Barium Strontium Titanate (BST) Array Antenna Covered with Hexagonal Split Ring Resonator (HSRR) Superstrate for High Gain and High Directive Antenna

#F.H.Wee , F.Malek
School Of Computer and Communication Engineering, Universiti Malaysia Perlis (UniMAP)
No 12&14, Jln Satu, Blok A, Kompleks Pusat Pengajian Seberang Ramai, 02000 Kuala Perlis
weefwenhoon@gmail.com, mfareq@unimap.edu.my

1. Introduction

Barium Strontium Titanate (BST) is a ferroelectric material which is under consideration as a high dielectric constant material for a number of electronic as well as microwave applications. Moreover, the ferroelectric materials present a great potential for electrically tuneable microwave devices such as phase shifters, mixers and parametric amplifiers [1]. The ferroelectrics in paraelectric phase may exhibit high dielectric constant, low losses at high frequencies, and a temperature coefficient of resonant frequency, which can be adapted to the specific application. The dielectric constant BaO-SrO-TiO_2, also known as BST, can be modified by applying a DC bias electric field.

Metamaterials which exhibit unique properties not existing for natural materials have attracted great interest in the last years [1]–[3]. Metamaterials are also called left-handed materials (LHM) in particular, in which the vectors *E, H* and *k* form a left-handed system. Since the idea proposed by Victor Veselago in 1968 [3], the availability of such a material is taken up nowadays and extended.

Recently, the demand of planar high directivity antennas, which can be applied to high speed wireless LAN, satellite reception and various point-to-point radio links, are rapidly rising. In the past few years, new methods for improving the antenna gain is the metamaterial that proposed [1]-[5] and theoretically discussed [6]. A high gain and high directive microstrip patch antenna formed with Barium Strontium Titanate (BST) ceramics and covered with Hexagonal Split Ring Resonator (HSRR) substrate has been investigated in this paper. High gain low-profile antenna design using metamaterial technology operating at WiMAX 2.3-GHz band (2.30-2.40 GHz) application is designed and simulated. The Computer Simulation Technology (CST) Microwave Studio [5] is used for the simulation.

2. BST Array Antenna Configuration

The antennas are designed using Duroid RT 5880 board as the substrate of the antenna which the dielectric constant, $\mathcal{E}r$ is 2.2 and the thickness of the board is 1.575 mm and give a characteristic impedance of almost 50 Ω (51.32 Ω) microstrip line as shown in Fig. 1 with width (*W_l*) and length (*L_l*). The length of the patch antenna determines the resonant frequency of the antenna. The width of the patch affects the resonant resistance of the antenna, with a wider patch giving a lower resistance. The patch length can be calculated :

$$L = 0.49\frac{\lambda}{\sqrt{\varepsilon}} \quad (1)$$

Where $\mathcal{E}$ is the substrate dielectric constant and *L* is the wavelength at resonance.

The microstrip feed line was 7.5 mm wide and a 0.035 mm thick copper are on the duroid RT 5880 substrate board. The BST array antenna with four different dimensions with width *w*, length *l* and thickness *t*, are adhered on the copper strip and substrate as shown in Fig. 1, while the dimensions shown in Table 1. The resulting of antenna design simulations are shown in Fig. 4 and Table 2.

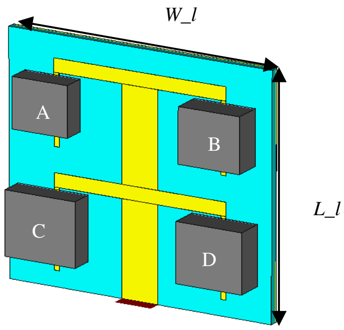


Figure 1: Four elements BST array antenna

Table 1: Dimensions of four element of BST array antenna

Configurations	Four element of BST array antenna			
Dimensions of Substrate (mm)	H_2 = 52 W_2 = 53 T_2 = 1.575			
Dimensions of BST (mm)	A	B	C	D
	h_1 =13 w_1=13 t_1 =5.5	h_2 =12 w_2=12 t_2 =4.5	h_3 =11 w_3=11 t_3=4.5	h_4 =14 w_4=14 t_4 =5.5

3. Superstrate Design

Many broadband techniques for microstrip antennas have been reported [7]-[8], and to overcome the disadvantage of low gain, some papers have proposed gain enhancement methods using multiple superstrates [8], [9]. Thus, the presence of superstrate above an antenna may adversely affect the antenna's basic performance characteristics, such as gain, radiation coefficient, and radiation efficiency. It has been reported that high gain and high directivity can be achieved if the substrate and superstrate layers are used appropriately [8]-[11].

