Improvement of ground radiation antenna performance using compact EBG in presence of battery effects

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In Internet-of-things devices, to alleviate the performance degradation of the ground radiation antenna due to the large battery, two compact electromagnetic bandgap (EBG) unit cells are introduced between the ground radiation antenna and the battery. The ground radiation antenna is comprised a small loop-type circuit that is designed within a 5-mm × 5-mm ground clearance for 2.4-GHz WLAN applications. The compact EBG unit cell is a modified square split-ring resonator that is designed by meandering-line technology. The measurement results showed that the 3:1 VSWR impedance bandwidth of the ground radiation antenna increased from 30 to 90 MHz, and the average total efficiency increased from 19% to over 54% with and without the introduction of the EBG structure, respectively.

Introduction: With the development of radio communication technology, Internet-of-things (IoT) technology has penetrated every aspect of our daily life, such as the Internet of vehicles, wearable devices, and smart homes. The antennas implemented in miniaturised IoT terminal equipment are often affected by surrounding components or carriers, especially when the antenna is close to the large battery or other metal carriers, degrading the antenna performance. Accordingly, it is an important issue for antenna engineers to improve the antenna performance by alleviating the undesired effects from neighbouring metal structures.

In the field of mobile communications, the effects on mobile phone antennas by the display screen and battery have been studied in [1, 2], but these studies did not consider how to eliminate the influence on the antenna because, at the time, enough clearance space was allocated for the antenna to assure high radiation efficiency. Recently, electromagnetic bandgap (EBG) structures, metamaterials, and ferrite sheets have been reported in [3–6] to achieve high antenna performance in wearable devices when they were introduced between the antenna and the human body to effectively improve the performance of the antenna in the presence of human-body influence. However, the adopted antenna types were planar monopole antennas, Yagi–Uda antennas, planar inverted-F antennas (PIFAs), and microstrip antennas, so these previous studies are difficult to apply directly to miniaturised IoT devices, where there is not enough clearance space remaining to install these antennas. A ground radiation antenna (GradiAnt) has a wide range of potential applications in the field of miniaturised IoT terminals. Since the GradiAnt can radiate by coupling the energy to the PCB (many components may be integrated on the PCB) of the device, only a very small ground clearance is required to install the antenna as a small loop-type circuit [7, 8].

However, the GradiAnt is easily influenced by the closely located large battery in the device, resulting in a narrow frequency bandwidth and decreased radiation efficiency. Therefore, it is essential to study the interaction between the GradiAnt and the battery and to improve the antenna performance, which has not been reported in previous studies. In this Letter, two compact EBG unit cells, which are comprised modified square split-ring resonator structures, are introduced between the GradiAnt and the battery to improve the antenna performance. The simulation and measurement results show that a wider impedance bandwidth and higher radiation efficiency of the GradiAnt can be realised in the presence of the influence of the battery.

Proposed antenna scheme: The overall structure of the proposed antenna consists of a GradiAnt in the top layer, two EBG unit cells in the middle layer, and the modelled battery in the bottom layer, as shown in Fig. 1. In the top layer of the overall structure, the GradiAnt is designed in a single-sided PCB with dimensions of 30 mm × 20 mm, which is etched on a 1-mm-thick FR4 substrate with $\varepsilon_r = 4.4$ and tan $\delta = 0.024$, as shown in Fig. 1*b*. The GradiAnt, which is designed as a small loop-type circuit within a 5-mm × 5-mm ground clearance, includes two capacitors, Cr (0.05 pF) and Cf (0.4 pF), that tune the antenna's resonant frequency and impedance characteristics, respectively. The bottom layer is a 50-mm × 30-mm battery. Since the battery's surface can be regarded as a metal surface, the battery is modelled by a fully grounded single-sided PCB for simplicity, which is fabricated on a 1-mm-thick FR4 substrate with $\varepsilon_r = 4.4$ and tan $\delta = 0.024$. The middle layer of the proposed antenna scheme is two compact EBG unit cells, which are modified square split-ring resonators designed by utilising meandering-line technology, as shown in Fig. 1*c*. It is noted that the EBG can be fabricated on a semi-flexible substrate or printed on paper by inkjet-printing technology. The gap between the EBG unit cells and the top layer PCB is 1 mm, and the gap of the air layer between the EBG unit cell and the bottom layer PCB is 4 mm, as can be observed in Fig. 1*a*. The detailed dimensions can be found in Fig. 1. The above GradiAnt and EBG designs are simulated and optimised by Ansoft high-frequency structure simulation (HFSS) 15.

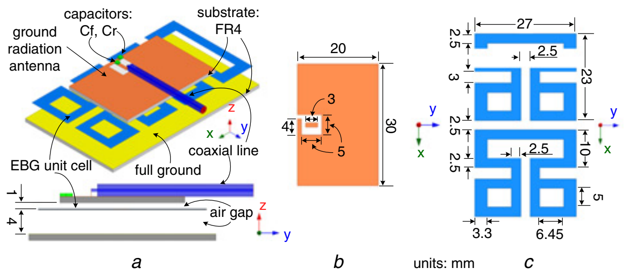

Fig. 1 *Schematic view of proposed antenna structure*

a Proposed antenna scheme
b Ground radiation antenna
c Two compact EBG unit cells

Simulated and experiment results: With the introduction of the EBG unit cells, the performance of the GradiAnt and characteristics of the EBG are affected simultaneously due to the interaction between the GradiAnt and the EBG. By adjusting the dimensions of the EBG, the gap between the antenna and EBG, and the capacitor values (Cf and Cr), a broad impedance bandwidth and high radiation efficiency are obtained in the operating frequency band.

