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3D Printing technique for the development of non-planar EBG structures for antenna applications

S. Jun, B. Sanz-Izquierdo and E.A.Parker

This letter proposes the use of 3D printing for the development of non-planar electromagnetic band gap (EBG) structures for antenna applications. A coplanar waveguide (CPW) fed antenna is tested on a non-planar EBG substrate, fabricated using additive manufacturing techniques. Inexpensive fuse filament fabrication (FFF) is used as the fabrication process. Silver-loaded conducting ink is employed for the metallic components of the EBG. The CPW antenna on the non-planar EBG structure has a satisfactory reflection coefficient at 2.45 GHz, which is suitable for Bluetooth/WLAN communications. The radiation patterns have reduced back lobes and improved gain compared with the antenna in free space.

Introduction: 3D printing (3DP) or additive manufacturing (AM) enables the layer by layer fabrication of structures from a digital model. This technology is able to realise designs with complex shapes and internal features. Fused filament fabrication (FFF) is the most common and accessible technology. It offers the lowest cost for 3DP. Three dimensional objects are created by melting a plastic which is deposited in layers. FFF has recently been proposed for the development of frequency selective surfaces (FSS) [1] – [2] and to assist in the fabrication of wearable antennas [3]. In [2], an FSS fabricated by partially metalising 3D printed shapes was able to reduce significantly the resonant frequency and improve the angle of incidence performance compared with the same but fully metallised design [4].
Electromagnetic band gap (EBG) structures have been widely applied to improve antenna performance [5] – [8]. They can act as high impedance surfaces for improved antenna matching and directivity. Compact CPW antennas have been proposed incorporating EBG substrates made from commercial laminates [5] and textile materials [6]. More recently, inkjet-printing technology has been used for the fabrication of a monopole antenna and an EBG array on photo paper substrate [7].

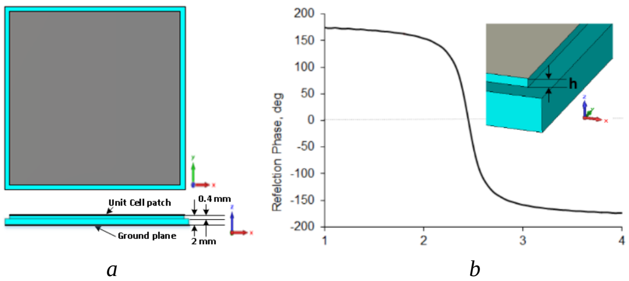

Fig. 1 N*on-planar EBG structure: a) geometry, b)* calculated reflection phase

In this letter, an additive manufacturing technique is proposed for the development of non-uniform EBG substrates for antenna applications. A relatively simple structure consisting of flat metallic patches and trenches between the patches illustrates the principle. A commercial FFF machine with low-cost polylactic acid plastic (PLA) is used for the fabrication of the substrate while silver loaded paint for the metallic patches. A 3D printed stencil allows the patterning of the patches on the substrate. A CPW antenna is tested on the EBG substrate. All simulation results have been carried out with CST Microwave Studio™. The emphasis in this letter is on the demonstration of a simple AM process for the fabrication of complex EBG geometries for antenna applications.

EBG and Antenna Design and Performance: The EBG is a periodic array of flat square patches with trenches between them. Fig. 1a shows the geometry of the unit cell. Each upper patch has side dimensions of 35mm, and is arranged on a unit cell of 37mmx37mm. The depth of the trenches is 0.4mm and the total thickness of the substrate 2mm.

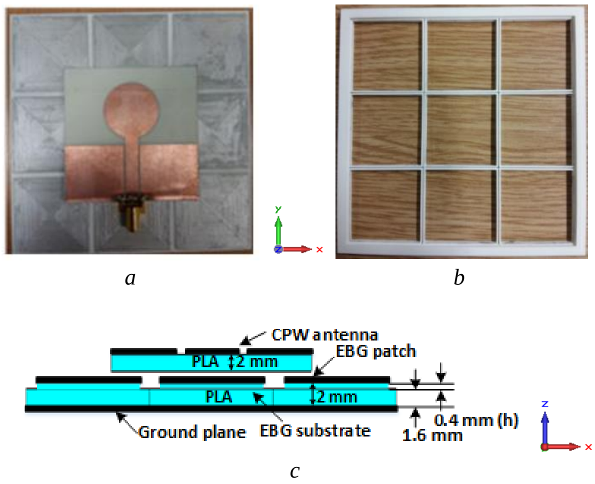

Fig. 2 *Coplanar waveguide (CPW) fed on EBG structure: a)* configuration, *b)* EBG stencil, *c)* side view with dimensions.

