Wideband Microstrip Patch Antennas with Transverse Electric Modes

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***Abstract* —** A wideband microstrip patch antenna, exciting the fundamental transverse electric (TE) mode, is investigated. The excitation of the TE mode is facilitated through replacing both of the patch and ground plane of a conventional microstrip antenna with artificial magnetic conductors (AMC), consisting of unipolar compact photonic bandgap (UC-PBG) unit cells. The AMC patch and the ground plane of this antenna behave as magnetic conductors within the bandgap region of the unit cells. Similar to conventional patch antennas, it is shown that by cutting a U-shaped slot in the AMC patch, wideband characteristics are realized. The antenna shows a 40% impedance bandwidth and operates at the TE_{10} mode. Moreover, the width of the patch is 1.75 times smaller than its length, reducing the overall size of the antenna by about 60%, compared with the conventional U-slot PEC antenna supporting the transverse magnetic (TM) mode.

***Index Terms* —** Microstrip patch antennas, transverse electric modes, wideband antennas.

I. INTRODUCTION

Microstrip patch antennas are narrowband antennas with a maximum bandwidth of 3-6% [1-3]. In emerging wireless communications and radar systems, however, large bandwidths are necessary to transmit massive amounts of data and to enhance the resolution in radar systems. The U-slot technique is used to enhance the bandwidth of a microstrip patch antenna by 30% [4]. If an L-probe is used to excite a U-slot rectangular PEC patch antenna, the bandwidth is increased by 40% [5]. Recently, a novel microstrip patch antenna exciting the TE_{10} mode was reported by the authors in [3], where both the patch and the ground plane consisted of uniformly distributed unipolar photonic bandgap (UC-PBG) [6] unit cells to mimic magnetic conductors' properties in order to satisfy the proper boundary conditions for the TE mode excitation. In [3], it was shown that the TE_{10} patch antenna was 44% smaller in size than its TM_{10} patch antenna counterpart. In this letter, the TE_{10} mode patch antenna is further investigated for wideband applications by implementing a U-slot in its patch layer. The wideband antenna supports the TE_{10} mode, which is excited by an L-probe, and shows a bandwidth of about 40%. Moreover, due to the inherent size reduction property of the TE patch antenna [3] [7], the width of the AMC patch is about 1.75 times smaller than its length, i.e., W=L/1.75. This results in about 60% reduction of the lateral size of the wideband TE antenna. Thus, the lateral dimensions of the proposed U-slot antenna exciting the TE mode would be smaller than those of the conventional U-slot patch antenna exciting the TM mode.

II. ANTENNA GEOMETRY

Herein, wideband characteristics of the TE patch antenna are studied based on the design reported by the authors in [3], which is a narrowband TE_{10} mode microstrip patch antenna. To widen its impedance bandwidth, a U-shaped slot is cut in the patch layer of the AMC antenna, a side view of which is depicted in Fig. 1. The antenna consists of a radiating patch and a ground plane, both made of UC-PBG AMC surfaces that are separated by a layer of air (ε_r=1) with a height of h=6.4 mm. Each AMC surface consists of periodic UC-PBG unit cells backed by a grounded dielectric substrate Rogers RO3010 [8] with relative permittivity of ε_r=10.2 and a height of h_1=0.635mm. The antenna excites the TE_{10} mode by an L-probe connected to a 50Ω SMA connector and oriented perpendicular to the length of the patch. The vertical arm of the L probe has a radius of r_v=0.635mm and a length of L_v=5.535mm, and the horizontal arm has a radius of r_h=1.1mm and a length of L_h=15mm. The L-probe is placed at an offset of L_f=7mm from the center of the patch. This antenna is numerically finalized to obtain a bandwidth of ~40%, which makes it suitable for wideband wireless communications. The numerical computations are carried out by ANSYS HFSS, V. 18 [9], which is a finite-element full-wave electromagnetic solver. The patch and the ground plane layers are detailed in the following sections.

A. Antenna patch layer

In order to excite the TE_{10} mode, the top and bottom walls of the antenna cavity should be made of magnetic conductors. To this end, the patch layer itself is constructed by an AMC, consisting of 7×4 UC-PBG unit cells placed on one side of the 82.6mm×82.6mm dielectric material Rogers RO3010 with relative permittivity ε_r =10.2 and a height h_l=0.635mm. The other side of the substrate contains a PEC metal plate of dimensions L×W=46.2mm×26.4mm. The top and bottom views of the patch layer are shown in Fig. 2. The combination of the unit cells and the metal plate, separated by the dielectric material, acts as an AMC within the frequency bandgap of the UC-PBG material. The vertical and horizontal arms of the U-slot, denoted by L_s and W_s in Fig. 2, are equal to 46 mm and 6 mm, respectively. The entire U-slot has a uniform thickness of 1 mm. The vertical and horizontal arms of the slot, i.e., L_s and W_s, are placed 4 mm and 0.1 mm away from the length and the width of the patch, respectively.

