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# Analysis of Mushroom-like EBG Structure and UC-EBG for SAR Reduction


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## 1. Introduction

Advances in telecommunications technologies today have led to a wide usage of mobile phones in global community. Nowadays, the mobile phone has become an essential communication tool for everyone. By the end of 2009, the number of mobile phone subscriptions was estimated 5 billion worldwide [1]. This is more than 370 times the number of users in 1990. Since the number of mobile phone users is huge and keep increasing every year, it is crucial to not only study, understand and monitor any potential public health effects from the mobile phone radiation exposures, but also propose an effective method for reducing the Specific Absorption Rate (SAR) to the minimum level.

Over the past few years, Electromagnetic Band Gap (EBG) structures have attracted a great deal of attention due to their unique characteristics in controlling the propagation of electromagnetic waves in specified frequency bands [2]. This property enables the EBG structure is used to block the propagation of waves and guide them in a desired direction by forbidding the propagation of EM waves in certain frequency band. Therefore, if the EBG structure is applied to the mobile phone, the undesired electromagnetic waves can be prevented.

This paper presents an analysis and a comparison of two types of Electromagnetic Band Gap (EBG) structures: mushroom-like EBG [3] and uni-planar compact EBG (UC-EBG) [4] to reduce the unwanted electromagnetic waves radiated from mobile phone. In this research, the surface-wave suppression band gap characteristics of these EBG structures and the SAR value in human head tissues have been investigated and analyzed. All the analyses are performed using CST Microwave Studio (CST MWS) software that based on Finite Integration Technique (FIT) method at the GSM 1800 frequency band. The results reveal that the highest percentage of SAR reduction effectiveness was obtained using mushroom-like EBG followed by UC-EBG. The results also conclude that the number of EBG elements is the most important factor for achieving a high value of SAR reduction effectiveness.

## 2. EBG Structures

Various types of EBG structures have been proposed and investigated in recent years. One of the most popular is mushroom-like EBG. In general, the electromagnetic properties of an EBG structure can be characterized based on their physical dimensions. For a mushroom-like EBG structure, there are four important parameters influencing its performance namely, patch width, gap width, substrate thickness and substrate permittivity [2]. To obtain a stop band at 1800MHz, the parameters of mushroom-like EBG are designed as: a=13.5mm, b=13mm and c=0.5mm.

Besides the mushroom-like EBG structure, another popular EBG structure is the UC-EBG structure. Fig. 1 compares the geometries of the mushroom-like EBG and the UC-EBG. An important feature in the UC-EBG design is the elimination of vertical vias. Hence, it simplifies the fabrication process. The dimensions of UC-EBG unit cell are as follows: a=13.5mm, b=12.5mm, c=d=0.5mm and e=1.5mm. To make a fair comparison, the unit cell size, substrate permittivity and substrate thickness are kept the same for both EBG structures. The substrate used is Roger RT/Duroid 6010LM with thickness of 1.905mm and dielectric constant of 10.2.

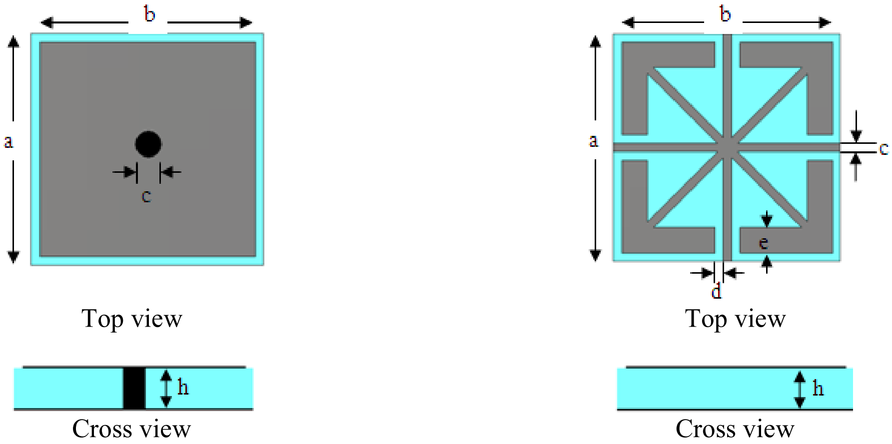



Figure 1: Geometries of a) a mushroom-like EBG unit cell structure and b) a UC-EBG unit cell structure

## 3. Results and Discussion

In this paper, the surface wave bands of EBG structures are designed to be around 1800MHz bands. It is expected that the electromagnetic waves with frequency within their frequency band gap are impenetrable. The dispersion diagrams of both structures are characterized using the eigenmode solver in CST MWS. The result of the mushroom-like EBG is plotted in Fig. 2a and the result of the UC-EBG is plotted in Fig. 2b. It can be seen that the band gap of the mushroom-like EBG is from 1.7 GHz to 2.65GHz, whereas for the UC-EBG is from 1.32 GHz to 2GHz. The band gap of the mushroom-like EBG is a little wider than the UC-EBG structure.

