**Proceedings of ISAP'04, Sendai, JAPAN**

# A Novel Uniplanar Electromagnetic Bandgap (EBG) Structure with a Tunable Open Stub

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An improved uniplanar electromagnetic bandgap (EBG) structure with good performance is proposed. Also, a novel tunable open stub and a useful formula between frequency shift and impedances are found herein. Further, the air-bridges and a special method of step compensation in the angle bends are employed to overcome as more disagreement in the radiation effects as possible. From the measured results, The insertion loss and return loss at center frequency are measured as –0.26 dB and –43 dB, respectively. More, the return loss of the lower and upper passband are below –14 dB, which is a very good performance in the practical usage.

*Key terms:* uniplanar, electromagnetic bandgap (EBG), tunable, open stub

## 1. Introduction

Recently, the electromagnetic bandgap structure (EBG) has been widely utilized in a lot of microwave circuits such as antennas, resonators and filters [1]-[4]. For the application in bandstop filter (BSF), the EBGs are usually formed by etching periodic cells of the various shapes on the ground plane to provide stopband and slow-wave characteristics. Consequently, they usually occupy larger size, and are affected by so many parameters. In order to overcome these problems, Ahn et al. proposed an improved EBG structure, which only needs one cell or series connection of a few cells to perform the bandgap responses in some frequency bands [5]. However, it needs to be etched lattices on the ground plane, and it will increase the difficulties of fabrication.

In this paper, we propose a novel uniplanar EBG structure to exhibit attractive characteristics as easy fabrication, better rolloff and low loss. It consists of a folded transmission line and a tunable open stub. Moreover, a useful formula between frequency shift and impedance is described herein, and the air-bridge of step compensate in the angle bends are employed to overcome as more disagreement in the radiation effects as possible. The simulated and measured results show good agreement with the proposed theory and calculation.

## 2. EBG structure with a Tunable Open-Stub

As is well known, the conventional quarter-wave open stub resonator can be considered as a BSF. However, it suffers from big size, narrow stop bandwidth and untunable with the same length. We now commentate the proposed EBG structure with a tunable open stub as Fig. 1(a), which is the nostrum of those drawbacks, gradually. In order to suppress the radiation caused by parasitic slot line mode, the air-bridges are employed in the bends. In previous researches and applications [6], it is confessable that the folded quarter wavelength open stub can achieve a BSF in smaller size, but unfortunately, it suffers from untunable bandwidth and hard to layout in the bended corners. We thus embedded the specific tunable open stub proposed before and made use of a method of step compensation [7] in the angle bends to compensate for both parasitic capacitances as well as bend reactance. Furthermore, we introduce a new tunable structure of open stub as shown in Fig. 1(b). From the basic theory of transmission line, we can know the input impedance of the specific quarter wavelength open stub which is viewed from the left side of open stub can be shown as

$$Z_{in} = \frac{Z_a^2 - Z_a Z_b (\tan\theta)^2}{jZ_b \tan\theta + jZ_a \tan\theta} \tag{1}$$

where the $\theta$ denotes the electrical length of each segment. Let $Z_{in}$ equal zero in the Eq. (1), then the relationship between $Z_a$ and $Z_b$ can be simplified as

ISBN: 4-88552-206-4 C3055©IEICE

$$\tan^2(\beta\ell) = \frac{Z_b}{Z_a} \tag{2}$$

where $Z_a$ and $Z_b$ are the segment near and off the main transmission line, respectively. From the result above, we can recognize that the frequency will shift owing to impedance transform. Consequently, how to control the frequency shift exactly comes the most noticeable point for us to research. Accroding to Eq. (2) and somewhat calculations, we can derive and abstract the formula of frequency shift as

$$\Delta f = f_0\left(\frac{2\cos^{-1} x}{\pi} - 1\right) \tag{3}$$

where $\Delta f$ denotes the frequency shift between f and $f_0$, and $f_0$ represents the primary resonant frequency without changing impedance.
And the *x* parameters is given as

$$x = \frac{Z_b - Z_a}{Z_a + Z_b} \tag{4}$$

In addition, we can readily figure out that the frequency will shift to lower place while $\Delta f$ is negative and shift to higher on the contrary. According to Eq. (4), Fig. 2 illustrates the relationship between frequency shift and impedance ratio x. In view of this end, frequency tuning becomes available though in the condition of same quarter wavelength.

## 3. Simulated and Measured Results

The proposed EBG structure herein is designed for the fundamental resonant frequency of 2.4 GHz and fabricated on a 1.0 mm-thick FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and loss tangent 0.018. With regard to simulation, full-wave EM simulator SONNET is employed. The parameters we indexed are listed as follows: $d_1$ = 21.6 mm, $d_2$ = 16.4 mm, $g_1$ = 0.75 mm, $g_2$ = 0.25 mm, $g_3$ = 0.95 mm, $w_1$ = 1 mm, $w_2$ = 0.65 mm. Fig. 3 shows the simulated results of insertion loss versus frequency with different impedance ratio. It is found that the frequency shift is very obvious when the impedance ratio changed. Then, the measured results are dealt by Network Analyzer HP 8720 ES from frequency 0.5 GHz to 5 GHz with standard calibration. On the strength of the mentioned conceptive method above, the simulated and measured results are illustrated in Fig. 4. In Fig. 4, it can be found that the results of simulation and measurement are in a good agreement, and a factional 20 dB bandwidth of about 35% at 2.4 GHz center frequency, which contributes better rolloff on both lower and upper side with compared to general bended quarter wavelength open stub BSF we mentioned before. The insertion loss and return loss at center frequency are measured as –0.26 dB and –43 dB, respectively. More, the return loss of the lower and upper passband are below –14 dB, which is a very good performance in the practical usage.

