# Circularly polarized patch antenna using metamaterial for 5G applications

*Mustafa KOÇER*[1*], *Tayfun GÜNEL*[2]

[1]*Graduate School, Department of Electronics & Communication Engineering, Istanbul Technical University, Istanbul, Türkiye*

[2] *Department of Electronics & Communication Engineering, Istanbul Technical University, Istanbul, Türkiye*

**Abstract**

In this paper, a new circularly polarized microstrip patch antenna operating at 3.5 GHz in the n78 frequency band of the 5G frequency spectrum below 6 GHz has been presented. AMC (Artificial Magnetic Conductor), a subclass of metamaterials, has been used to increase the performance of the antenna. AMC structure designed as a 4x4 array has been placed on the microstrip antenna without using air gap. HFSS (High Frequency Structural Simulator) has been used for simulation process. According to the obtained results, the designed AMC structure increases the performance of the antenna and reduces the size of the antenna. In addition, the effects of substrate and metamaterial thickness on the antenna performance have been examined. The results are also compared with the results given in literature.

***Keywords:*** *5G, Patch Antenna, Metamaterial, Artificial Magnetic Conductor, HFSS*

## 1. Introduction

With developing communication technology, the amount of data increases in parallel. Therefore, high-frequency communication systems are now a necessity [1, 2]. Circularly polarized antennas have gained more importance in 5G communication systems [3]. However, it is not easy to design high gain microstrip antennas with circular polarization in the desired frequency range. In recent years, metamaterials have widely been used to increase the bandwidth and the gain of circularly polarized microstrip antenna [4, 5]. In [5] the antenna's performance is satisfactory but its dimension is large in terms of wavelength. In literature, in order to increase the performance of the antenna designed with FR-4 material, the design of the AMC structure is placed over a certain distance from the antenna. The antenna presented in [6] works in the frequency range of 3.31-3.9 GHz while it has circular polarization in the frequency range of 3.31-3.73 GHz and the gain of the antenna is 5.62 dBic. However, the dimension of the antenna is large as 44mm x 44mm x 14.8mm. FR-4 material is used in [7] and the gain of the microstrip antenna is obtained as 6.6 dBic. It is aimed to increase the bandwidth of the antenna with periodic metallic plates placed in a square shape next to the coaxial fed microstrip antenna [8].

In order to obtain circular polarization some techniques can be used [9, 10]. In this work, arc truncated corners and slot are used. Microstrip antennas with various thicknesses and a 4x4 array AMC structure have been designed at 3.5 GHz. HFSS software is used for the analysis and design processes. The microstrip antenna has been designed on the FR-4 substrate material with a dielectric constant of 4.4 and a tangent loss of 0.025. The thicknesses of microstrip antennas (heights of the substrate) are selected as 1.2 mm, 1.6 mm and 2 mm respectively. The thickness of the material used in the AMC structure is chosen the same as the thickness of the microstrip antenna underneath.

## 2. AMC and Microstrip Patch Antenna Design

In this study AMC structure whose reflection phases bandwidth is between +90 and -90 degrees [11] is used. Figure 1 shows the AMC structure.

*Corresponding author. *e-mail address: kocer21@itu.edu.tr*

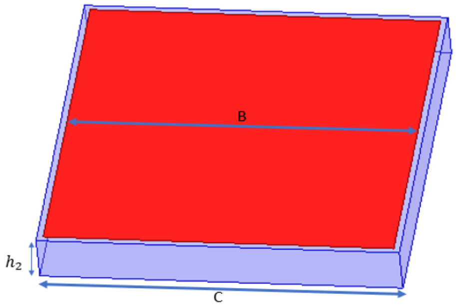


**Figure 1.** AMC structure.

AMC structure is designed with FR-4 material in 3 different thicknesses by using Floquet Port in HFSS software. The dimensions and operating frequency ranges of the square-shaped AMC structure are given in Table 1.

