A Compact Polarization dependent Electromagnetic Band Gap structure

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Abstract : In this paper, a novel Electromagnetic Band-Gap (EBG) structure in a hammer spanner type shape with compact size and dual band gap is proposed. Design and analysis of Hammer Spanner type EBG (HS-EBG) are done by LC analytical model. From LC analytical model, in order to design the compact EBG structure, the product of inductor (L) and capacitance (C) should be high. HS-EBG structure increases the value of C per unit EBG cell by making rectangular slot, stretched strip and square patch at the end of stretched strip. HS-EBG structure is simulated using Ansoft HFSS and tested. Asymmetrical structure of the HS-EBG results in different band-gap properties in X- and Y-directions. Simulated and experimental results prove that, compared with Central Located Via EBG (CLV-EBG), Edge Located Via EBG (ELV-EBG), CSRR-based EBG, and Two Via Slot Type EBG (TVS-EBG), a size reduction of 42.86%, 23.60%, 26.88%, and 11.69% has been achieved respectively.

IndexTerms— Dispersion diagram, Dual-band gap, Electro- magnetic Band Gap (EBG) Structure, Size reduction.

I. INTRODUCTION

Electromagnetic Band-Gap (EBG) structures have become important in the microwave and antenna area as many applications can be obtained from their characteristics. In recent years, several EBG structures has been proposed [1]- [3]. It has been reported that, period of EBG should be half wave length at the stop band frequency, so the EBG structure have large size at the lower frequency. To solve this problem, many compact EBGs were proposed [4]- [8]. These proposed EBGs are with a single band-gap. EBGs with dual band gaps are much suitable in some microwave and antenna applications, such as Global Position System (GPS), Personal Communications (GSM900/DCS1800). In recent years, several EBG structures for dual band application has been proposed. X. L. Bao et al [9] introduced fractal type EBG with dual band gap characteristics centered at 1.24 GHz and 1.775 GHz. O. Folayan, and R. Langley [10] investigated bowtie type of EBG for dual band application with EBG patch size 0.129λ0 at lower band gap center frequency. Lin peng et al [11] reported Complementary Split Ring Resonator (CSRR) based EBG for dual/triple band gap applications with 28% size reduction compared to the CLV-EBG. Xi Chen et al [12] presented dual band gap Meandering Slotted EBG (MS-EBG) with 0.125λ0 patch size at lower band gap center frequency. In our previous work [13], a compact Two Via Slot type EBG (TVS-EBG) with frequency variation ability was investigated for single band gap application. In this work, we propose a compact Hammer Spanner Type Electromagnetic Band Gap (HS-EBG) structure, which is an extension of ELV-EBG [6] and Fork-like EBG [7] structure. Compared to other EBGs, the proposed HS-EBG structure has advantages of compactness, dual band gap characteristic in two orthogonal directions, and band gap center frequency variation capability. Section II presents a proposed prototype, its design and corresponding dispersion diagram. Section III describes the experimental re- sults for the band gap of HS-EBG structure by using truncated microstrip line method. Finally, conclusions are provided in section IV.

II. PROTOTYPE OF EBG, AND DISPERSION DIAGRAM

CLV-EBG can be characterized by parallel LC resonator with band gap centre frequency (fc) [2]

$$f_c = \frac{1}{2\pi \sqrt{LC}} \qquad (1)$$

$$L = \mu_0 h \qquad (2)$$

where, μ_0 = permeability of free space, and h = substrate height, and

$$C = \frac{W \varrho_0 (\varrho_r + 1)}{\pi} \cosh^{-1}\left\{ \frac{2W + tt}{tt} \right\} \qquad (3)$$

(W) is the width of each EBG metal patch, (G) is the gap between two EBG cell, (ϱ_r) is the dielectric constant of the substrate, and ϱ_0 is the permittivity of free space. From (1), to design compact EBG structure, C and L should be increased. In CLV-EBG, fc can be changed with changing patch width (W) or gap between adjacent EBG (G). In Edge Located Via- EBG (ELV-EBG) [6], concept of LC resonator and λ0/4 horizontal corrugation soft surface are used to get compactness. In Fork like EBG [7], additional capacitance is formed between the neighbouring edges of the slot and the stretched strip from an adjacent patch. But CLV-EBG, ELV- EBG, and fork-like EBG are with a single band gap.

