic ground size is 15 mm, and the cavity height is 3.4 mm. A single element antenna was simulated using CST Microwave Studio, showing a peak gain of 16.9 dB at 64 GHz with a 3-dB fractional bandwidth of 21%, as shown in Fig. 2.

$$T = \frac{\lambda_{low}}{2\sqrt{\varepsilon_{super}}} \quad (1)$$

$$\varepsilon_{super} = \frac{\varepsilon_1 A_{Z1} + \varepsilon_2 A_{Z2} + \varepsilon_3 A_{Z3} + \varepsilon_4 A_{Z4} + \varepsilon_5 A_{Z5}}{A_{Z1} + A_{Z2} + A_{Z3} + A_{Z4} + A_{Z5}} \quad (2)$$

where $\lambda_{low}$is the free-space wavelength at the lowest frequency of the operating band (56 GHz).

Region	1	2	3	4	5
Substrate	Graphite	Arlon AR	ESL4120-70C	Rogers TMM6	Rogers TMM4
Permittivity	12	10	8	6	4.5
Outer Radius	2.5 mm	3.7 mm	4.9 mm	6.1 mm	7.3 mm

Table 1: Superstructure characteristics

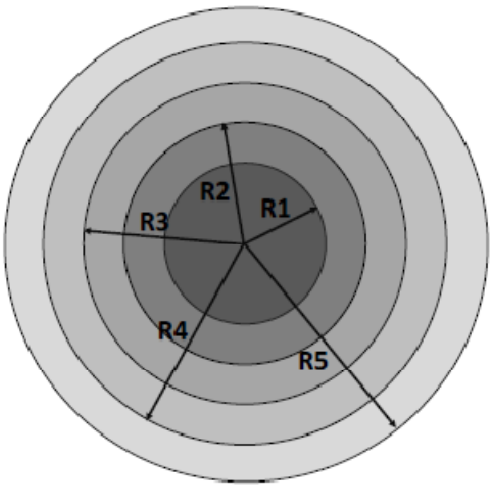


Fig. 1 Configuration of the proposed superstructure.

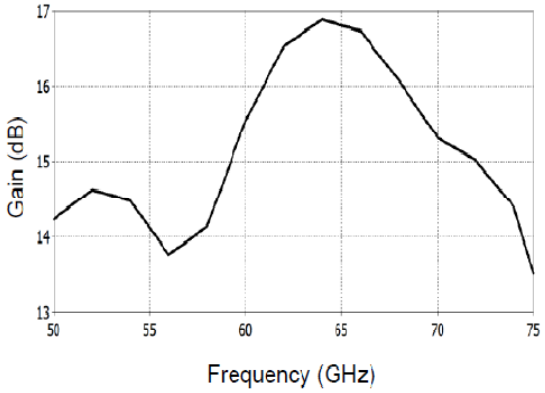


Fig. 2 Gain versus frequency of a single element antenna.

The area of the single antenna's superstructure is 5.83 $\lambda_{low\ 2}$. To make a 2×2 array of EBG resonator antenna, four single antennas are positioned at an inter-element distance of 5 mm, as it is depicted in Fig. 3. The array performance is studied using CST Microwave Studio (Time Domain). The peak directivity of the 2×2 array computed is 21.3 dB with a large 3-dB directivity bandwidth which fully covers the 3 dB gain bandwidth of a single element. The radiation patterns of the array at some frequencies over the bandwidth are shown in Fig. 4.

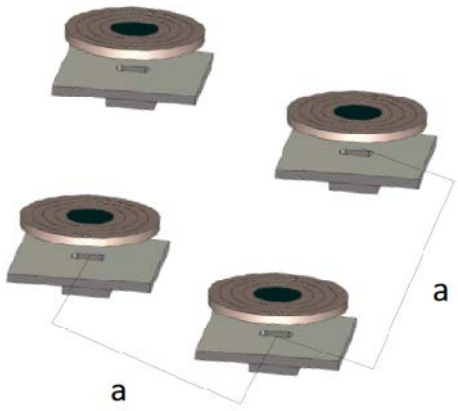


Fig. 3 2×2 array of EBG resonator antenna.