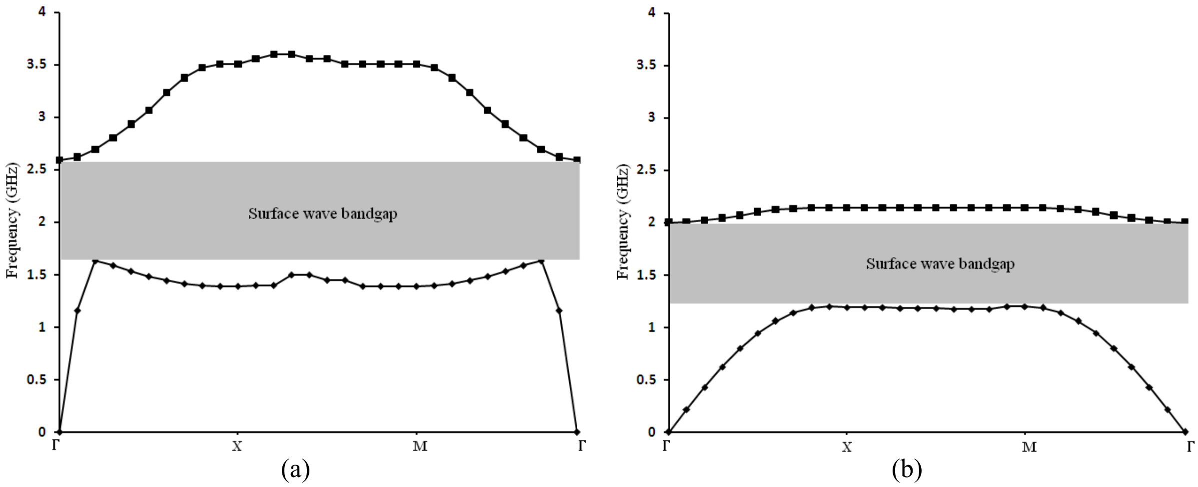



Figure 2: Dispersion diagram of a) a mushroom-like EBG unit cell structure and b) a UC-EBG unit cell structure

After the simulation for dispersion diagram completed, the designed EBG structure is used to reduce the SAR value. The designed EBG structure is placed between antenna and human head in order to calculate the SAR value. In general, SAR can be defined as [5]:

$$\mathrm{SAR}\ (\mathrm{W/kg}) = \frac{\sigma |E|^2}{2\rho} \qquad (1)$$

where σ is the tissue conductivity (S/m), ρ is the tissue density ($kg/m^3$) and E is the peak amplitude of the electric field in human tissue (V/m). This value refers to the actual amount of electromagnetic energy absorbed in the biological tissues, thus a lower value of SAR indicates a lower radiation exposure risk to the human body.

As a three-dimensional (3D) model of the whole realistic human head model with the presence of EBG structure generally requires a large amount of memory in computation, a simplified homogeneous muscle cube has been used to study the effect of SAR reduction, whereas the mobile phone has been modeled as a half wavelength dipole antenna. A complete simulation model which includes the dipole antenna, EBG structure and the muscle cube is shown in Fig. 3. The size of muscle cube is chosen to be equal to the length of the dipole antenna. The electrical properties of muscle tissue at 1800MHz used for simulation are as follows: $\varepsilon_r$=49.4, σ=1.53 S/m and ρ=1040 $kg/m^3$. The radiated power of dipole antenna is set to 500mW.

