Bandwidth Enhancement of a Microstrip Patch Antenna Using the Metamaterial Planar Periodic Structure

Salim Lamari, Roman Kubacki, and Miroslaw Czyżewski
Faculty of Electronics, Military University of Technology, Warsaw, Poland

Abstract— In this paper we present a compact microstrip antenna with an ultra-wide frequency bandwidth. The ultra-wideband characteristic is obtained by applying the metamaterial concept to an ordinary rectangular microstrip patch antenna with a limited bandwidth of 0.225 GHz. This concept consists of embedding the metallic parts of the antenna, patch and ground plane, by repeating the patterns of a unit cell. The unit cell, designed with different pattern shapes on its upper and lower layers, verifies the metamaterials criterion by means of the dispersion diagram, showing the phase velocity and the group velocity oppositely directed. The new antenna, resulting from this operation was designed and simulated by means of CST Microwave Studio. To attest this approach, the design of the new antenna was experimentally verified after fabricating it on the Rogers RT5880 substrate ($\varepsilon_r = 2.2$ and $h = 0.787$ mm) and measuring its characteristics.

1. INTRODUCTION

Nowadays, light weight compact and low cost devices seem to be much preferred by wireless communication users. Printed antenna technology can meet these needs for the radiating element equipping these devices [1, 2, 5, 10, 16, 18, 19, 23, 24]. But, the same users are more and more eager to be continuously connected. To meet this requirement, these devices should comply with all systems like cellular systems, Wi-Fi, Bluetooth, GPS, NFC, etc. [3, 4, 6, 7, 8, 9, 11–14, 19]. Consequently the printed antenna such as the microstrip antenna, which enjoys its low profile, conformality, low cost, has a narrow bandwidth and hence cannot work with all those systems. Many efforts have been achieved to address this issue which remains the main drawback of the microstrip antenna. Since its inception, the microstrip antenna experienced many methods and techniques in order to enhance its bandwidth. A direct technique to widen the bandwidth can be done by achieving a good impedance matching between the feeding line and the radiating element [20]. Another technique consists of adding parasitic patches electromagnetically gap coupled with the main patch, hence the resonances staggering will yield wider bandwidth. Electromagnetic gap coupling can be used differently to enhance the bandwidth by stacking two or three patches. To keep the low profile of the microstrip patch antenna and at the same time enhance the bandwidth, a U shaped slot was cut on the patch. Cutting 2 slits on the patch, giving hence a patch with the shape of the E letter also widens the bandwidth [23, 24]. But unfortunately, these techniques couldn't exceed the level of 40% fractional bandwidth, and then another approach is needed to tackle this issue.

The appearance of new materials, human engineered, called metamaterials because of their properties not found in natural materials, like both negative permittivity and permeability or double negative materials (DNM), negative refractive index (NRI), and left-handedness (LHM), gave some possibilities [22]. Metamaterials are divided into categories, resonant and non-resonant. The first category is based on cells consisting of split ring resonators and wires [21]. However, this type is less interesting because of its high loss and narrow bandwidth. On the other hand, the second type can be realized directly on a planar transmission line, and showed hence possible realization of microwave devices and antennas in the microwaves range. Thus, the non-resonant type is LHM is better from an application point of view. This type can be easily manufactured in a planar structure, with distinct pattern, by means of lithographic technique. The patterns are usually formed by repeating periodically a unit cell in such way to make an array.

Following a similar approach, we propose in this paper a different metamaterial patterned structure to be applied on a microstrip patch antenna, in order to enhance further the bandwidth. The planar patterns of the patch consist of an array of 3×4 cells, and those of the ground of an array of 7×6 cells. The arrangement of both upper and lower patterns, formed by the repetition of the unit cell, produced a periodic structure.

2. THE METAMATERIAL STRUCTURE

The unit cell, which is the basis of the periodic structure, is square and consists for the lower layer, of etched slots along the four edges and radially in the four angles, and for the upper layer of four cross-ordered L-shaped slots, as shown in Figure 1.