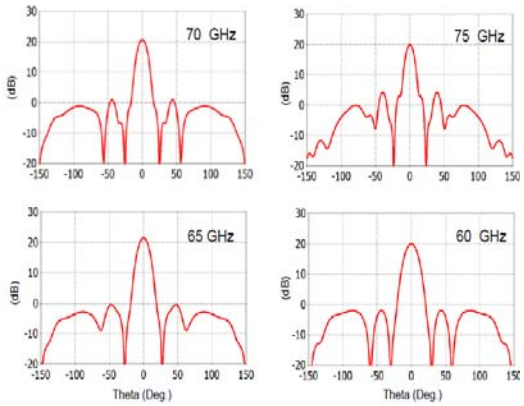


Fig. 4: Radiation patterns of the 2×2 EBG resonator array at four distinct frequencies.

III. CONCLUSION

A high-gain wideband EBG resonator antenna composed of 5 different concentric dielectrics has been proposed in the paper. The simulation results show that a single antenna has a peak gain of 16.9 at 64 GHz with a large bandwidth of 21%. A 2×2 array of the proposed antenna has been designed and simulated verifying the stable wideband performance of the proposed structure when it is used in an array configuration.

IV. REFERENCES

[1] M Hayati, S Roshani, "A broadband Doherty power amplifier with harmonic suppression" AEU-International Journal of Electronics and Communications 68 (5), 406-412, 2014.

[2] A. Lalbakhsh, M. U. Afzal, K. P. Esselle, and S. L. Smith, "Wideband Near-Field Correction of a Fabry- Perot Resonator Antenna, " IEEE Transactions on Antennas and Propagation, vol. 67, no. 3, pp. 1975-1980, 2019.

[3] R. M. Hashmi, B. A. Zeb, and K. P. Esselle, "Wideband high-gain EBG resonator antennas with small footprints and all-dielectric superstructures," IEEE Trans. Antennas Propag, vol. 62, no. 6, pp. 2970-2977, 2014.

[4] L. Moustafa and B. Jecko, "Broadband high gain compact resonator antennas using combined FSS," in Proc. IEEE Int. Antennas Propag. Symp., 2008, pp. 1–4.

[5] S Roshani, "A compact microstrip low-pass filter with ultra wide stopband using compact microstrip resonant cells," International Journal of Microwave and Wireless Technologies 9 (5), 1023-102, 2017.

[6] C. Cheype, et al., "An electromagnetic bandgap resonator antenna," IEEE Trans. Antennas Propag., vol. 50, no. 9, pp. 1285–1290, 2002.

[7] M. Thevenot, C. Cheype, A. Reineix, and B. Jecko, "Directive photonicbandgap antennas," IEEE Trans. Microw. Theory Techn., vol. 47, no. 11, pp. 2115–2122, Nov. 1999.

[8] A. Lalbakhsh, M. U Afzal and Karu P. Esselle, "A High-gain wideband ebg resonator antenna for 60 ghz unlicenced frequency band," in Proc. IEEE. 12th European Conference on Antennas and Propagation (EUCAP), April. 2018, London, UK.

[9] Affan A. Baba, et al., "A simple electromagnetic bandgap resonator antenna for 60 ghz wireless application," in Proc. IEEE. 10th European Conference on Antennas and Propagation (EUCAP) 2016, Paris, France.

[10] A. Lalbakhsh, M. U Afzal and Karu P. Esselle, "Design of an Improved Resonant Cavity Antenna," in Proc. IEEE. Int Conf. on Electromagnetics in Advanced Applications (ICEAA), Sep. 2017, Verona, Italy .

[11] A. Lalbakhsh, M. U. Afzal, K. P. Esselle, and S. L. Smith, "Single-dielectric Wideband Partially Reflecting Surface with Variable Reflection Components for Realization of a Compact High-gain Resonant Cavity Antenna, " IEEE Transactions on Antennas and Propagation, vol. 67, no. 3, pp. 1916-1921, 2019.

