Artificial Magnetic Conductor Surface for AM Radio Broadcast Applications

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Abstract

The AM radio service uses different modes of propagation for different frequency bands. The short-wave (SW) signals usually propagate in sky wave mode by using refraction of ionosphere. In this mode, excitation of ground wave not only attenuates sky wave propagation but also forms a fading zone through interference. The bandgap structures are capable of mitigating the surface wave (or ground wave). But, the low frequency of signal makes the structures too huge to utilize the usual Printed-Circuit-Board (PCB) materials. Therefore, soil is used as substrate material due to availability. This paper proposes a tunable Electromagnetic Bandgap (EBG) structure for AM radio applications. The proposed design is uniplanar and the conventional metallic plate patch has been replaced by metallic ribbons. The bandgap of the structure lies between 8 MHz to 8.35 MHz with a resonance frequency of 8.2 MHz. In the end of designing, parametric sweep of designing parameters demonstrates the tunability of the bandgap and resonance frequency. The proposed structure is applied to an aperture antenna to investigate the effects on radiation characteristics. The proposed structure can also be applied to radio broadcasting stations to reduce the mutual coupling between radiating elements.

Keywords: AM radio, Sky wave propagation, Electromagnetic Bandgap (EBG), Artificial Magnetic Conductor (AMC), High Impedance Surface (HIS).
1- Introduction

The AM radio broadcast is among early communication services. The service can cover large areas as it uses high power transmitters. There are several frequency bands for AM broadcasting: Long-Wave (or LW) broadcast: ranging from 148.5 kHz to 283.5 kHz, Medium-Wave (or MW) broadcast: ranging from 535 kHz to 1606.5 kHz and Short-Wave (or SW) broadcast: ranging approximately from 2.3 MHz to 26.1 MHz [1]. It should be noted that the frequency allocation standard may slightly vary from one region to another. Unlike the FM radio, the propagation of AM radio is Non-Line-of-Sight (NLOS) which eases signal reception. There are two main modes for propagation of AM signals: sky wave mode and ground wave mode (or surface wave mode). The sky wave propagation utilizes refraction of ionosphere for short-wave broadcast, while the ground wave propagation is used for medium-wave broadcast. In sky wave regime, the signal can travel far distances as the attenuation of ionosphere is considerably less than ground. Nevertheless, the alternating configuration of ionosphere layers limits broadcasting to a specific time schedule. In spite of having a comparably restricted service area, the ground wave is less sensitive to environmental issues and provides a nonstop radio service. Furthermore, the ground wave is not limited by the microwave horizon as it follows the curvature of earth. The sky wave propagation is influenced by many factors such as fadings, absorptions, noises, multipath problems, regional anomalies and high altitude effects [2]. By excitation of ground waves (or surface waves) in this mode, the power of sky wave propagation decreases and service area reduces due to the energy leakage. Moreover, according to [3], the interference between sky waves and ground waves causes a fading zone. The propagation modes and fading zone are illustrated in Figure 1. A possible solution is to minimize the surface wave excitation. The Electromagnetic Bandgap (EBG) structures are widely used in microstrip antenna engineering. By definition, the EBG structures are periodic structures that have the ability of prevention/assistance of electromagnetic waves for all incident angles and polarization states in a specified frequency band (usually called bandgap) [4]. As a class of metamaterials, the structures demonstrate extraordinary properties in their bandgap such as: forming an Artificial Magnetic Conductor (AMC) surface, in-phase reflection and High Impedance Surface (HIS) [5]. The high surface impedance of EBG structures within bandgap prevents excitation of surface waves along the interface by suppression of surface currents. A typical EBG unit cell consists of a metallic patch over a grounded dielectric substrate and a metallic via to connect the patch to the ground layer. In uniplanar EBG structures the metallic via is removed in order to simplify the fabrication process. Designing EBG structures at low frequencies encounters a serious challenge: usually, dimensions of EBG structures used in microstrip technology do not exceed several centimeters, while the structures are of metric order at low frequencies. Therefore, it is impossible to load the substrate with usual microstrip materials. The idea of utilizing soil as dielectric substrate has been proposed for radar applications to surpass the limitation [6,7]. It is worth noting that the electrical properties of soil may alter with climate change and moisture [8]. The previous authors used mushroom-like structure in their work. The huge dimensions of patch in mushroom-like design may still be troublesome and add on implementation expenses. Additionally, the metallic vias increase fabrication complexity. This paper focuses on designing a realizable uniplanar EBG structure by substituting mushroom-like patch with metallic ribbons to reduce costs and facilitate fabrication process. In the following sections, designing procedure of the structures will be discussed and the effects of changing design parameters on bandgap and the resonance frequency will be investigated.