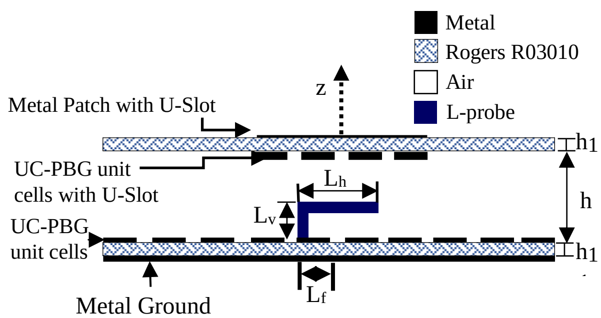


Fig. 1. Side-view of the wideband TE_{10} patch antenna with UC-PBG unit cells in both the patch and the ground plane excited by an L-probe with L_v=5.535 mm, L_h=15 mm, L_f=7mm, h=6.4mm, and h_1=0.635mm.

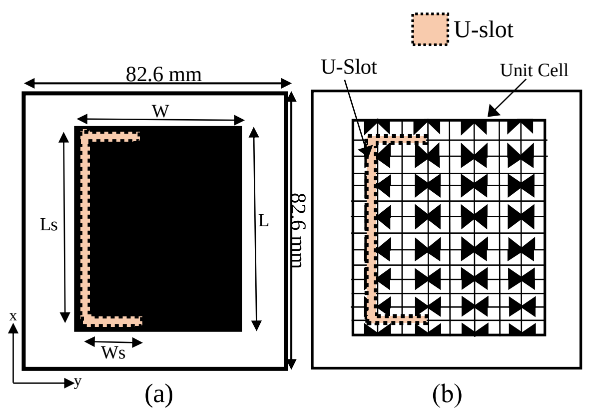


Fig. 2. (a) Top-view of the patch with PEC metal plate with a U-slot. (b) Bottom-view of the patch with unit cells and U-slot placed exactly below the PEC metal plate with dimensions of L×W=46.2mm×26.4mm; L_s=46mm, W_s=6mm.

B. Antenna ground layer

To satisfy the proper boundary conditions for the TE patch antenna under study, the ground plane should also be made of an AMC layer, which consists of 12×12 UC-PBG unit cells etched on the thin grounded Rogers RO3010 of ε_r=10.2 and height h_1=0.635mm. It has 144 UC-PBG unit cells placed above the dielectric material with a size of 82.6 mm×82.6 mm. The UC-PBG unit cells along with the dielectric material and the metal plate together form the AMC ground plane. This ground plane behaves as a high impedance surface within the frequency band of the UC-PBG unit cells. The top and bottom views of the designed AMC ground plane are depicted in Fig. 3.

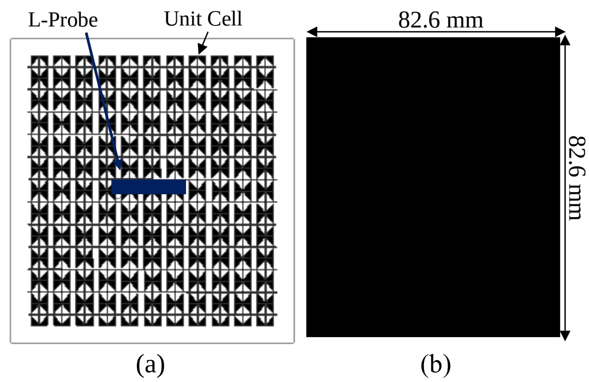


Fig. 3. (a) Top-view of the ground plane consisting of a 12×12 unit cells. (b) Bottom-view of the ground plane consisting of a solid PEC metal plate.

III. NUMERICAL RESULTS

The proposed U-slot AMC antenna shows a wide bandwidth of ~40%, ranging from 3.1 GHz to 4.8 GHz. The reflection coefficient of the antenna with the U-slot is plotted in Fig. 4. It is worth mentioning that the AMC antenna without the U-slot shows a bandwidth of 10% due to the L-probe, whose result is also overlaid in Fig. 4 for comparison. The impedance bandwidth increases to ~40%, when the U-slot is cut from the patch layer. The frequncy range of the UC-PBG material in [3] will shift down due to the miniaturization attribution of the U-slot in the patch layer. More specifically, it is observed that the AMC antenna with the U-slot has three distinct resonat frequencies of 3.2 GHz , 3.9 GHz and 4.6 GHz below the -10 dB line, which are closely coupled together to widen the impedance bandwidth. It is found that the bandwidth is quite sensitive to the length of the longer arm (L_s) of the U-slot, which is manily due to the strong interaction of the U-slot with the unit cells of the engineered magnetic material in the patch layer.

The antenna peak gain versus frequency is plotted in Fig. 5, reaching to a maximum value of 8.4 dBi near the frequency of 3.3 GHz, with less than a 2-dB gain variation over the entire frequency range of 3.1 to 4.8 GHz. Such a small variation in the antenna gain is in part attributed to the potential impact of the U-slot on the effective bandwidth of the reflection phase response of the UC-PBG unit cell.