[12] M. Akbari, S. Gupta, M. Farahani, A. R. Sebak, and T. A. Denidni, "Gain enhancement of circularly polarized dielectric resonator antenna based on FSS superstrate for MMW applications," IEEE Trans. Antennas Propag., vol. 64, no. 12, pp. 5542–5546, Dec. 2016

[13] M. U. Afzal, A. Lalbakhsh, K. P. Esselle, "Electromagnetic-wave beam-scanning antenna using near-field rotatable graded-dielectric plates," Journal of Applied Physics 124 (23), 234901, 2018.

[14] A. Lalbakhsh and K. P. Esselle. "Directivity improvement of a Fabry-Perot Cavity Antenna by Enhancing Near Field Characteristic," in Proc. IEEE. 17th Int Symp. Antenna Technology and Applied Electromagnetics (ANTEM), Montreal, Canada, 2016.

[15] Pan Feng, and Chen Xing, "A non-uniform design of the metamaterial superstrate for the resonant cavity antenna with wideband property," Wireless Information Technology and Systems (ICWITS) and Applied Computational Electromagnetics (ACES), 2016 IEEE/ACES International Conference on. IEEE, 2016.

[16] A. Lalbakhsh, M. U. Afzal and K. P. Esselle, "Multi-objective Particle Swarm Optimization to Design a Time-delay Equalizer Metasurface for an Electromagnetic Band Gap Resonator Antenna," IEEE Antennas Wireless Propagation Letters, vol. 16, pp. 912–915, 2016.

[17] N. Wang, Q. Liu, C. Wu, L. Talbi, Q. Zeng, and J. Xu, "Wideband Fabry-Perot resonator antenna with two complementary fss layers," IEEE Trans. Antennas Propag., vol. 62, no. 5, pp. 2463–2471, 2014

[18] A. Lalbakhsh, M. U. Afzal, B. A. Zeb, and K. P. Esselle, "Design of a Dielectric Phase-correcting Structure for an EBG Resonator Antenna Using Particle Swarm Optimization, " in Proc. IEEE. Int Symp. Antennas Propag. (ISAP), Hobart, Australia, Nov. 9-12, 2015, pp. 408-410.

[19] M. Akbari, H. A. Ghalyon, M. Farahani, A.-R. Sebak, and T. A. Denidni "Spatially decoupling of CP antennas based on FSS for 30-GHz MIMO systems," IEEE Access, vol. 5, pp. 6527–6537, 2017.

[20] A. Lalbakhsh, M. U Afzal and Karu P. Esselle, S. L. Smith "A fast design procedure for quadrature reflection phase," in Proc. Progress in Electromagnetics Research Symposium-Fall, 2017, Singapore.

[21] A. Lalbakhsh, M. U. Afzal, B. A. Zeb, and K. P. Esselle, "Multi-objective particle swarm optimization for the realization of a low profile bandpass frequency selective surface, " in Proc. IEEE. Int Symp. Antennas Propag. (ISAP), Hobart, Australia, Nov. 9-12, 2015, pp. 408-410.

[22] A. Lalbakhsh, M. U Afzal and Karu P. Esselle, S. Smith "Design of an artificial magnetic conductor surface using an evolutionary algorithm," in Proc. IEEE. Int Conf. on Electromagnetics in Advanced Applications (ICEAA), Sep. 2017, Verona, Italy.

[23] A. Dadgarpour, B. Zarghooni, B. S. Virdee, and T. A. Denidni, "One-and two-dimensional beam-switching antenna for millimeter-wave MIMO applications," IEEE Trans. Antennas Propag., vol. 64, no. 2, pp. 564–573, Feb. 2016.

[24] A Lalbakhsh, UM Afzal, PK Esselle, LS Smith , "A Fabry-Perot Cavity Antenna with a Non-Uniform Permittivity Superstrate for V-band Applications," 2018 IEEE Asia-Pacific Conference on Antennas and Propagation (APCAP), 223-224.

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