**Table 1.** AMC structure dimensions and working frequencies

| $h_2(mm)$ | Operating freguency (GHz) range | B(mm) | C(mm) |
|---|---|---|---|
| 1.2 | 3.29-3.57 | 17.5 | 18 |
| 1.6 | 3.34-3.74 | 15.5 | 16 |
| 2 | 3.32-3.82 | 14 | 14.5 |

Arc truncated corners and slots are used to design the microstrip antenna with circular polarization. Rectangular slot is in the center of the square-shaped microstrip antenna. It is rotated to the right at an angle of 45° to conform to the left-handed circular polarization (LHCP). The AMC structure is designed as a 4x4 array. It is integrated on the microstrip antenna (Figure 2).

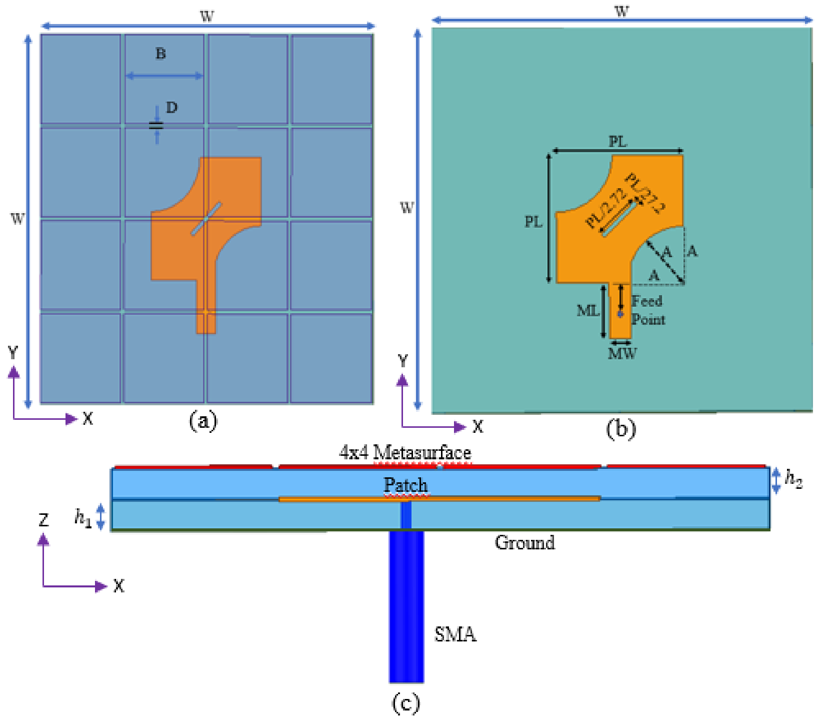


**Figure 2.** Geometry of the proposed antenna. (a) Top view of antenna with metamaterial. (b) Top view of antenna without metamaterial. (c) Side view.

The dimensions of the antennas designed in 3 different thicknesses are given in Table 2. When the B values given in Table 1 have been used, a decrease in size is obtained. By using the B values given in Table 2 instead of the B values given in Table 1, a size reductions of 39.5%, 43.75% and 47.56% have been obtained respectively. While the thickness of the antennas increases the antenna size reduces.

**Table 2.** AMC based patch antenna dimensions

| Antenna Parameters | $h_1 = h_2 = 1.2mm$ | $h_1 = h_2 = 1.6mm$ | $h_1 = h_2 = 2mm$ |
|---|---|---|---|
| PL | 15.2 | 15.8 | 16.5 |
| A | 7.3 | 7 | 6.6 |
| ML | 15 | 13.85 | 13 |
| MW | 2.2 | 2.7 | 3 |
| Feed Point | 4.4 | 3.9 | 4.25 |
| B | 13.5 | 11.5 | 10 |
| D | 0.5 | 0.5 | 0.5 |
| W | 56 | 48 | 42 |
| Total Dimensiones | 56x56x2.4 | 48x48x3.2 | 42x42x4 |

## 3. Results and Discussion

$|S_{11}|$ parameter of the antenna is shown in Figure 3. According to the simulation results, the bandwidth for $h_1 = h_2 = 1.2$ mm is 1.23 GHz, for $h_1 = h_2 =1.6$ mm the bandwidth is 1.57 GHz and for $h_1 = h_2 =2$ mm the bandwidth is 1.77 GHz.