## 4. Conclusions

An innovative tunable EBG, which consists of a folded transmission line and a tunable open stub, is presented in this paper. Simulation and measurement were shown with good accordance. Most attractive performance of all, we propose a novel tunable open stub and derived the relation between impedances and frequency shift. This helpful formula certainly will inspire and help researchers to design for many applications. This uniplanar structure is notably efficient and flexible in practical circuit application.

## 5. References

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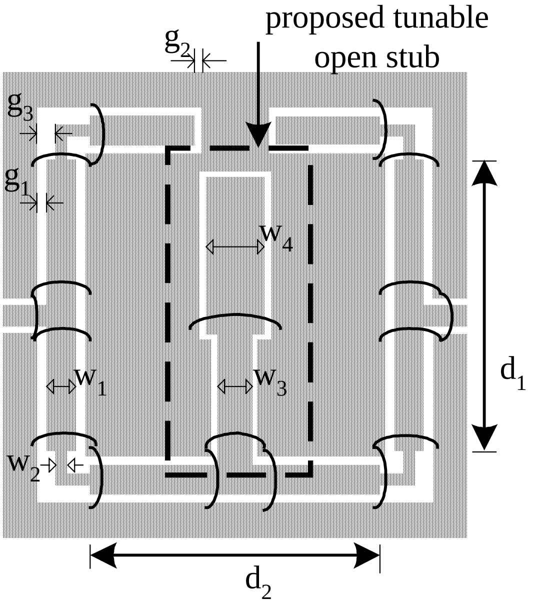

Fig. 1(a) Novel EBG structure with a tunable open stub.

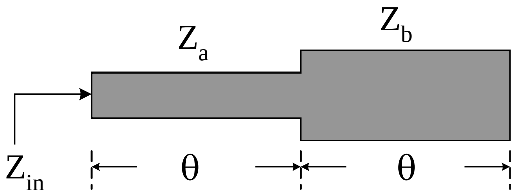

Fig. 1(b) Tunable open stub, where $\theta = \lambda/8$.

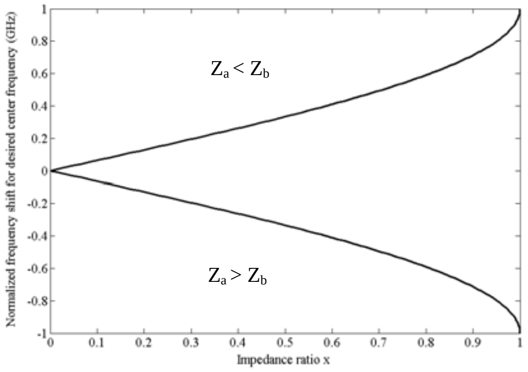

Fig. 2 Relationship between frequency shift and impedance ratio x.

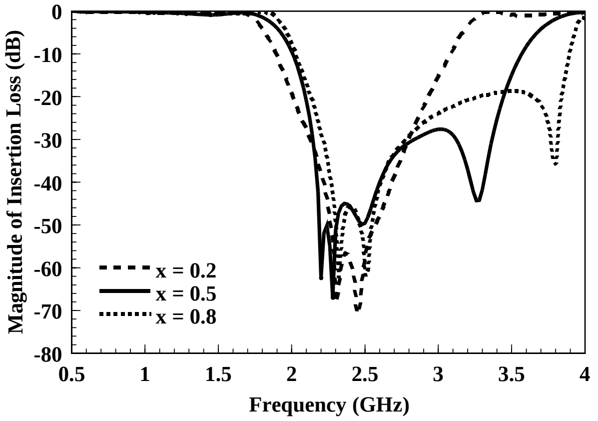

Fig. 3 Simulated results of insertion loss with respect to frequency, where x = 0.2, 0.5, and 0.8.

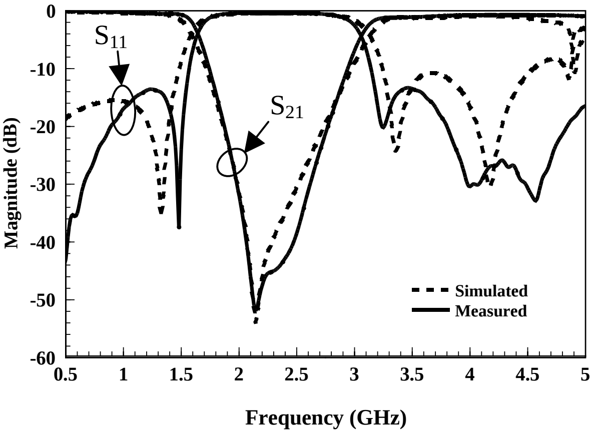

Fig. 4 Simulated and measured results of the proposed EBG unit cell, where $w_3$ = 1.72 mm and $w_4$ = 2.26 mm.