

IMPROVING WEARABLE SLOT ANTENNA PERFORMANCE WITH EBG STRUCTURES

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Abstract: This paper presents a 2.8GHz slot antenna over an EBG (Electromagnetic Band Gap) substrate with the objective of higher antenna efficiency, wide bandwidth and compact operation in close proximity to the human body. To achieve compact size, two different size EBGs are developed and the antenna return loss and efficiency are measured in a reverberation chamber. From these results, the EBG substrate demonstrates 60% improvement of the antenna efficiency compared to other methods in the wearable antenna scenario.

1. Introduction

Wireless networks for body worn applications need small efficient antennas when working near the human body. Because of the effects on antennas in close proximity to the human body, such as resonant frequency shifts, radiation pattern fragmentation and signal absorption; body worn antennas have recently received much attention [1]. Novel micro strip antennas and EBG substrates were investigated to reduce or eliminate signal radiation in the area of the user, thus reducing signal absorption in tissue. Also because of its low profile structure, the micro strip patch antenna is a promising candidate for body worn applications [2] [3].

A copper wire antenna built on an EBG surface is described in [4] that is designed for the form factor of a portable handset. Measurements carried out for the radiation pattern show high radiation efficiency near the center of the band gap without taking the antenna return loss into account. In this paper, we propose a 2.8 GHz slot antenna over an EBG substrate capable of providing total antenna efficiency around 76% in proximity to the human body and directly obtain the antenna efficiency in a reverberation chamber. For comparison, we work out the slot antenna performance without EBG and with PEC (Perfect Electric Conductor) in proximity to the human body.

2. Antenna and EBG structure

Fig. 1(a) shows the configuration of the proposed 2.8 GHz slot antenna and the EBG substrate. The patch antenna is based on Taconic RF-35 ($\epsilon_r=3.5$, Loss tangent=0.0018) with a thickness of 1.52 mm. The antenna size is 30 mm \times 36 mm. The EBG in Fig. 1(b) consists of 6 \times 6 and 4 \times 4 small patch segments over a solid metal sheet. The space between patches and ground plane is filled with Taconic CER-10 ($\epsilon_r=10$, Loss tangent=0.0035) of thickness 3.18 mm and the dimensions of the substrates used are 63.75 mm \times 63.75 mm and 44.25 mm \times 44.25 mm. The EBG design method [5] is used to select the patch dimensions and substrate thickness. Only the suppression of the TE surface current is of interest, so we do not use a via-array in the substrate.



Fig. 1 (a) Slot antenna and (b) EBG structure (6 \times 6 elements and 4 \times 4 elements)

EBG (Electromagnetic Band Gap) is a nearly lossless reactive surface, usually realized as a printed circuit board, that presents a reflection coefficient of the order of 1 to incident plane waves and simultaneously inhibits the propagation of surface current across its surface over a prescribed band of frequencies (the so-called band gap). Surface current was measured by a pair of small current loops with the EBG structure placed above an absorber. Fig. 2 (a) shows the band edge of the TE surface wave is 3.2 GHz.

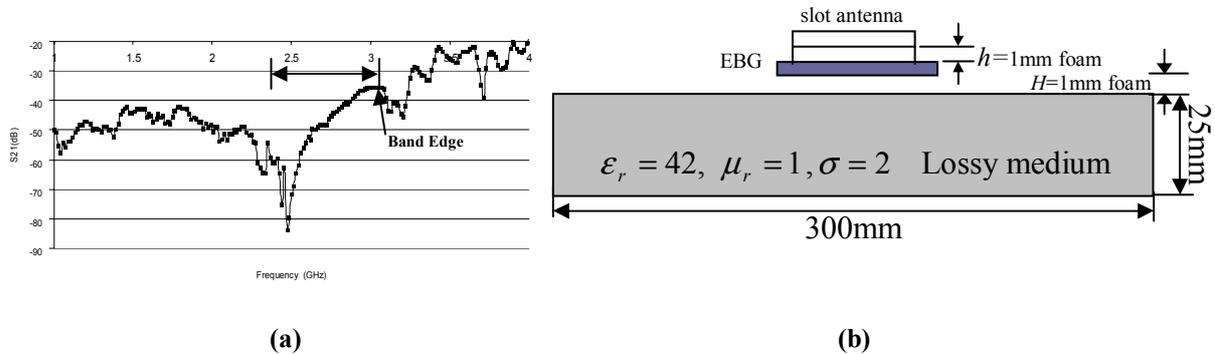


Fig. 2: (a) The measured surface wave coupling (b) The Simulation configuration for antenna and EBG

