# Novel Spiral With and Without Patch EBG Structures for EMI Reduction

Zuhairiah Zainal Abidin, Musaab Abdulghani Qasem, Samsul Haimi Dahlan and Mohd Zarar Mohd Jenu
*Center for Applied Electromagnetic, Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia.*
*zuhairia@uthm.edu.my*

***Abstract*—Electromagnetic bandgap structures (EBGs) have the ability to provide excellent reduction of electromagnetic interference (EMI). In this work, a 3 by 3 spiral with and without patch electromagnetic bandgap planar was fabricated on low cost FR4 substrate with permittivity of 4.3 and thickness of 1.6mm. Both designs have dimensions of 36 mm x 36 mm covering 9 unit cells planar design. The simulation and experimental characteristics are illustrated in this paper. An acceptable agreement between the simulated and measured results was obtained. It was found that the spiral without patch EBG experienced better bandgap than the spiral with patch design, which covered bandgap of (5.8 – 7.4 GHz) with relative bandwidth of 22.56%. Meanwhile, for the spiral with patch structure, it covered C band (4.5 – 7 GHz) with extended relative bandwidth of 43%. The results of the characteristics demonstrate that the proposed EBGs are attractive candidates for the integration into the high speed circuitry designs where spiral with patch can be involved in C band applications to suppress the EMI emitted by their circuitry.**

***Index Terms*—Electromagnetic Bandgap (EBG); Electromagnetic Interference (EMI); Electromagnetic Compatibility (EMC); Radiated Emission (RE).**

## I. INTRODUCTION

In recent years, electromagnetic interference (EMI), namely the lack of EMC emitted by high speed circuitry due to fast edge rates have become an extremely common issue [1]. Any electronic product must pass Electromagnetic Compatibility (EMC) standards in accordance to the government requirements. Besides, if the producer manages to make the product pass but it is still emitting or radiating, this would result in signal integrity and reliability issues. Mobile communication devices, such as smart phones and tablet computers have become small, compact and have data rates involving high speed digital interfaces where their designs have to meet the standards at their operating high frequencies. Furthermore, the design must be low cost, small size, low power and lightweight. To control EMI in such products, it is essential that all components within these products coexist while performing their tasks. Therefore, neither whatever unintentional signals that are generated must interfere with intentional signals, nor do any intentional signals with the operation of any circuit component.

Electromagnetic compatibility in modern designs has major concern of switching noise as it produces high EMI that could cause serious signal integrity and power integrity problems in the form of EMI for the high-speed circuitry. To overcome this issue in particular, the characteristics such as frequency stop bands, pass bands and band gaps could be identified using electromagnetic bandgap structure. Generally, EBG structures are defined as artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states [2]. As they are designed to prevent the propagation of a designated bandwidth of frequencies acting like filters, they can be used to reduce EMI that is generated from applications circuitry or to decrease the antenna coupling to enhance its performance.

## II. RESEARCH METHOD

### *A. Electromagnetic Bandgap Configuration*

Two types of spiral EBG unit cell which consist of 10 metallic sectional traces, (i) with patch and (ii) without patch are proposed. Each trace was represented mathematically using Greenhouse Formulas [3] which are based on lumped elements representations. Figure 1 shows the side view of the EBG structure which consists of EBG on the top, substrate in the middle and ground plane on the bottom. This EBG structures was designed on a FR4 substrate with relative permittivity of 4.3 with thickness (d) of 1.6 mm and 0.035 mm (t) thick copper.