For the purpose of further size reduction and dual band   gap applications, a HS-EBG is proposed. As shown in Fig. 1, it is based on ELV-EBG [6] and fork-like EBG [7] with hammer spanner like structure. HS-EBG is with rectangu   lar symmetry along X-direction and asymmetric along Y- direction. As shown in Fig. 1, gray part represents metallic structure, etched on a dielectric substrate. Each cell of HS- EBG consists of square metal patch with rectangular slot on it, stretched strip and square patch at the end of stretched strip. Position of via for each cell is kept at middle of the stretched strip. Neighbouring edges of the rectangular slot and square patch from an adjacent cell embedded in slot for additional capacitance. Inductance L is due to a path length of the stretched strip located via to via of adjacent HS-EBG. Capacitance C1 is due to a rectangular slot and adjacent HS-EBG. C2, C3, and C4 are due to square patch located at the stretched strip and slot of adjacent HS-EBG. C5 is due to the gap between two adjacent HS-EBG. Due to asymmetric nature of HS-EBG, different band gap properties in X-and Y-directions are obtained. To verify the band gap properties, proposed HS-EBG with same parameter [6] [13] is simulated in Eigen mode solution of Ansoft HFSS and dispersion diagram is plotted in Fig. 2. As shown in Fig. 1, parameters are taken as: substrate dielectric constant (ϱ_r) =

4.4, substrate height (h) = 1.50 mm, the gap between two EBG (G) = 2 mm, square patch width (W) = 7 mm, diameter of via (r) = 0.20 mm, width of the slot (Sy) = 5mm, length of the slot (Sx) = 6 mm, width of the stretched strip (d) = 1 mm, length of the stretched strip is equal to the gap between two EBG (G), width of square patch located at the end of stretched strip (P) = 4 mm. From dispersion diagram as shown in Fig. 2, different centre frequency band gaps are observed in X-and Y-directions [14]. In X-direction (gamma-X), band gap (gray part) is centered at 2.91 GHz with lower frequency cutoff (fl) = 2.81 GHz and higher frequency cutoff (fh) = 3.01 GHz with BG-BW 6.87%. In Y-direction (Y-Gamma), band gap (red part) is centered at 3.14 GHz with lower frequency cutoff (fl) = 3.03 GHz and higher frequency cutoff (fh) = 3.25 GHz with BG-BW 7.00%. Increased in C, reduces the band gap band-width of HS-EBG in X-and Y-directions. Simulated results of the parametric study are shown in Fig. 3 and Fig. 4 for X- direction and Y-direction respectively. It is observed that as the value of p increases, the distance between square patch located at the end of stretched strip and slot strip decreases and therefore results in higher value of C and from (1), we obtain lower fc with same patch width and vice-versa in X-and Y-direction. By adjusting the p, d, and Sx, HS-EBG structure can be used for different fc in X-and Y-direction for dual band gap applications, without changing the patch width of HS-EBG and G. This band gap center frequency variation capability of the HS-EBG is useful in many practical applications
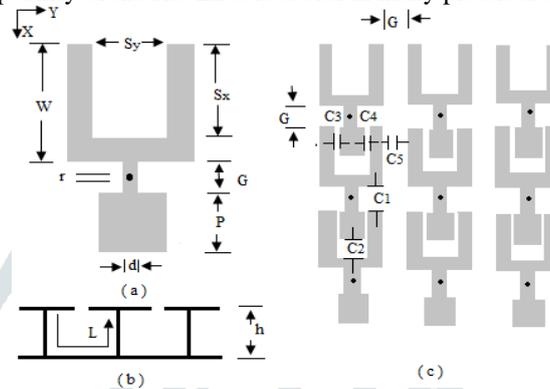

Fig. 1. Hammer Spanner-Type Electromagnetic Band Gap (HS-EBG) structure
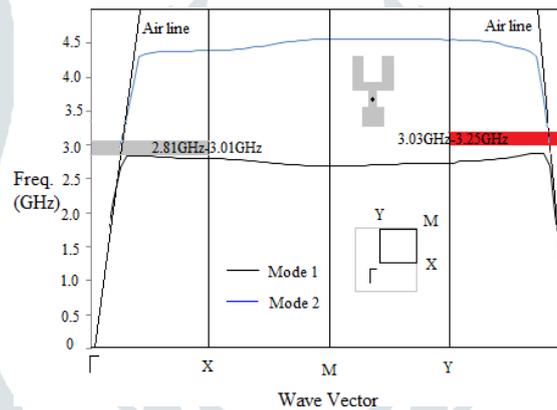**(a) Unit cell (b) Side view (c) Configuration of 3×3 cell.**

