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Miniaturization of Mobile GPR Antenna Assembly

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Summary:
For miniaturizing a mobile ground penetrating radar (GPR) antenna assembly, an electromagnetic band gap (EBG) structure to reduce the transmitting and receiving cross-talk is proposed. The antenna assembly works around 2.45 GHz and supposed to detect motions though concrete and other building materials. Dimension of the required EBG-structure for both air-coupled and ground-coupled scenarios are analytically estimated. Finite element method based radio frequency simulations are conducted to verify the estimations and to find the optimal dimensions.

Keywords: GPR, planar antenna, miniaturization, RF-cross-talk isolation, electromagnetic band gap

Introduction

A ground penetrating radar (GPR) is capable of detecting motion even through layers of material. After an earthquake, a GPR can be used to find survivors that trapped under collapsed buildings by detecting the body motion caused by their respiration. The most volume consuming part of a traditional GPR is the transmitting and receiving (Tx- and Rx-) antenna assembly. Beside the physical size of the antenna itself, the Tx- and Rx-antennas usually need to be spatially separated by a certain distance to reduce the cross-talk which would otherwise obliterate the signals of interest. However, increasing the Tx- and Rx antennas distance will increase the volume of the assembly, which impacts the mobility of the system.

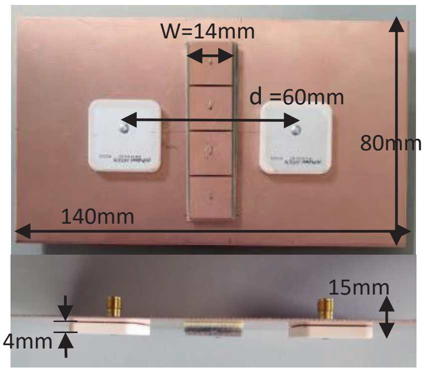

Fig. 1. Tx- and Rx-antenna assembly with a 4-element EBG structure, $W = 14$ mm. Top: front view. Bottom: side view.

For a coplanar antenna assembly, the cross-talk occurs as surface waves between the Tx- and Rx antenna. In studies of metamaterial, it was found that some structures exhibit band-stop features for surface electromagnetic waves, this kind of structure is called electromagnetic band gap (EBG). There are various kinds of EBG structures, among them the mushroom-like EBG earned increasing attention in the recent decade, as first published in [2]. The mushroom-like EBG consists of evenly distributed metallic patches of the same shape, a ground plane in parallel and conducting vias (see Fig. 1. and 2). This special metallic structure introduces an LC resonator and the capacitance and inductance are determined as [2]:

$$L = \mu_0 \cdot h , \qquad (1)$$

$$C = \frac{W\varepsilon_0(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{2W+s}{s}\right), \qquad (2)$$

in which h is the EBG substrate height, W is width of one EBG element, s is the gap between elements and ε_r is the relative permittivity of the substrate.

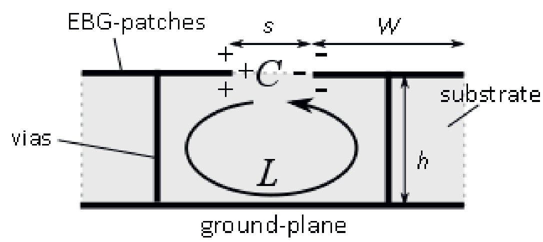

Fig. 2. Schematic side-view of a mushroom-like EBG structure with two elements. [2]

By cascading these elements, a high-order band-stop filter can be built. In [3], simulations show that the EBG provides better isolation than other surface wave reduction approaches, such as substrate removal or cavity-backed structure.

Method

Here we work with two commercial 2.45 GHz ceramic patch antennas [1] and restrict the analysis on single row mushroom-like square shape EBG structure (see Fig. 1). The EBG substrate is FR4 with the same height as the antenna: 4 mm, gap between elements is 0.5 mm. The Tx- and Rx-antennas share a 0.8 mm thick ground plane with a width of 80 mm and a length of 140 mm. Center to center distance of the two antennas is 60 mm. By using the resonance frequency of a simple LC-circuit:

$$f_{stop} = \frac{1}{2\pi\sqrt{LC}}, \quad (3)$$

together with eq. (1) and (2), the required width of EBG-element W can be estimated. The desired f_{stop} is 2.45 GHz. For the air-coupled case, the required capacitance is about 0.84 pF and the W should be about 12 mm. For ground-coupled case, the permittivity of ground $\varepsilon_{r,grd}$ should be considered in the equation for capacitance as:

$$C = \frac{W\varepsilon_0\varepsilon_{r,grd}(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{2W+s}{s}\right) \quad (4)$$

The relative permittivity of common building material is between 2 and 9 [4]. For $\varepsilon_{r,grd} = 2$, 4 and 6, the required W shall be 7 mm, 4 mm and 3 mm respectively.

To verify the estimation, the model is analyzed with FEM based RF simulation. For air-coupled case, the number of EBG-elements is kept as 4, W varies from 10 mm to 18 mm. For ground-coupled cases, the number of elements is kept as 8, W varies from 2 mm to 9 mm.

Results

The transmission coefficient S_{21} indicates the mutual coupling between Tx- and Rx- antenna.

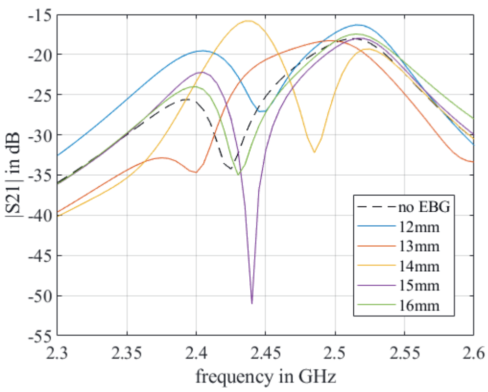

Fig. 3. S_{21} of air-coupled simulation. Comparison between no EBG and a 4-element EBG of various widths.

From the air-coupled simulation (see Fig. 3), that only EBG structure with a width of 15 mm forms a stopband around 2.45 GHz. In the measurement, the antenna assembly with 14 mm EBG has the weakest mutual coupling at 2.45 GHz. From the ground-coupled simulation with $\varepsilon_{r,grd} = 4$ (see Fig. 4), 8 mm width EBG is most suitable to isolate the cross-talk around 2.45 GHz. However, in both scenarios the band-stop frequency is very sensitive to the EBG width, only 1 mm difference could lead to completely different mutual coupling in the desired frequency band.

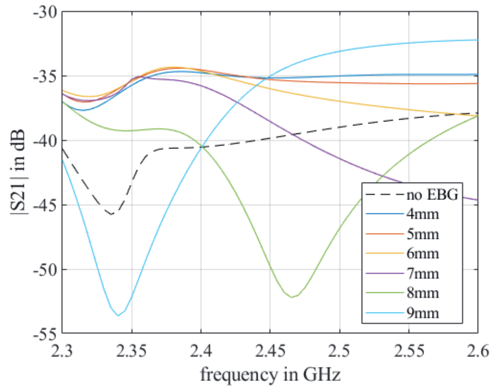

Fig. 4. S_{21} of ground-coupled $\varepsilon_{r,grd} = 4$ simulation,. Comparison between no EBG and an 8-element EBG of various widths.

Conclusion

In this work, a single-row EBG structure is implemented to reduce the cross-talk between planar Tx- and Rx- antennas. Simulations and measurements exhibit that the implemented EBG could reduce antenna mutual coupling by up to 10 dB.

Acknowledgment

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