Figure 1: Side view of EBG Unit Cell

### *B. Mathematical Model*

An iterative process consisting of the following proposed steps was carried to design and optimize the spiral and spiral with patch EBG structures. First of all, the resonance frequency of the L–C lumped elements was determined. Equation (1) was used to calculate the resonance frequency. Then, using Equation (2), the values of L and C were chosen to achieve the resonance frequency, while maintaining the L–C ratio relatively high to obtain a wide stopband the dimensions of the unit cell of the EBG structure were calculated as L to derive the C values. If the calculated dimensions were not realizable with the available and cost-effective substrates, the whole process was repeated with a slightly different resonant frequency that will match the need. This work aimed to consider the 4 GHz resonance frequency to calculate the spiral with patch design and 4.3 GHz for the spiral design. The center frequency of this stop-band configuration can be expressed as [4]:

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

While the relative bandwidth is proportional to the ratio of L-C as following:

$$\Delta\, BW \alpha \sqrt{\frac{L}{C}} \qquad (2)$$

Therefore, an increase in the value of L will benefit the range relative to bandwidth. Then, we calculated C and L to obtain the self-inductance, mutual inductance and parasitic capacitance to design an EBG unit cell. Greenhouse has provided expressions for inductance for both rectangular and circular geometries based on self-inductance of inductor sections and mutual inductances between sections. These relations are known as Greenhouse formulas for spiral inductors, as shown in Equation (3), (4) and (5).

$$L(nH) = 2\,x\,10^{-4} Li\left[In\left(\frac{Li}{w+t}\right) + 1.193 + \frac{w+t}{3Li}\right].K \qquad (3)$$

$$Mi = 2x10^{-4}Li[In\left\{\frac{Li}{d} + \sqrt{\left(1+\frac{Li^2}{d^2}\right)}\right\} - \sqrt{\left(1+\frac{d^2}{Li^2}\right)} + \frac{d^2}{Li^2}] \qquad (4)$$

$$C(pF) = 16.67x10^4 Li\frac{\sqrt{\varepsilon_r}}{Z_\circ} \qquad (5)$$

$$K = 1 + 0.333(1 + \frac{\sqrt{2g}}{w}) \qquad (6)$$

where;
L = self-inductance;
Mi = the mutual inductance;
C = the capacitance;
Zo = surface impedance;
w = Trace width;
Li = Metallic Sectional Length;
d = Distance between two middle sections
t = Metallic Thickness;
g = Gaps Width;
Ɛr = dielectric constant; and
K= Spacing constant

### *C. Mathematical Model*

To construct a waveguide model which supports a propagating plane wave, PEC boundary condition to two parallel walls of the waveguide and PMC boundary condition to the other two parallel walls were assigned, as shown in Figure 2.

The input port of waveguide was excited (at the top) and the other port was terminated at the bottom of the EBG. This propagating plane wave was polarized parallel to the PMC walls and normal to the PEC. This was one of the techniques used to obtain the characteristic of the EBG unit cell based on its reflection phase results.

### *D. Spiral with Patch EBG characteristics*

Figure 3 shows the spiral with patch EBG unit cell design. The reflection phase of the unit cell EBG is depicted in Figure 4. It is clearly shown that the electromagnetic bandgap of this structure was between 4.05 - 4.12 GHz, indicating the reflection phase changed between 90 ± 45 [5]. The geometrical parameters of this design are shown in Table 1.