Fig. 2 Dispersion diagram for the HS-EBG structure for gap between two HS-EBG (G) = 2 mm.
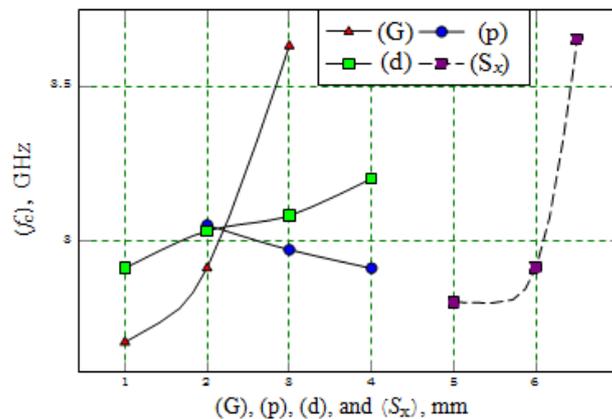

Fig. 3. Simulated band gap center frequency (fc) of the HS-EBG as variation of parameter (G), (p), (d), and (Sx) keeping (ρr) and (h) constant in X- direction. (When one parameter is changed, other parameters are kept fixed.)
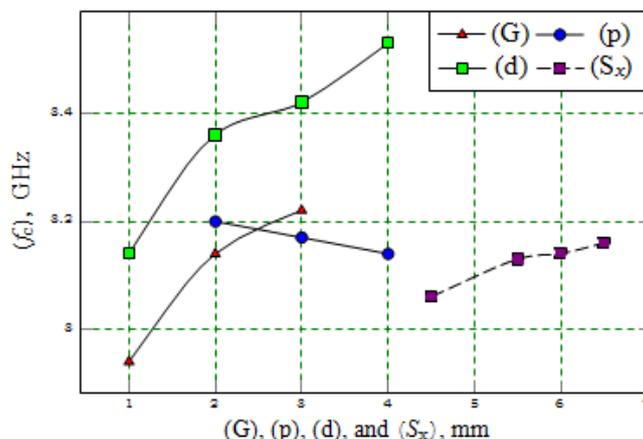
Fig. 4 Simulated band gap center frequency (fc) of the HS-EBG as variation of parameter (G), (p), (d), and (Sx) keeping (ǫr) and (h) constant in X- direction. (When one parameter is changed, other parameters are kept fixed.

III. EXPERIMENTAL RESULTS

To further validate the properties of the HS-EBG, 5 5 lattice of HS-EBG fabricated on FR4 epoxy substrate with (ǫr) = 4.4 and (h) = 1.50 mm. The Agilent N9923A network analyzer with maximum measurable frequency of 6.00 GHz is used in the measurement. As shown in Fig. 5 (a) and (b), truncated microstrip line method [11] [13] at the both ends is used to measure the transmission coefficient S21 in X-and Y- directions. Coupled gap between microstrip line and HS-EBG is kept 2 mm (G = 2mm). Geometry parameters of HS-EBG are the same as given in section II. Measured S21 of truncated microstrip line with HS-EBG is demonstrated in Fig. 6. Different band gaps are observed in X-and Y-direction [14]. In X-direction, band gap is observed from 2.82 GHz to 2.98 GHz (gray part) with centre frequency 2.90 GHz and in Y- direction, it is observed from 3.04 GHz to 3.18 GHz (red part) with centre frequency 3.11 GHz. The difference between the simulated and measured results are due to reasons mention in [11] [14]. Comparison of proposed HS-EBG and other EBG structure in terms of lower band gap centre frequency (fcl), higher band gap centre frequency (fch), and EBG patch width at lower band gap centre frequency (fcl) are given in Table I.
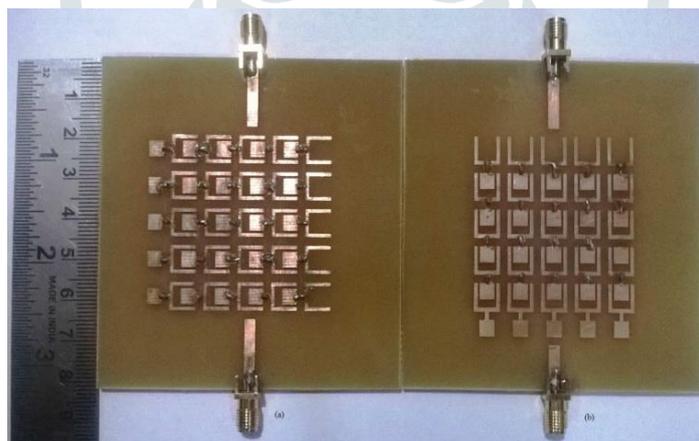