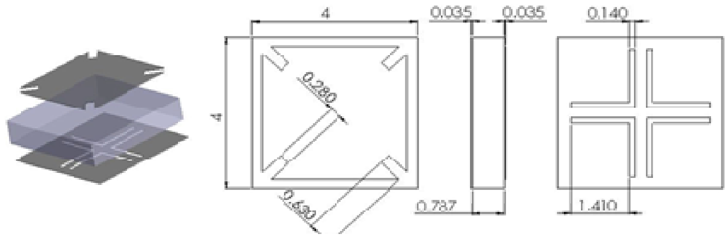


Figure 1: The metamaterial unit cell with dimensions.

A dispersion diagram was simulated under the CST Microwave Studio environment after applying periodic boundary conditions in the x and y directions. Figure 2 shows the dispersion characteristics of the unit cell along the paths between the high symmetry points Γ, X and M in the Brillouin zone, and are represented by and a ω-β curve.

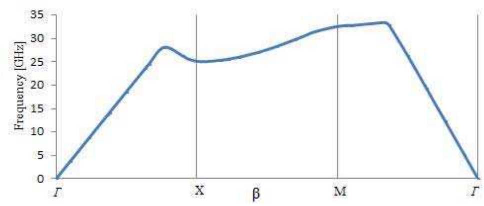


Figure 2: The dispersion diagram.

The slope of the straight line connecting the origin and a certain point on the ω-β curve represents the phase velocity V_p, and the that the slope of the line tangential to the curve at that point represents the group velocity V_G. We notice from Figure 2 that the slope representing V_G is negative, hence the group velocity and phase velocity are in opposite directions, which leads to the conclusion that the structure supports backward (LH) waves.

3. THE ANTENNA DESIGN

A conventional microstrip patch antenna with $28 \times 32 \times 0.787\,\text{mm}^3$, was designed and simulated for comparison. Its patch is $12 \times 16\,\text{mm}^2$, and its feeding line is $2.46 \times 8\,\text{mm}^2$. Our antenna has the following dimensions: $28 \times 32 \times 0.787\,\text{mm}^3$, the feeding line is $2.4 \times 8\,\text{mm}^2$, we notice that the feeding line is less wider here. The geometry of the proposed antenna is shown in Figure 3. The substrate of the antenna is Rogers RT 5880, with dielectric permittivity of 2.2. The metamaterial structure consists for the patch of four cross ordered L shaped slots cells, and the ground plane of star gaps connected by slots on the corners of the cells. The left handed property is driven by the whole structure comprising the patch, the ground plane and the coupling between them, enabling thus much wider impedance bandwidth. The designs and the simulations were carried out under CST Microwave Studio environment.

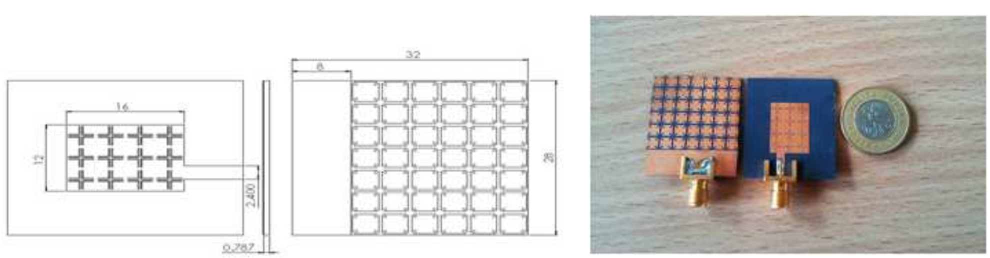


Figure 3: The antenna configuration and picture of its fabrication.

4. RESULTS AND DISCUSSION

During the simulation, all the dimensions of the antenna, comprising its length and width, the width and offset of the feeding line and the size of every edge composing the planar pattern were submitted to parameter study for optimization.