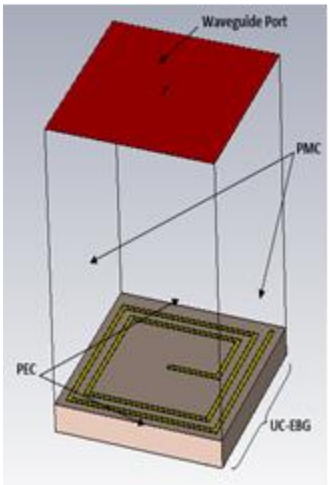


Figure 2: Waveguide model of spiral without patch unit cell

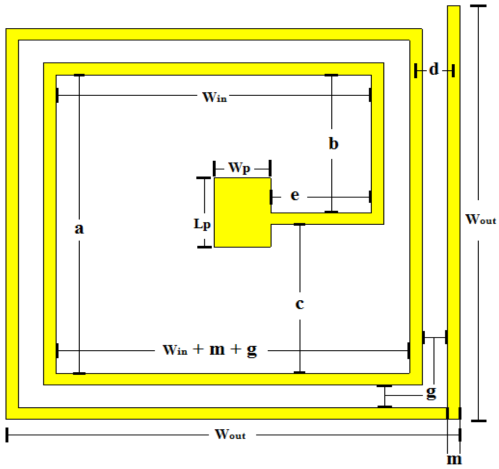


Figure 3: Unit cell for spiral with patch design

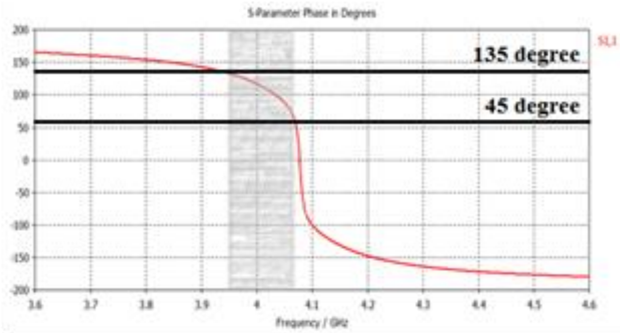


Figure 4: Reflection phase of spiral with patch unit cell EBG

Table 1
Geometrical Parameters of Spiral with Patch Unit Cell

| Parameter | Value (mm) | Description |
|---|---|---|
| $W_{out}$ | 10.80 | Metallic Outer Width |
| $W_{in}$ | 7.50 | |
| a | 7.80 | |
| b | 3.60 | Internal Gaps of Unit Cell |
| c | 3.90 | |
| g | 0.60 | Gaps Width |
| e | 3.45 | Central Metallic Element |
| m | 0.30 | Metallic Width |
| d | 0.90 | Distance Between Middle Sections |

### *E. Spiral without Patch EBG characteristics*

Spiral without patch EBG unit cell was designed as depicted in Figure 5. The reflection phase resulting from a plane wave normally incident on the EBG surface is as depicted in Figure 6. The geometrical parameters calculated based on L-C values are shown in Table 2. A stopband with central frequency of 4.33 GHz and bandgap width of 4.28 - 4.36 GHz was observed for this design.

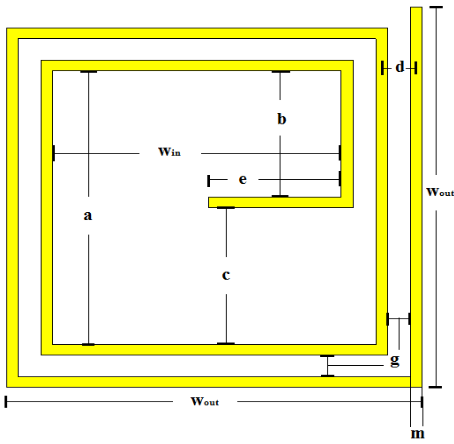


Figure 5: Unit cell for spiral without patch design

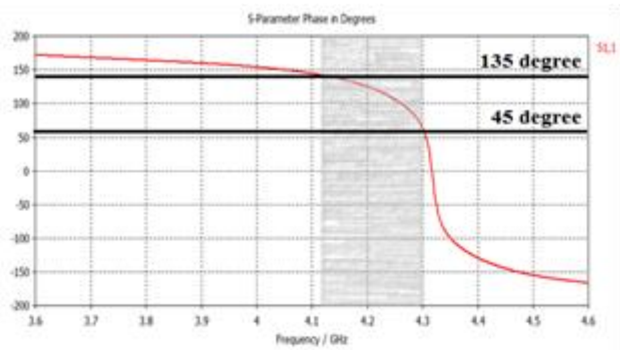


Figure 6: Reflection phase of spiral without patch unit cell EBG

Table 2
Geometrical Parameters of Spiral without Patch Unit

| Parameter | | Value (mm) | Description |
|---|---|---|---|
| $W_{out}$ | | 10.80 | Metallic Outer Width |
| $W_{in}$ | | 7.50 | |
| a | | 7.80 | |
| b | | 3.60 | Internal Gaps of Unit Cell |
| c | | 3.90 | |
| g | | 0.60 | Gaps Width |
| e | | 3.45 | Central Metallic Element |
| m | | 0.30 | Metallic Width |
| d | | 0.90 | Distance Between Middle Sections |
| Patch | Wp | 1.35 | Patch Width |
| | Lp | 1.80 | Patch Length |