Fig. 2(b) shows the simulation configuration of the slot antenna with an EBG substrate in close proximity to the human body. The human body phantom model is 300 mm \times 200 mm \times 25 mm in size with a homogeneous lossy medium which has the relative permittivity $\epsilon_r = 42$ and the conductivity $\sigma = 2.0$ S/m [6] [7]. The size of this body model was found by comparing the simulation results in terms of antenna performance when a larger model was used. No significant differences were found.

3. Results

The slot antenna was measured in the reverberation chamber in ECIT, Queen's University Belfast. The reverberation chamber, also called a mode-stirred chamber is used to obtain the antenna efficiency, which is especially useful for body worn antennas. In the design of traditional antennas which work in free space, the measured parameters are often the reflection coefficient S_{11} and the radiation patterns measured in the E or H planes around the antenna. The reflection coefficient describes how much of the available power is reflected at the antenna port, but it does not give any information about whether the rest of the power is radiated or dissipated in the antenna. Therefore, the reflection coefficient alone cannot determine if the antenna is a good or a poor radiator. The radiation efficiency is defined as being the total radiated power divided by the maximum available power when the antenna is impedance matched. The antenna efficiency includes the effects of mismatch, as well as absorption in the antenna and its near field environment, which is defined as being the total radiated power divided by the total incident power [8]-[10]. The reverberation chamber in ECIT is 2.4 m \times 2.4 m \times 2.4 m.



Fig. 3: Reverberation chamber in ECIT, Queen's University Belfast

3.1 Return Loss on Body

Fig. 4(a) examines the return loss performance of the slot antenna. The resonant frequency of the slot antenna is 2.85 GHz, the bandwidth is 350 MHz in free space. When the slot antenna is placed on a

phantom, the resonant frequency is around 2.75 GHz by the detuning effect. When the EBG structure antenna is placed on the phantom, the resonant frequency stays at 2.85 GHz, the bandwidth decreases to 100 MHz, which is caused by the strong coupling effect by only a 1 mm separation between the slot antenna and the EBG surface. (EBG6 means the EBG structure with 6×6 elements and EBG4 for 4×4 elements). For comparison we placed a PEC reflector instead of the EBG and in this case there is no apparent resonant frequency and S_{11} is above -10dB from 2.6 GHz to 3.2 GHz.

3.2 Efficiency and Radiation Pattern

As signal absorption occurs in close proximity to the human body, the antenna efficiency has become the key parameter in our design. Fig. 4 indicates the antenna efficiency in different scenarios. As illustrated in Fig. 4, the slot antenna in free space has an efficiency of $\eta_a = 95\%$ while with the antenna 5 mm away from the human body, the efficiency becomes $\eta_a = 16\%$ and $\eta_a = 10\%$ with a PEC reflector. However, when an EBG is applied under the slot antenna, the antenna efficiency is $\eta_a = 76\%$ for a 6×6 element EBG and 67% for a 4×4 element EBG which has a 50%-60% improvement compared to the antenna without EBG. The improvements arise from the characteristic of in-phase reflection and surface wave suppression thus it effectively isolates the slot antenna from the surrounding environments.

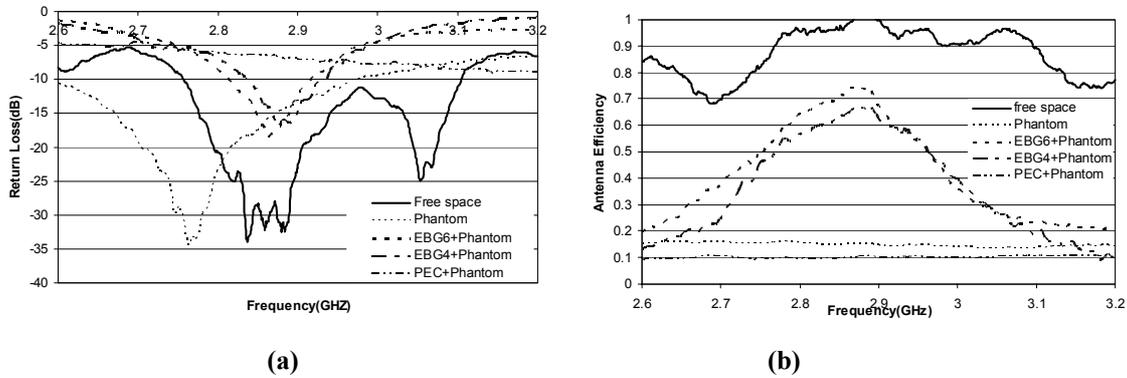


Fig. 4 (a) Measured Return Loss from 2.6 to 3.2 GHz (b) Measured Antenna Efficiency from 2.6 to 3.2 GHz