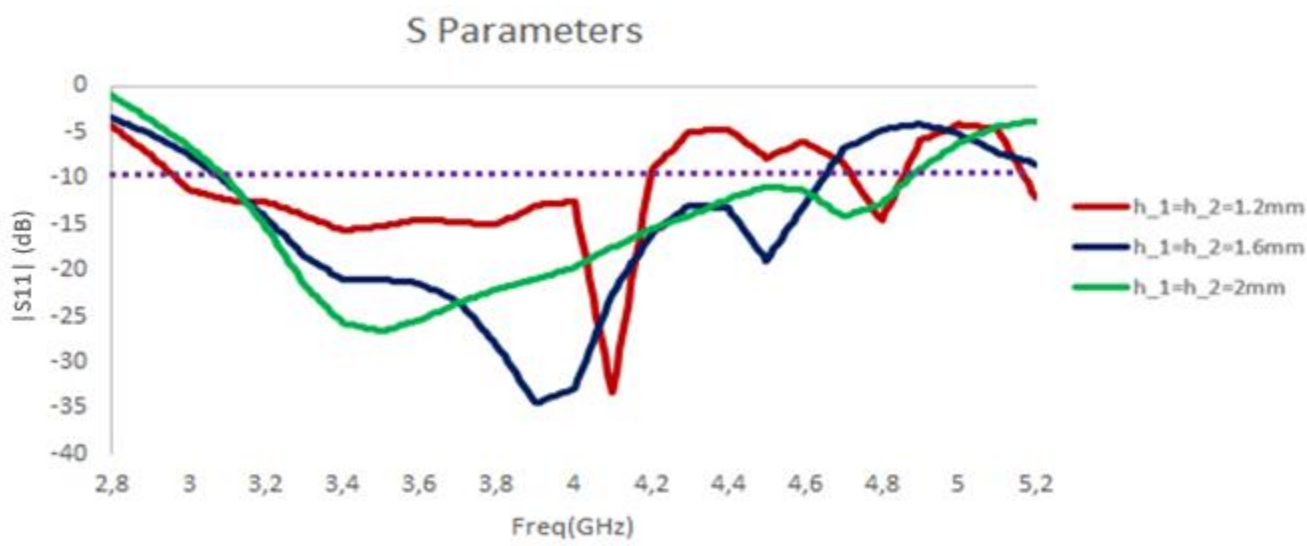


**Figure 3.** $|S_{11}|$ parameter of the antenna.

The gains and efficiencies of the antennas are shown in Figure 4. The peak maximum gain and peak maximum efficiency of the antennas have been computed to be 7.1 dBic and 89.38%, 6.66 dBic and 89.7%, 6.25 dBic and 89.9%, respectively.