Figure 4 and 6 illustrate that the EBG reflection phase was close to 0° in the simulated reflection phase characteristic of the spiral with patch and spiral EBG structures and at the resonant frequency respectively. This condition assists the property of an artificial magnetic conductor (AMC) surface. However, the examination of the proposed spiral with patch and spiral EBG unit cell configurations was intended. Thus, the surface wave suppression characteristics for this purpose were considered. The resonances of reflection phase and suspended line transmission coefficient, S21 were apart from each other as shown in the next section in Figure 9 and 10. This is because the computation schemes were different and they were concerned with two different properties [6]. For example, in Figure 4 of spiral with patch design, the 0° was located at 3.8 GHz with a narrow bandwidth of 0.8 GHz within 90° ± 45 phase values. In addition, patterned surface experiences were illustrated by the very high impedance nature at the resonance around 3.8 GHz. It is worth noted that the AMC point existed nearby the surface wave bandgap resonant point [7].

### *F. Planar Design Construction*

Spiral with and without patch EBG planar with 3 x 3 unit cells has been simulated and fabricated for the measurements with the size of 36 mm x 36 mm. A 50 Ω suspended microstrip line was placed 1.6 mm above the EBG planar with FR4 substrate. The array of both EBG structures has been analyzed to investigate the bandgap properties. Figure 7 shows the array of the 3 by 3 planar of spiral without patch.

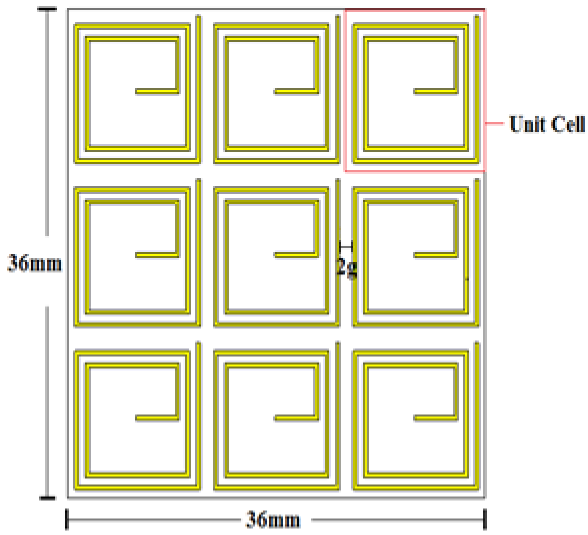


Figure 7: 3 by 3 Spiral without EBG planar

The suspended line was connected to 50 Ω SMA connecters at both ends where the EBG planar represents the ground [8, 9]. This method can be illustrated as shown in Figure 8.

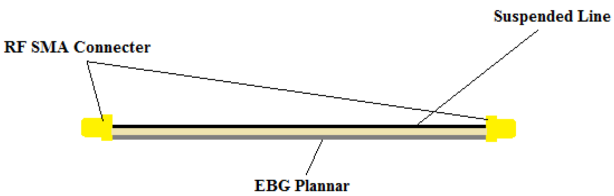


Figure 8: Suspended line method

## III. Results And Discussion

The transmission coefficient S21 was simulated using CST Microwave Studio where the measured result was obtained using Agilent Technologies Vector Network Analyzer for the proposed spiral with and without patch EBG planar.

### *A. Spiral with Patch Planar Design*

Figure 9 shows the transmissions loss, S21 for the simulated and measured results of spiral with patch design planar. The bandgap of the simulation result was from 4.55 GHz to 6 GHz below -20 dB reference. After fabrication, the measured result has a bandgap that was slightly shifted starting from 4.5 GHz to 7 GHz having improved relative bandwidth of 43% which covers C band.