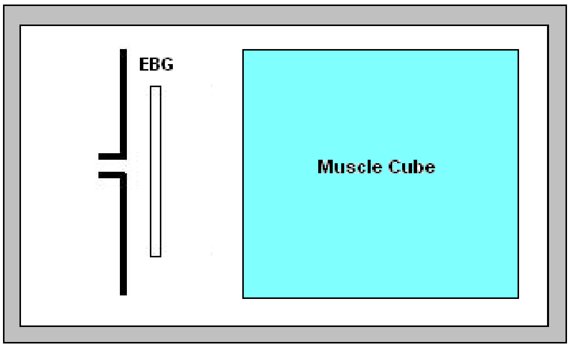



Figure 3: Simulation models for SAR calculation

Comparisons of the SAR reduction effectiveness with two different types of EBG structures are analyzed. To evaluate the SAR reduction effectiveness of the EBG structures, the SAR reduction factor (SRF) formula has been used. The SRF is defined as [5]:

$$SRF\ (\%) = \frac{SAR_{withoutEBG} - SAR_{withEBG}}{SAR_{withoutEBG}} \times 100 \qquad (2)$$

where $SAR_{withoutEBG}$ denotes the SAR value measured without the EBG structure and $SAR_{withEBG}$ the SAR value measured with the EBG structure.

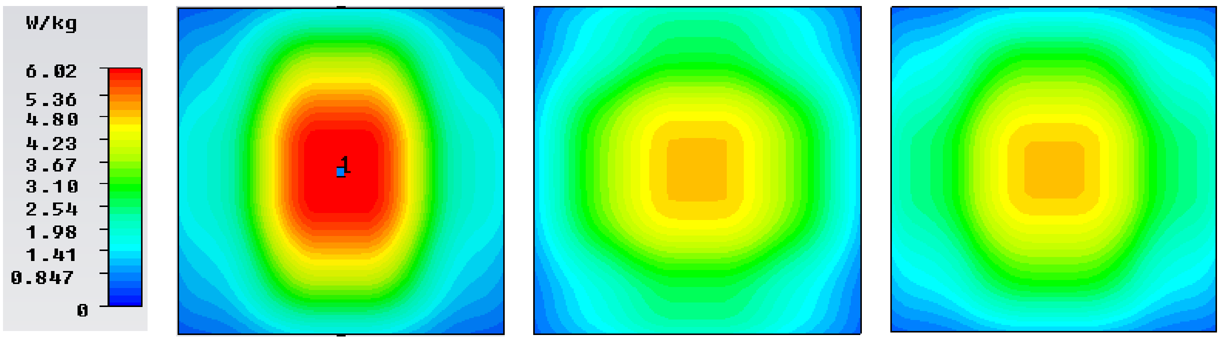
Simulation results are summarized in Table 1. The distance between dipole antenna and EBG structure is varied from 5mm to 1mm. As shown in Table 1, it is found that SRF is decreased with the increasing of the distance between antenna and EBG structures, which means that the SRF is increased when the EBG structure is closed to the dipole antenna. In terms of the number of EBG elements, we can see that SRF is increased with the increasing of the number of EBG elements for both EBG structures. For example, the SRF for mushroom-like EBG with the 2x3 elements is 33.2%, while for 3x3 elements is increased to 43.49%. This is because the EBG structure with higher number of elements suppressed more surface waves compared than EBG structure with low number of elements. Table 1 also shows that the mushroom-like EBG have higher SRF compared than UC-EBG. Fig. 4 show the SAR distributions in muscle cube for dipole antenna with the presence of the 3x3 elements EBG structure. It can be clearly seen that the SAR distributions reduce after the EBG attachment. This is due to the surface wave suppression by the EBG structure.

## 4. Conclusion

The analysis and comparison of two types of EBG structures: mushroom-like EBG and UC-EBG to reduce the electromagnetic waves radiated from mobile phone has been presented in this paper. The stop band for each EBG structure has been designed at operation bands of mobile phone radiation. The results revealed that mushroom-like EBG structure gives a higher reduction of SAR compared than the UC-EBG. Besides, the results also indicated that the number of EBG elements play an important role in the SAR reduction effectiveness. The human head can be protected from unwanted electromagnetic radiations by placing the EBG structure in between antenna and human head.

Table 1: Comparison of SAR reduction effectiveness between mushroom-like EBG and UC-EBG

| Distance between antenna and EBG | Mushroom-like EBG | | Uni-planar Compact EBG | |
|---|---|---|---|---|
| | SRF (%) 2x3 elements | SRF (%) 3x3 elements | SRF (%) 2x3 elements | SRF (%) 3x3 elements |
| 1mm | 33.2% | 43.49% | 26.21% | 33.67% |
| 2mm | 26% | 35.66% | 22.7% | 26.61% |
| 3mm | 22.73% | 30.86% | 19.37% | 23.25% |
| 4mm | 21.2% | 27.73% | 17.6% | 20.39% |
| 5mm | 18.7% | 21.92% | 14.64% | 21.89% |




Without EBG | With 3x3 mushroom-like EBG | With 3x3 uniplanar Compact EBG

Figure 4: SAR distribution on muscle cube

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