The conventional microstrip patch antenna and the proposed antenna with planar patterned metamaterial, after being designed and simulated, were physically fabricated in order to compare them, the proposed one is depicted in Figure 2. Once this done, we carried out measurements of the S_{11} by means of the HP network analyzer. As we can notice from the Figure 4, where respectively results of the conventional and the proposed antenna are depicted, that there is a good agreement between the simulation and measurement.

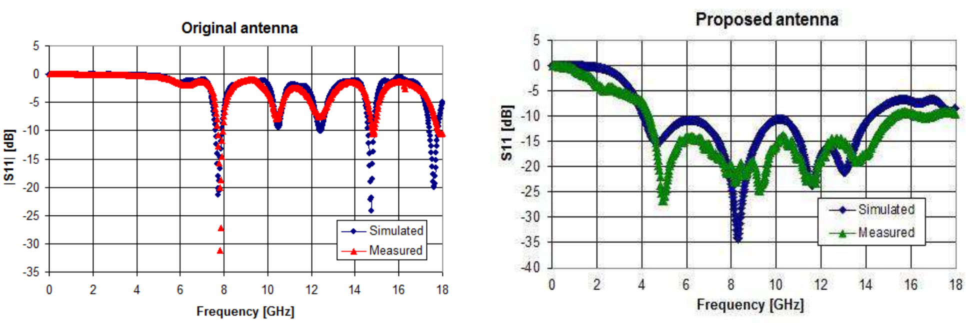
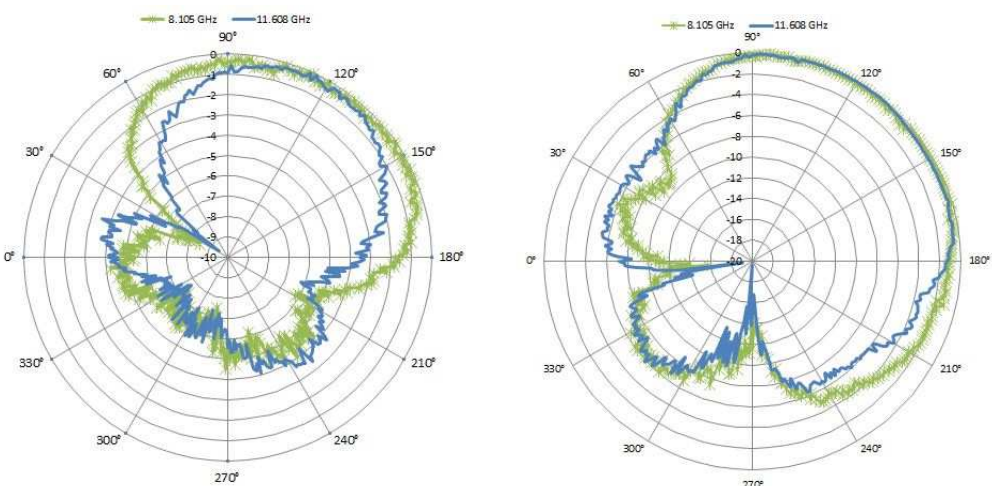


Figure 4: The simulated and measured S_{11} of the original and the proposed antennas.

The proposed antenna achieved a -10 dB frequency band ranging from 4.314 to 15.237 GHz, which represents 10.923 GHz bandwidth, realizing 111.77% fractional bandwidth, whereas the conventional one realized 0.220 GHz. The bandwidth enhancement is almost by fifty times. The results of the radiation pattern are also carried out and plotted in Figure 5 for the following frequencies 8.05 GHz and 11.608 GHz in the x-z and x-y planes respectively. The radiation is mainly directed around the 120° for both planes and frequencies.



(a) (b)

Figure 5: The radiation pattern for the (a) x-z and (b) x-y planes at 8.105 and 11.608 GHz.

5. CONCLUSION

A compact ultra wideband antenna is proposed in this paper basing on the principle of planar patterned metamaterial. This structure allowed a much wider frequency bandwidth of about 10.923 GHz, which represents 111.7% fractional bandwidth. The radiation pattern of the antenna was also measured and showed the same direction in two planes at two distinct frequencies.

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