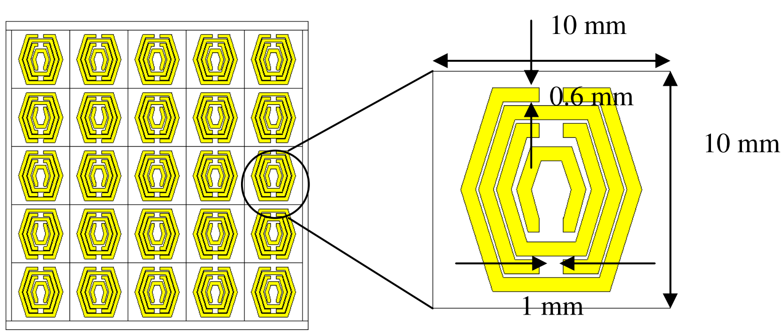
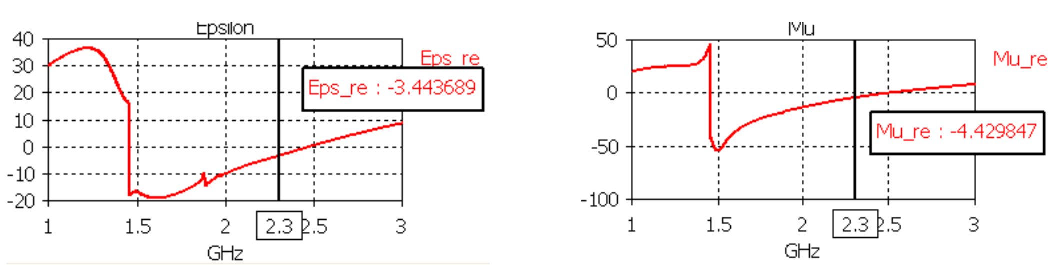


Figure 2: Hexagonal Split Ring Resonator Metamaterial Superstrate

This paper experimentally investigates the effect of a HSRR metamaterial substrate as in Fig. 2. Metamaterial exhibit negative electrical permittivity and permeability, it then having negative refractive index and left- handed material. This relationship is shown by the following Maxwell's equation for refractive index:

$$n = \pm\sqrt{\varepsilon\mu} \tag{2}$$



(a) (b)

Figure 3: Double Negative for HSRR (a) Electrical Permitivity (b) Magnetic Permeabiltiy

The superstrate that is made up of a metamaterial layer is a HSRR that composed of few cells with copper strips of three hexagon shapes in a single 10 mm x 10 mm tarconic substrate (in one cell). The width and the split distance of HSRR is 0.6 mm and 1 mm respectively as shown in Fig.2. The transmission for single-ring SRR structures is plotted in Fig.3, which is associated with a $\varepsilon < 0$ and$\mu<0$ regime (negative permittivity and negative permeability regime). In Fig. 4, the HSRRs superstrate is placed above the radiating patch BST elements at a distance d = 15 mm. The dielectric constant of the substrate (Roger RO 3010) is εr = 10.2. The thickness of the substrate is 1.575 mm. The metamaterial layer consists of 5×5 units (see Fig. 1), so the size of the substrate and the HSRR superstrate cover is 52 *mm*×53 *mm* .