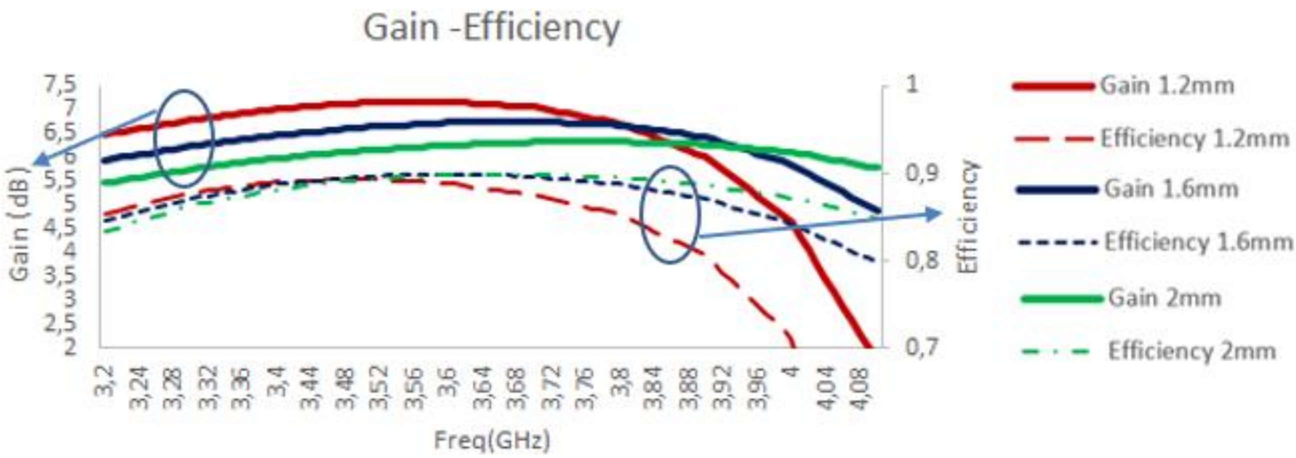


**Figure 4.** Gain and Efficiency of the antenna.

In Figure 5, axial ratios of the antennas are shown. The AR bandwidths of the antennas have been obtained as 0.57 GHz, 0.75 GHz and 0.87 GHz, respectively.

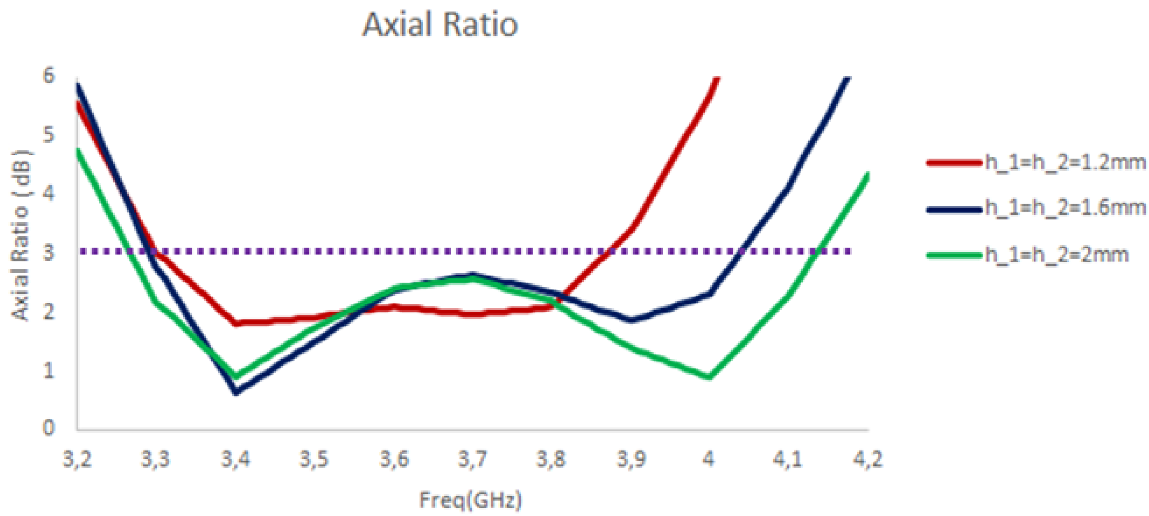


**Figure 5.** Axial ratio of the antenna.

Radiation patterns of the antennas are shown in Figure 6. In Table 3 results of the proposed antenna for $h_1$=$h_2$=2 mm are compared with the results of the antennas given in literature.