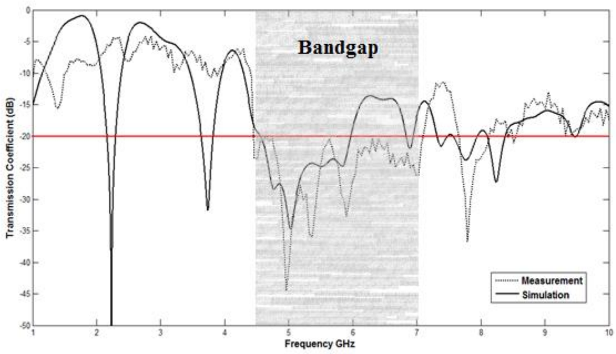


Figure 9: Simulation & measurement results for spiral with patch EBG planar

### *B. Spiral without Patch Planar Design*

The simulated and measured results S21 of spiral design show the bandgap that was from 4.8 GHz to 6.5 GHz and from 7.3 GHz to 8.1 GHz, as shown in Figure 10, respectively. For the measurements, the bandgap was from 5.8 GHz up to 7.4 GHz with relative bandwidth of 22.56%, indicating a lesser measurement compared to spiral with patch design. Although, there was a shift from 4.5 GHz to 5.8 GHz at the lower frequency of the bandgap, the resulting bandgap is considered wide. There was a slight deviation due to fabrication error where some dimensions are very small; hence, requiring accurate and precise fabrication work.

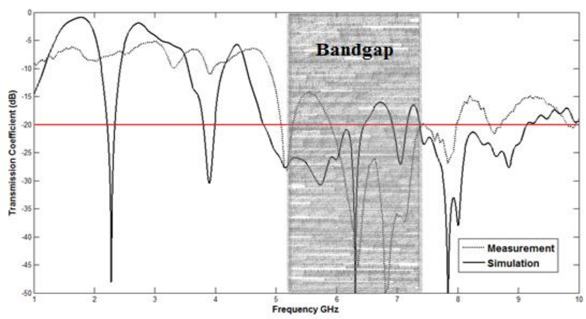


Figure 10: Simulation & measurement results for spiral without patch EBG planar

### *C. Spiral with and without Patch Planar Comparison*

The measured result of spiral with patch design showed an extended bandgap compared the spiral without patch design. It was from 5.8 GHz up to 7.4 GHz with improved relative bandwidth of 43% with better mutual coupling of -54dB at 5 GHz, as shown in Figure 11. This improvement explains the effect of increased inductance by adding a patch to the structure. The bandgap of spiral without patch design has better mutual coupling of -50dB at 6.8 GHz and bandgap that was from 4.5 GHz to 5.6 GHz with relative bandwidth of 22%. This results show that there are good characteristics for both designs with good relative bandwidth.

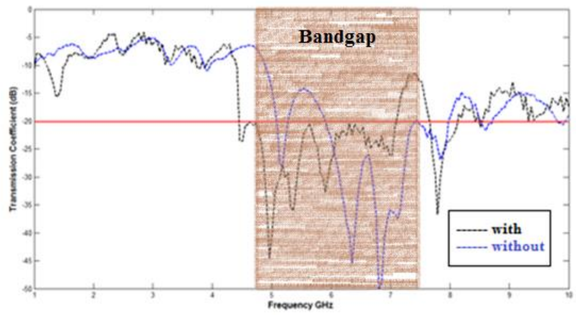


Figure 11:. Measurement results for spiral and spiral with patch EBG planar

## IV. CONCLUSION

A novel spiral with and without patch EBG structural planar have been presented in this paper. Simulations and experiments have been performed. The band-stop properties of the structures have been investigated by using suspended microstrip line method. The transmission loss was obtained including the frequency bands 4.5 – 7 GHz for spiral with patch EBG planar and 5.8 – 7.4 GHz for spiral without patch planar respectively. The measuring results were in close agreement with the simulating results. The spiral with patch design has better and wider bandwidth of 43%. Besides, both of the proposed designs have no vertical vias that will ease the fabrications of the structures.

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