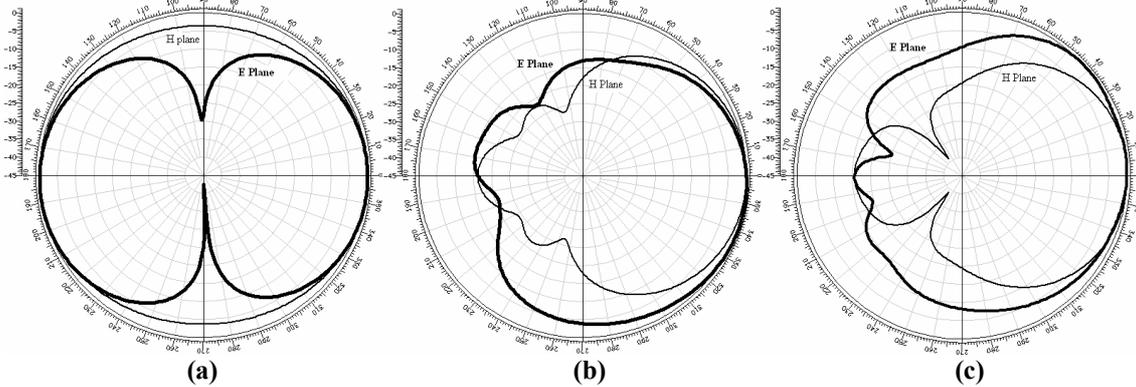


Fig. 5 Simulated Radiation Pattern (a) free space (b) On Phantom w/o EBG (c) On Phantom w EBG

3.3 The separation effect between the antenna and EBG surface

In previous experiments, we set the gap h between the slot antenna to the EBG surface to be 1 mm which makes sure the whole structure is more compact. To indicate the separation effect, we adjust the gap h between 2 mm and 3 mm. The simulation ($h=*mm_S$) and measurement ($h=*mm_M$) results are shown in Fig. 6.

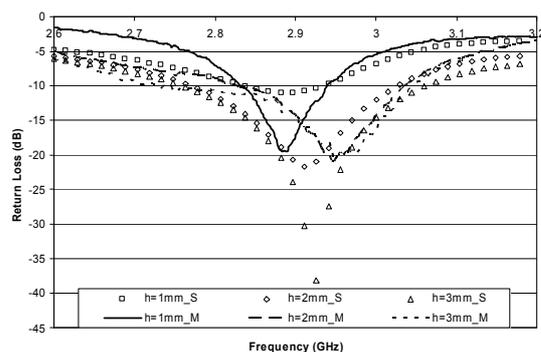


Fig. 6 Measured and Simulated Return Loss at given h

Table 1: Measured Bandwidth and Max. Antenna Efficiency

h	1 mm	2 mm	3 mm
Bandwidth (MHz)	103	202	318
Max. Antenna Efficiency	76%	73%	71%

The antenna efficiency is shown in Table 1. The efficiency decreases around 2-3% when h is increased by 1 mm, this is within the quoted error (0.5dB) for the reverberation chamber. Nonetheless the difference may be attributed to the EBG in-phase reflection feature. The slot antenna radiates a linear polarized wave to the EBG surface, the phase difference of the reflection field from the EBG surface to the incident E field is larger when h becomes larger, in that the antenna efficiency decreases from 76% down to 71%.

4. Conclusions

An EBG surface for improving the antenna efficiency in a wearable scenario has been proposed. We have selected two different size EBGs to compare their performance as the target for compact operation. By changing the proposed design h , we can discover how the centre resonant frequencies shift and bandwidth increases. For our future work, we are improving our structure to obtain a higher efficiency, wider bandwidth and compact design simultaneously.

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