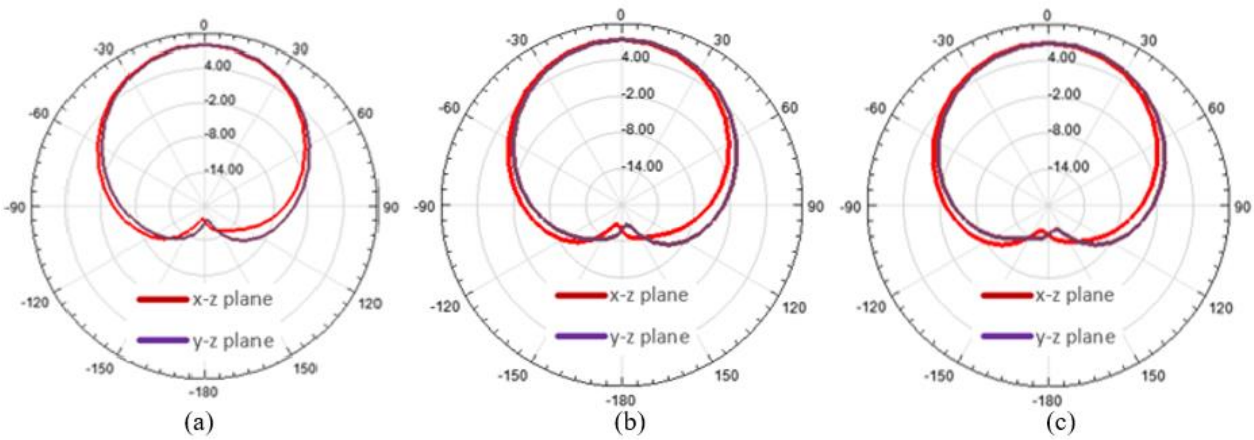


**Figure 6.** Radiation patterns of the antennas at 3.5 GHz (a) $h_1 = h_2 = 1.2$ mm (b) $h_1 = h_2 = 1.6$ mm (c) $h_1 = h_2 =$ 2 mm.

**Table 3.** Comparison with other antennas in literature.

| Results | [5] | [6] | [7] | [8] | Proposed ($h_1$=$h_2$=2 mm) |
|---|---|---|---|---|---|
| Bandwidth(GHz)/ (%) | (4.7-7.48)/ (45.6) | (3.31-3.9) / (16.36) | (5.02-7.3)/ (37) | (5.1-6.2)/ (19.7) | (3.1-4.87)/ (50.6) |
| AR BW(GHz)/ (%) | (4.9-6.2)/ (23.4) | (3.31-3.73)/ (11.93) | (5.24-5.56)/ (5.9) | (5.12-6.32)/ (21) | (3.27-4.14)/ (24.86) |
| Polarization | LHCP | LHCP | LHCP | RHCP | LHCP |
| Efficiency | >90% | 82.8% | Not Reported | Not Reported | 89.9% |
| Gain | 7.6 dBic | 5.62 dBic | 6.6 dBic | 6.9 dBic | 6.25 dBic |
| Total Size(mm)/ ( λ) | 32 x 32 x 3/ (0.58 x 0.58 x 0.056) | (44 x 44 x 14.8)/ (0.51 x 0.51 x 0.16) | Not Reported/ (0.616 × 0.616 × 0.065) | Not Reported / (0.6 x 0.6 x 0.06) | (42 x 42 x 4)/ (0.49 x 0.49 x 0.047) |
| Size Reduction | Not Reported | 38.7% | Not Reported | Not Reported | 47.56% |

While the thickness of the proposed antenna increases, the bandwidth, size reduction and efficiency values increase. The gain and overall size decrease while the thickness of the antennas increases. The bandwidth of the proposed antenna is 50.6%. Although FR-4 material is used, its efficiency is 89.87%. The size reduction value is obtained as 47.56%. The dimension of the proposed antenna given in wavelength is the smallest among others in Table 3. The proposed antenna can be efficiently used in n78 frequency band for 5G applications**.**

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