Fig. 5. Prototypes of the constructed HS-EBG with truncated microstrip line with coupled gap between microstrip line and HS-EBG = 2 mm. a) feed from X-direction b) feed from Y-direction
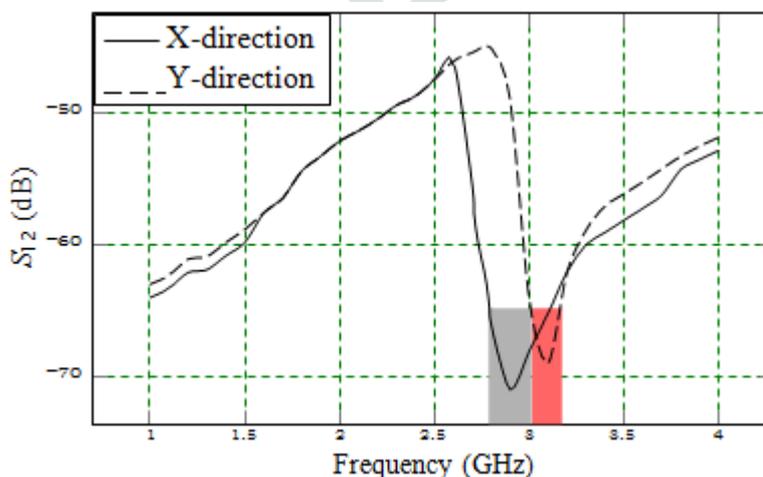

Fig. 6. Measured S12 (dB) in X-and Y-direction with truncated microstrip line method for HS-EBG structure

IV. CONCLUSION

In this paper, a compact Hammer Spanner-type EBG struc- ture has been investigated. Proposed HS-EBG structure has been simulated and results have been validated experimentally. The period size of HS-EBG is only $0.068\lambda0$ at the desired lower band gap center frequency. The asymmetrical structure of HS-EBG leads to different band gap properties in X-and Y-direction. By changing the width of square patch located   at the end of stretched strip, length of the slot, and width of the stretched strip, wide range of band gap center frequency can be obtained in X-and Y-direction with same period of EBG. Simulated and experimental results prove that, compared with CLV-EBG, ELV-EBG, CSRR-based EBG, and TVS- EBG, a size reduction of 42.86%, 23.60%，26.88%，and 11.69% at lower band gap centre frequency has been achieved, respectively. The proposed HS-EBG can be used for dual band applications and where compact size is highly desired.

Table 1 Lower band gap Centre frequency, higher band gap Centre frequency, EBG patch width at lower band gap Centre Frequency of proposed HS-EBG and other EBG structure

Ref.	Type of EBG	f_{cl} (GHz)	f_{ch} (GHz)	Patch width at f_{cl}
[6]	CLV-EBG	5.08	N.A.	$0.119\lambda_0$
[6]	ELV-EBG	3.83	N.A.	$0.089\lambda_0$
[7]	Fork-EBG	4.80	N.A.	$0.072\lambda_0$
[9]	Fractal-EBG	1.24	1.78	$0.134\lambda_0$
[10]	Bowtie-EBG	1.70	2.60	$0.129\lambda_0$
[11]	CSRR-EBG	3.82	6.40	$0.093\lambda_0$
[12]	MS-EBG	3.95	8.22	$0.125\lambda_0$
[13]	TVS-EBG	3.32	N.A.	$0.077\lambda_0$
P. E.	HS-EBG	2.90	3.11	$0.068\lambda_0$

P.E. = Proposed EBG, N.A. = Not Applicable

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