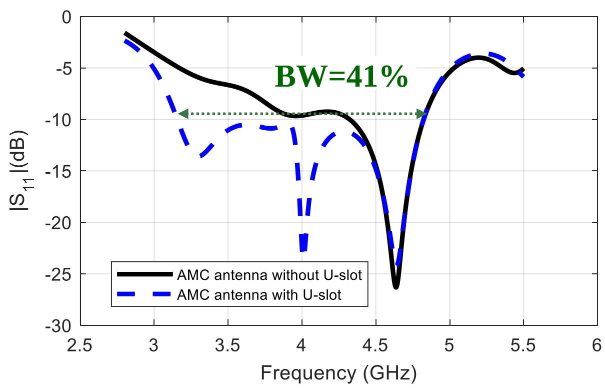


Fig. 4. Reflection coefficients of the AMC antenna exciting the TE_{10} mode with and without the U-slot.

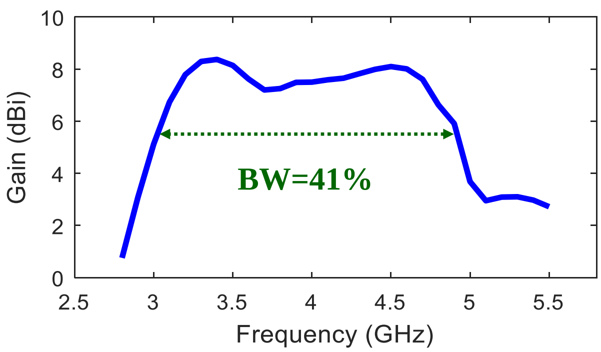
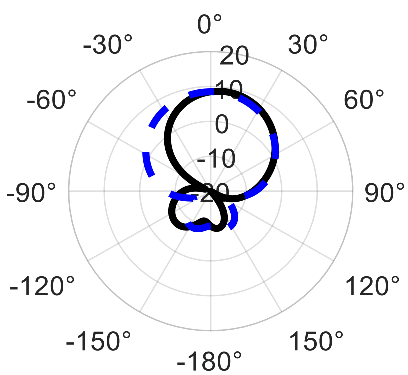
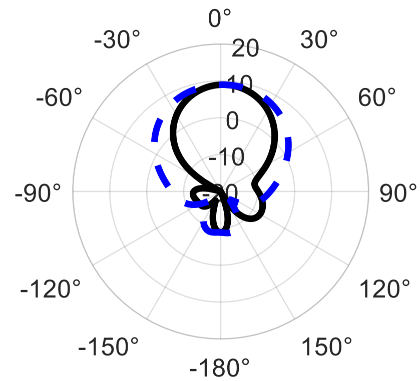


Fig. 5. Peak gain of the wideband U-slot AMC antenna against frequency.

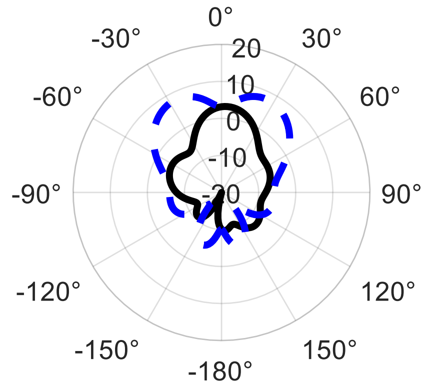
The radiation patterns of the antenna at the three distinct frequencies of 3.2 GHz, 3.9 GHz and 4.6 GHz are plotted in Fig. 6. It is found that the antenna generates broadside radiation patterns up to 4.3 GHz. As the frequency increases beyond 4.3 GHz, higher order modes are excited to some extent, which create a saddle-shaped pattern. The same trend is also observed for the conventional U-slot antennas [4]. Thus, the bandwidth within which the radiation pattern of this PMC antenna remains broadside is ~30%.



(a)



(b)



(c)

Fig. 6. Radiation patterns of the wideband AMC U-slot patch antenna at: (a) 3.2 GHz, (b) 3.9 GHz, and (c) 4.6 GHz; E-plane: solid black line, H-plane: dashed blue line.

IV. CONCLUSION

The concept of the U-slot patch antenna was investigated in the AMC microstrip patch antenna, exciting the TE_{10} mode using an L-probe. It was shown that the U-slot AMC antenna proposed in this letter provided a bandwidth of ~40%, ranging from 3.1 GHz to 4.8 GHz. The antenna parameters such as impedance bandwidth, gain, and radiation patterns were studied. The radiation patterns remained broadside for about 30% of the bandwidth. More importantly, it was demonstrated that the width of the U-slot TE_{10} patch is 1.75 times smaller than its length, i.e., W=L/1.75, resulting in ~60% reduction in the overall size, compared with the conventional U-slot patch antennas.

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