Before and after the introduction of the compact EBG structure, the simulated and measured reflection coefficients (S_{11}) of the GradiAnt in different cases are given in Fig. 2. The data for the GradiAnt without the EBG is achieved by removing the EBG while retuning the capacitor values of Cf and Cr to 0.1 and 0.3 pF, respectively, so that the resonant frequency of the GradiAnt falls in the operating frequency. It can be observed that the impedance bandwidth of the GradiAnt without the EBG is very narrow (3:1 VSWR impedance bandwidth of 30 MHz). With the introduction of the EBG structure, a broad impedance bandwidth of 90 MHz is obtained. The simulated and measured results are consistent with each other. Therefore, the impedance bandwidth has been greatly improved, by a factor of three, by utilising the two proposed compact EBG unit cells.

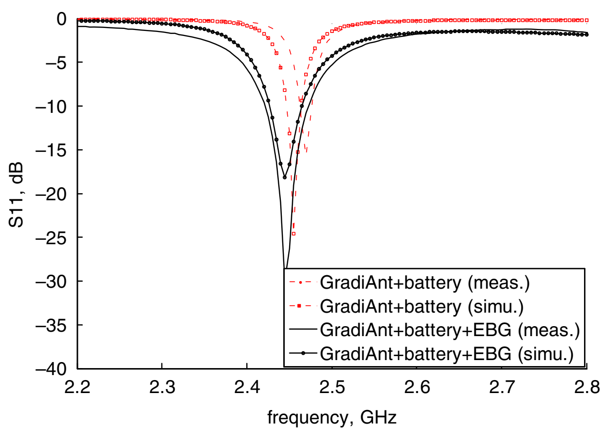

Fig. 2 *Simulated and measured S_{11} of GradiAnt in different cases*

The simulated and measured total efficiencies, including the reflection loss, are shown in Fig. 3. It can be seen that the measured total efficiency of the antenna without EBG is very low, with an average efficiency of 19% and peak efficiency of 42% at 2.47 GHz. With the introduction of EBG, the total efficiency has been improved significantly, with an average efficiency of 54% and peak value of 65% at 2.46 GHz.

Moreover, the experimental results nearly agree with the simulated data, indicating the higher performance of the proposed antenna design.

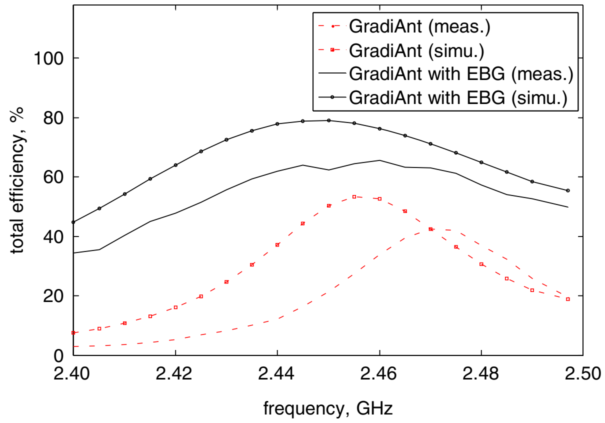

Fig. 3 *Simulated and measured total efficiency of GradiAnt in different cases*

Furthermore, the measured radiation patterns of the GradiAnt are verified in Fig. 4. It can be seen from the shape of the radiation pattern after the introduction of the EBG that the radiation is weakened near $\theta = \pm 90°$, and the radiation is enhanced near the $\pm z$ direction. With and without the introduction of EBG structure, the maximum gains of the antenna appear in the direction of $\theta = 0°$, reaching −0.33 and 4.89 dBi, respectively, whereas the maximum gains in the $\theta = 180°$ direction are −1.95 and 3.42 dBi, respectively.

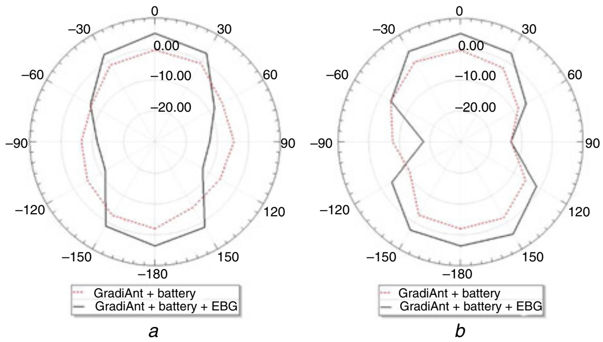

Fig. 4 *Measured radiation patterns of GradiAnt at 2.46 GHz in different cases*

a xz-plane
b yz-plane

Conclusion: In this Letter, two compact EBG unit cells are utilised to improve the radiation performance of a small loop-type ground radiation antenna for 2.4-GHz WLAN applications. By introducing EBG structures between the antenna and the battery, the impedance bandwidth has been improved by a factor of three, and the total efficiency has been increased from 19 to 54% on average. Furthermore, only two EBG unit cells are adopted, which are compact enough for practical IoT applications for performance improvement. Therefore, the proposed technique can be used in the presence of not only large batteries but also other metal carriers, e.g. display screens, to achieve high antenna performance.

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One or more of the Figures in this Letter are available in colour online.

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