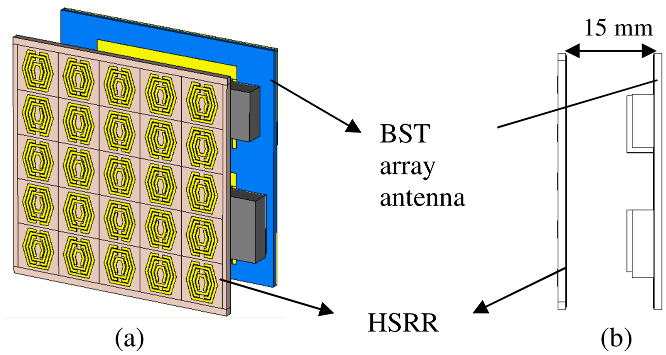


Figure 4: Four elements of BST array antenna covered with HSRR

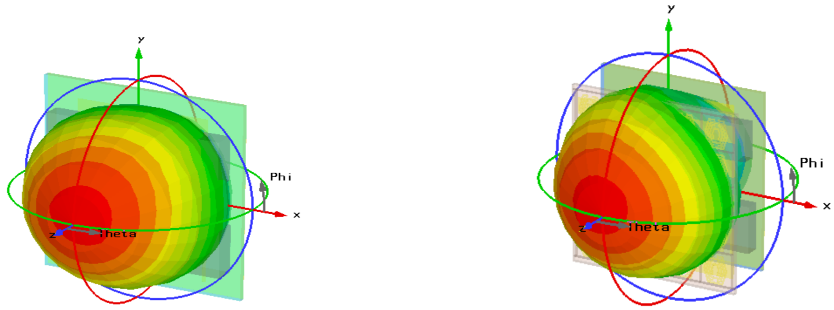
4. Results

The simulation software, CST Microwave Studio was used to optimize the design parameters and the simulated reflection coefficient (return loss), bandwidth, radiation efficiency and VSWR result for WiMAX application. Fig. 5 shows result of the radiation pattern of the rectangular BST for superior performance within the 2.3 GHz to 2.4 GHz frequency band which is at WiMAX frequency range and corresponds to 50Ω impedance. The directivity and gain parameters of four BST elements array antenna can be observed good reflection resonant frequency which based on the radiation pattern at high frequency of 2.3 GHz. The appearance of hexagonal SRR had been investigated which will affect the result of the four elements of BST array antenna. The bandwidth remains constant which cover the range 2.3 GHz to 2.4 GHz with above 10 dB of return loss. This shows more than 90 % of microwave signal will radiate from this antenna with less loss.

Table 2: Antenna parameters results

Antenna parameters	Without HSRR		With HSRR	
Frequencies, GHz	2.3	2.4	2.3	2.4
Directivity, dBi	5.80	5.76	7.493	7.759
Gain, dB	3.86	2.63	5.23	3.26
Bandwidth, MHz	100			

Table 2 shows antenna parameters simulated result of the four elements BST array antenna. This results show that the gain of four elements BST array antenna has improved greatly compared with the common convention antenna and it is optimized for superior performance within the 2.3 GHz to 2.4 GHz frequency band corresponds to 50Ω impedance. The radiation patterns for four elements BST array antenna with HSRR has boost up about 1.73 dB gain and 0.63 dBi directivity higher than four elements BST array antenna without HSRR respectively. Theoretically the aperture antenna's maximal directivity is $D\max = 4\pi A/\lambda_0^2$. Since the area of the aperture is A=52 *mm*×53 *mm*, and $\lambda=c/f$ =0.13 *mm*, so one has $Dmax$ = 6.3 dB. The directivity of the designed patch antenna with the metamaterial cover is very close to the maximum directivity (6.3 dB) physically possible for this size of antenna.



(a) (b)

Figure 5. Radiation Pattern of BST array antenna (a) without HSRR (b) with HSRRs

5. Conclusions and Future Work

This paper introduced experimentally the effect of a superstrate layer for high gain on a BST array antenna. The designed BST array antenna using HSRRs superstrate layer had a high gain of over 5.23 dBi and directivity of 7.493 dBi with the impedance bandwidth constant on the WiMAX range. The proposed antenna will be useful for high gain and high directivity systems that enable to transmit and receive maximum signals. However, there is advance experimental of HSRRs superstrate which will be further investigated in order to obtain the comparison results of simulated and measured as well as to ensure that the fabricated hardware antenna can be utilized in certain application.

Acknowledgments

The authors wish to acknowledge Universiti Malaysia Perlis and the short term grant vote 27000 which enabled the production of this article.

References

[1] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, “Composite medium with simultaneously negative permeability and permittivity”, *Phys. Rev. Lett.*, vol. 84, no. 18, pp. 4184-4187, May 2000.

[2] R. A. Shelby, D. R. Smith, and S. Schultz, “Experimental verification of a negative index of refraction”, Science, vol. 292, pp. 77-79, Apr 2001.

[3] V. G. Veselago, “The electrodynamics of substances with simultaneously negative values of ε and μ”, Soviet Phys. Uspekhi, vol. 10, no. 4, pp. 509-514, Jan. 1968.

[4] L. Chen, S. He, and L. Shen, “Finite-size effects of a left-handed material slab on the image quality”, Phys. Rev. Lett., vol. 92,no. 10, pp. 107404-1–107404-4, Mar. 2004.

[5] ‘Microwave Studio’, CST GmbH, Darmstadt, Germany: www.cst.com.

[6] Mohammad Tariqul Islam, Mohammed Nazmus Shakib Norbahirah Misran, “High Gain Microstrip Patch Antenna,” European Journal of Scientific Research ISSN 1450-216X Vol.32 No.2 (2009), pp.187-193 © EuroJournals Publishing, Inc. 2009.

[7] G. Tayeb, S. Enoch, P. Sabouroux, N. Guerin and P. Vincent, “Compact directive antennas using metamaterials,” 12th International Symposium on Antennas, pp. V2-101-V2-104, Nov, 2002.

[8] David M. Pozar, “*Microwave Engineering*”, 3rd Ed., Wiley, 2005.

[9] Fangming Zhu, Qingchun Lin and Jun Hu, “A Directive Patch Antenna with a Metamaterial Cover”, Microwave Conference, 2005. APMC 2005 Proceedings, Asia Pacific vol. 2, 2-3, Page(s): 347-350, Dec 2005.

[10] Hung-Hsuan Lin, Chun-Yih Wu, Shih-Huang Yeh, “Metamaterial Enhanced High Gain Antenna for

[11] WiMAX Application”, Antennas and Propagation Society International Symposium, pp. 19-22, Jul., 2006.