Fig. 1b shows the simulated reflection phase of the EBG structure. The unit cell was designed for a resonance frequency of 2.45 GHz, where the phase angle is zero. The depth of the trenches (h) can control the resonance frequency without changing the overall patch size.
In order to test the effect of such an EBG, a wideband CPW antenna was set at the centre and at a distance of 1 mm over 3 x 3 patch cells of the EBG structure as shown in Fig. 2a. The overall size of the EGB substrate was 120 × 120 mm. The antenna was designed to cover frequencies higher than 2GHz in free space with reflection coefficient levels (S_{11}) of less than -10dB. The CPW antenna's overall size is 60 × 60 mm, the ground plane patches are 26.5 × 25 mm, and the feed line 6 × 28.3 mm. The radius of the circular radiator is 6.25 mm, and the gap between feed line and ground was 0.5 mm. The PLA substrate had a thickness of 2mm. The metallic components of the antenna were etched on a copper clad *Mylar®* polyester film and attached to the PLA substrates using double side tape. These substrates were made with an Ultimaker2 3D printer. Their density was set to 100% in the machine data. The stencil shown in Fig. 2b was also 3D printed. This fitted tightly on the EBG's substrate. Silver-loaded conducting ink was evenly spread on the latter by hand, using the stencil. The measured average resistance between the ends of the 9 patches was 1 Ω. Curing the EBG in an oven for about 15 minutes and 90 degree temperature was able to reduce the resistance to less than 0.5 Ω. The side view of the CPW antenna on the non-planar EBG structure is illustrated in Fig. 2c. The antenna substrate had four printed 2 x1mm spacers to keep the 1mm distance between the antenna and EBG substrate.
Fig.3 presents the simulated and measured reflection coefficient (S_{11}) of antenna in free space, on the EBG structure, and on an equivalent perfect electric conductor (PEC) ground plane. Simulated and measured results compare very well. In free space, the -10 dB bandwidth spans from 2.01 to 3.15 GHz. On the perfect metallic ground (PEC) the antenna is clearly mismatched. On the other hand, the combined CPW antenna and EBG spans from 2.32 to 2.53 GHz, filtering out most frequencies beyond the 2.4 GHz WLAN band. At 2.45 GHz the impedance match shows an improvement of more than 10dB compared with that of the antenna in free space.
The measured E and H plane radiation patterns for the antenna in free space and on the EBG structure are shown Fig. 4. The back lobe of the radiation pattern decreased by over 10 dB while the maximum gain increased by 2.44 dB when the antenna was on the EBG substrate. The squinting from the beam in Fig.4 (a) arises from the non-symmetry of the structure in Fig 2a about the (*x, z)* plane and the effect of the feed cable.

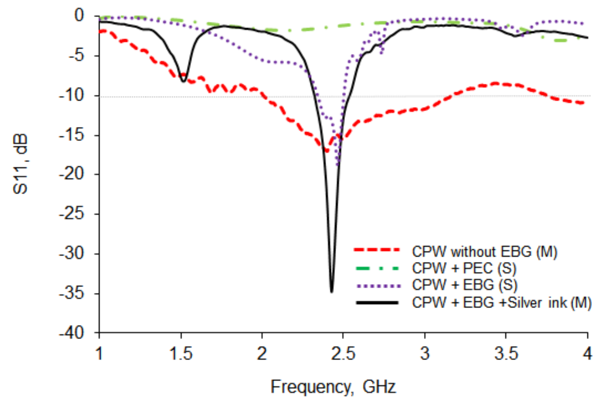

Fig. 3 *Measured (M) and simulated (S) reflection coefficient (S_{11})*

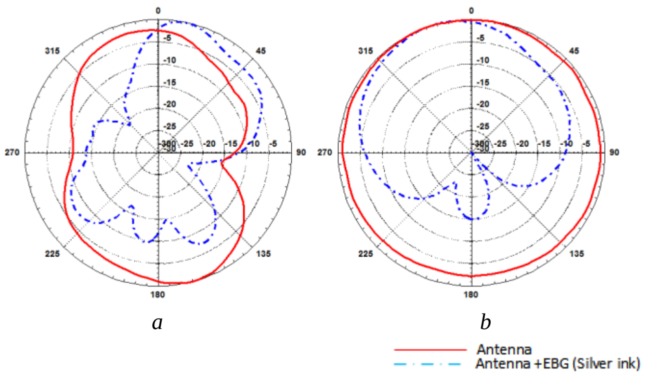

Fig. 4 *Measured radiation pattern for the CPW antenna in free space and on the non-planar EBG structure*
a E plane
b H plane

Conclusions: The applicability of inexpensive additive manufacturing technologies to the development of non-planar EBG substrates for antenna applications has been described. A relatively simple structure consisting of metallic patches with trenches has been used for this demonstrator. PLA plastic is a low-cost material suitable for this application. The patches of the 3D printed EBG structure were painted using Silver-loaded conducting ink. An also printed mask was employed to assist the addition of the metal layer. Measurements and simulations showed that this particular demonstrator is capable of providing significant antenna matching and gain improvements that in turn can deliver significant improvements in wireless communications. Results could be further improved by using inks with higher conductivity. This technique could be applied to more complex 3D EBG structures, an issue that the authors are currently investigating.

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