Figure 1- (a) Modes of propagation, (b) Fading Zone.
2- Designing Procedure

The Photonic Bandgap (PBG) structures were developed to manipulate the propagation of light. The EBGs are periodic structures that operate analogously, but at lower frequencies. The reflection phase (S11 Phase) from EBG structures alters by frequency. At the resonance frequency, phase difference between incident wave and reflected wave equals to zero. Bandgap is known as the range of frequency where the reflection phase varies from $\frac{\pi}{2}$ to $-\frac{\pi}{2}$. The proposed structure and simulation setup in CST Studio Suite are shown in Figure 2. The [5] explains details and essential formulas for designing mushroom-like structures. The relation between bandgap and the height of substrate for the structures is

$$h = \frac{c \cdot BW}{\omega_0}$$

Where $c$ and $\omega_0$ are the speed of light and angular resonance frequency respectively. Based on the equation, thicker substrates demonstrate wider bandgaps at a given resonance frequency. Figure 3 shows how the change of substrate height can shift the resonance frequency and bandgap. On the other hand, the resonance frequency and bandgap are directly proportional for a fixed height of substrate. The angular resonance frequency is defined by

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Where $L$ is the inductance caused by via and $C$ is the capacitance between neighboring patches. The material used for substrate is dry sandy soil with dielectric constant of 2.53. The electrical properties of soil depend on frequency of measurement, temperature and moisture, thus the values may insignificantly vary in different sources. Table 1 presents design parameters of the proposed structure and Figure 3 illustrates the variation of bandgap and the resonance frequency by different values of substrate height. Figure 4 illustrates the reflection phase diagrams for different soil types, in which loading substrate with a lower dielectric constant material results in an increase of the resonance frequency and bandgap. The resonance frequency and bandgap of the structure are 8.2 MHz and 350 kHz (from 8 MHz to 8.35 MHz) respectively. As shown in Figure 5, the width of ribbons can move the resonance frequency and bandgap. The purpose of using ribbons instead of metallic plate patch is to reduce costs and ease the implementation. Distance between neighboring patches is also effective on the resonance frequency and bandgap which is exhibited in Figure 6. By increasing the distance between neighboring patches the capacitance decreases and subsequently the resonance frequency increases according to (2).

![Figure 2](image-url)
Table 1- Design Parameters of the proposed structure

<table>
<thead>
<tr>
<th>Relative permittivity ((\varepsilon_r))</th>
<th>wp (m)</th>
<th>wr (m)</th>
<th>ws (m)</th>
<th>dis (m)</th>
<th>p (m)</th>
<th>h (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.53</td>
<td>4</td>
<td>0.05</td>
<td>0.35</td>
<td>0.1</td>
<td>0.425</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Figure 3- Reflection phase diagram for different values of h.

Figure 4- Reflection phase diagram for different soil layers.

Figure 5- Reflection phase diagram for different values of wr.

Figure 6- Reflection phase diagram for different values of dis.
3- Simulation for Antenna Application

To investigate the effects of applying the bandgap structure on antenna performance, three cases have been studied. Utilizing analogous method of [7], two identical aperture antennas are located at the distance of 75 m and the antennas have been designed to resonate at 8 MHz approximately. In the first case, no bandgap structure has been applied, while in the second and third cases the ground has been covered by three and six rows of EBG structures respectively. The cases under study and the simulation setup have been demonstrated in Figure 7. It should be noted that as shown in Figure 8, using more unit cells requires additional computational resources due to complexity of meshing. Thus, an array of 6×9 unit cells have been applied, which may not allow the best performance of the structure. The simulation results for mutual coupling reduction and Sky wave to Ground wave Ratio (SGR) improvement have been exhibited in Figure 9 and Figure 10. The formula for calculating SGR is

\[ SGR = \frac{1 - |S_{11}|^2 - |S_{21}|^2}{|S_{21}|^2} \]  

According to the figures, the maximum reduction of \( S_{21} \) and improvement of SGR are about 1.5 dB and 0.8 respectively. By utilizing more unit cells, \( S_{21} \) reduces and a greater SGR are expected.

Figure 7- Simulation setup for three cases of study, (a) no EBG, (b) 3 rows of EBG, (c) 6 rows of EBG.
Figure 8- Meshing details.

Figure 9- Sky wave to Ground wave Ratio (SGR) of three cases of study.

Figure 10- S21 for three cases of study.
4- Conclusion

This paper has presented an implementable bandgap structure for AM radio applications. The aim of designing such structures is to remove surface wave and boost the sky wave propagation. Moreover, the in-phase reflection from AMC surface can enhance sky wave propagation by constructive superposition. The effects of changing designing parameters on bandgap and the resonance frequency have been demonstrated in diagrams. In radio broadcasting stations with too many radiating elements, such structures may be helpful to alleviate the interelement coupling. Designing multi-band surfaces by progressively magnified EBG structures for AM radio applications is considered as a future work.

5- References: