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Bow-tie patch antenna for 5G

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Abstract

The goal of this work was to design, simulate, build, and test bow-tie antenna for 5G networks. In this paper, it will be shown how the radiation pattern and input match are improving by changing angles on some points of the antenna. The first angle is from the central point of the bow-tie antenna (mark A) and another angle is from the side points of the bow-tie antenna (mark B). Bandwidth improvement is shown in the simulation between 4 GHz and 6GHz. S11, Eθ, Eφ for the nominal design are -27.31 dB, 7.39 dB, -3.30 dB respectively. After simulations, the nominal antenna is fabricated and tested with reference antenna A-info LB8180. Simulation results, testing results with fabricated antenna, and angle change results will be shown in further text.

Keywords: Microstrip antenna, Bow-tie antenna, High gain, Dielectric constant

1. Introduction

When the first commercial cellular network has launched in 1979 by "Nippon Telegraph and Telephone**"** it was clear that world is entering in whole new era with wireless technologies, but the true wireless revolution started at 1990s [1]. Microstrip patch antennas are discovered shortly before the "wireless revolution", in early 1970s [2] [3]. How the world is changing in direction where every device should be connected it requests high speed communication networks. In the table below [4] it can be observed that in range of 50 years network bandwidth is improved around 1,000,000 times, which shows that world is getting more and more connected through different devices and that needs a huge amount of network bandwidth.

Table 1. Description of wireless network generations through years

Technology	1G	2G	3G	4G	5G
Bandwidth	1.9kb/s	14..4 kb/s - 384 kb/s	2Mb/s	2Mb/s/ 1Gb/s	1Gb/s and higher
Year represented	1970 – 1984	1990	2001	2010	2015
Frequency range	800 – 900 MHz	850 – 1900 MHz	1.6 – 2.5 GHz	2 – 8 GHz	25 – 39GHz

Table 1 shows that wireless network bandwidth is increased rapidly through years, but the devices that are using networks are decreasing their size so the microstrip patch antennas have good use in that area field because they are easy to produce, light weight, small dimensions and low profile [5].
We can divide microstrip antennas in different types, but most commonly they are defined by the design shape, which is shown on figure below [6].

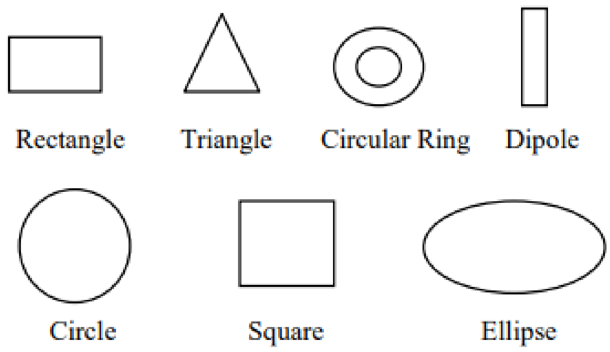

Figure 1. Different types of microstrip patch antennas

Antenna which is designed for this purpose is the specific subset of the microstrip patch antennas and it is called bow-tie like its name said, it resembles the shape of the bow-tie. Bow-tie antenna have a characteristic design with two symmetrical triangles [7] with a small gap between which resembles the shape of a bowtie. A lot of parametric studies has been done for the different types of bow-tie antenna [8] and they gave different results for the fields where they be used. This type of antennas can be easily tweaked by changing some points on the nominal design so it can achieve significantly better results with small changes.
This antenna can be used in a 5G network and it is simulated and tested with the frequency range between 4GHz - 6GHz.

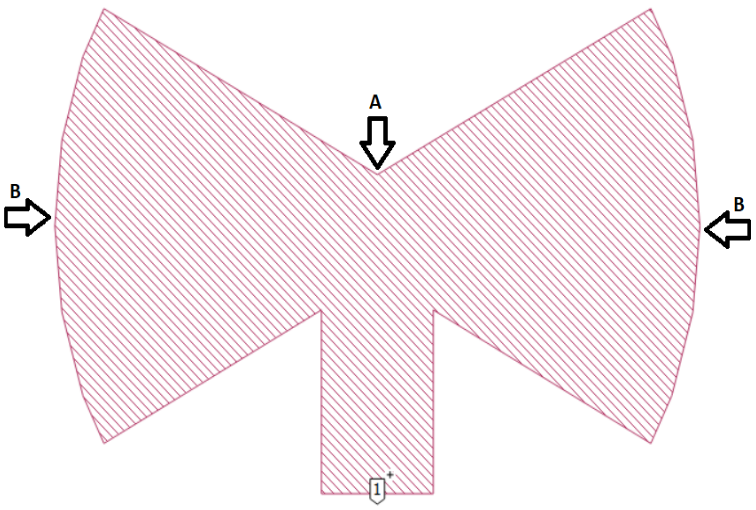

Figure 2. Bow-tie antenna design

Bow-tie antenna design for this paper is shown on Figure 2 and it is not classically design with triangle shapes, instead, it is rounded from both sides. Bow-tie antennas are widely used in the applications for the ground penetrating radar (GPR) [9] and SCaN (Space Communication and Navigation) [10] because they shape allow to focus signal at particular endpoint.

2. Design of bow-tie antenna

Sonnet suites [11] is used for the design and simulation of the bow-tie antenna. The antenna have dimensions 5.53 x 3.914 cm and it is printed with FR-4 substrate, where a dielectric constant is εr =4.4. S11 parameter represents power reflection from the antenna and it is known as input match [12]. Making circular arc sides for the bow-tie antenna have a significant role to improve the parameters which will be shown through the paragraphs in this paper. For this bow-tie antenna S11 is -27.31 which is really good if we consider dimensions. The most important parameter of an antenna is radiation pattern or power density radiated by the antenna in different angular directions. The radiation pattern for this bow-tie antenna is shown on Fig. 3.

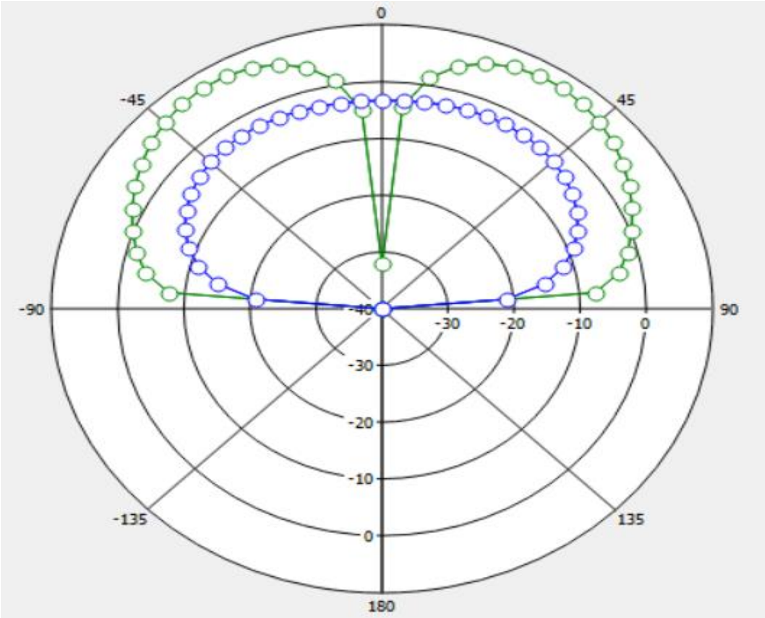

Figure 3. Far field radiation (Eφ and Eθ) for bow-tie antenna.
Green represents Eθ, blue represents Eφ

Parameter values for the nominal design are in the table below:

Table 2. Parameters for this bow-tie antenna

S11 (dB)	E_θ (dB)	E_φ (dB)	Frequency (GHz)
-27.31	7.39	-3.30	5.25

Parametrization has done by changing the angle on points which are shown on the Fig. 1.
S11 parameter is -27.31 dB and it is shown on Fig. 4.

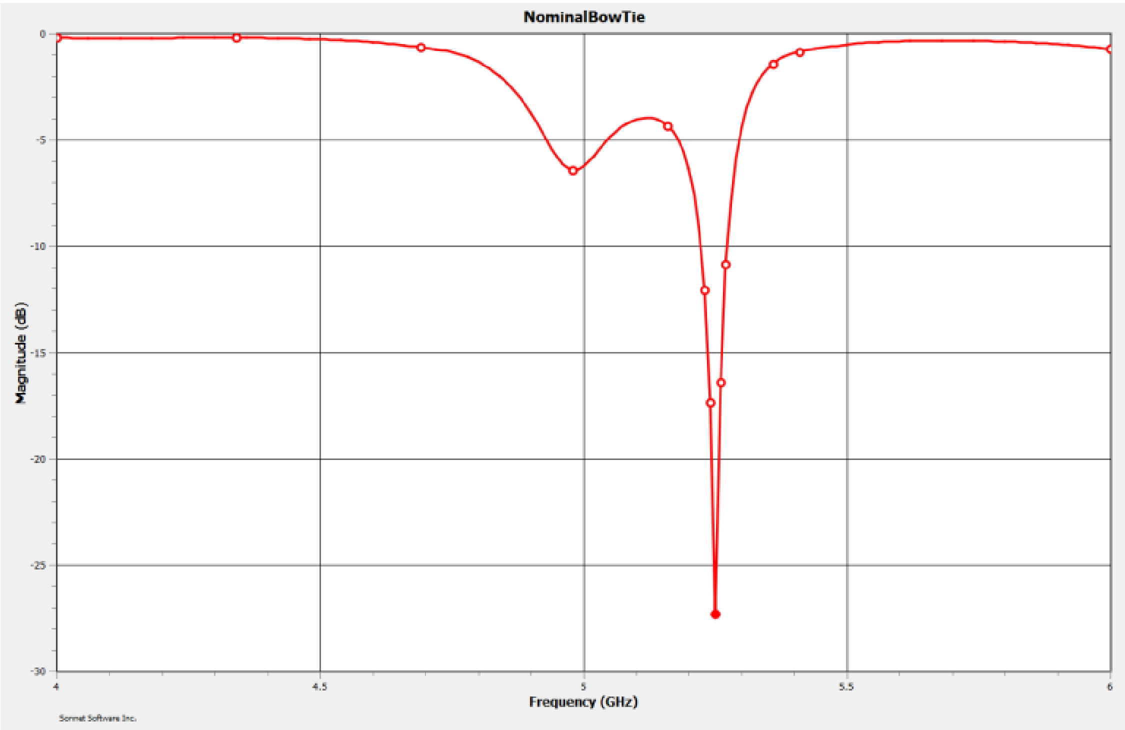

Figure 4. Magnitude/Frequency graph

Results for the changing angle on point A and on points B will be represented in the next chapters. Simulation is done for the five angles for both points.

2.1. Simulation results

The first parametric observation has done by changing the five different angles for point A on Fig. 1, and the second observation has done the same with the B point on Fig. 1. Every change will increase the dimensions of the antenna which will increase the radiation pattern.

2.1.1. Angle changes for point A

Simulation has done for five angle changes for point A and Table 2 represents the results for every angle change:

Table 3. Simulation results for angle changes on point A

Angle	**S11** (dB)	**E_θ** (dB)	**E_φ** (dB)	**Frequency** (GHz)
119°	-19.70	7.60	-3.26	5.25
120°	-22.66	7.54	-3.35	5.25
121°	-21.73	7.54	-3.28	5.25
122°	-19.70	7.60	-3.26	5.25
123°	-15.04	7.81	-3.29	5.25

S11 parameter have done most changes which is most obvious for the 120° angle. We can observe improvements of the Eθ and Eφ for some angles but most important, parameters did not have bigger negative deviations from the nominal design. On Fig. 5 it is shown S11 changes on graph level.

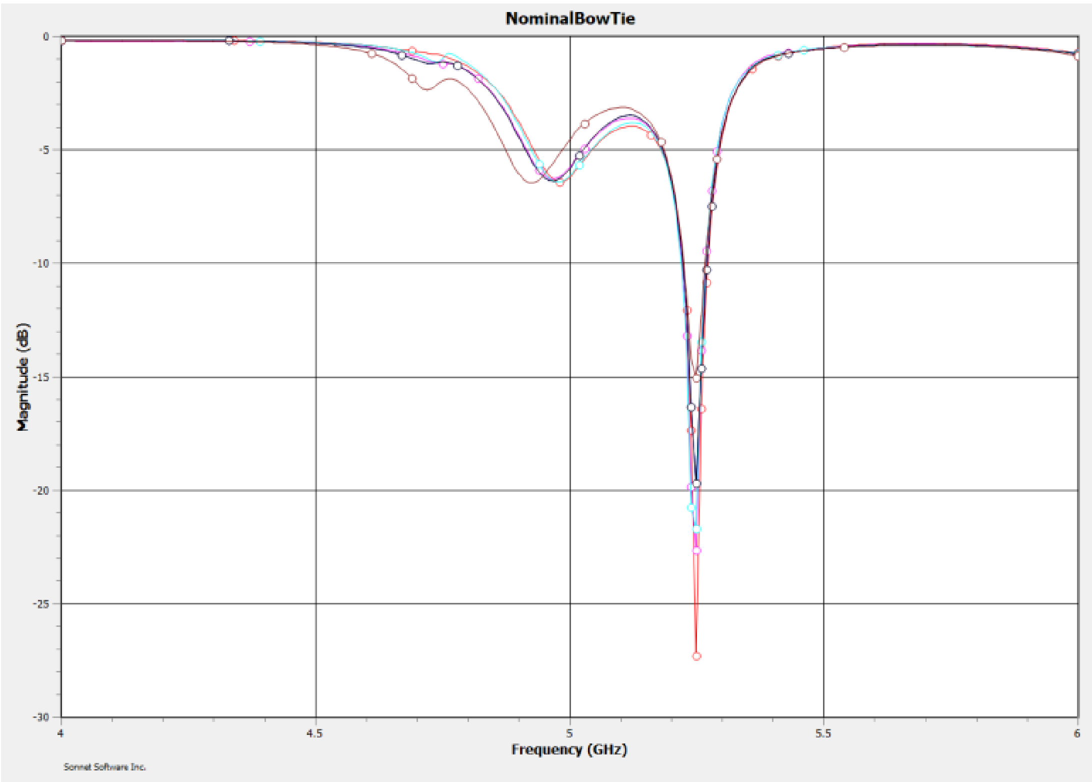

Figure 5. Magnitude/Frequency graph for all angle changes in point A

2.1.2. Angle changes for points B

In Table 3 are shown results for changing angle on B point from Fig. 1.

Table 4. Simulation results for angle changes on point B

Angle	S11 (dB)	E_θ (dB)	E_φ (dB)	Frequency (GHz)
70°	-28.98	7.35	-3.08	5.25
83°	-24.59	7.39	-3.30	5.25
89°	-33.03	7.31	-3.38	5.25
93°	-24.59	7.23	-3.66	5.25
97°	-16.69	7.02	-3.76	5.25

Fig. 6 shows S11 changes on graph level.

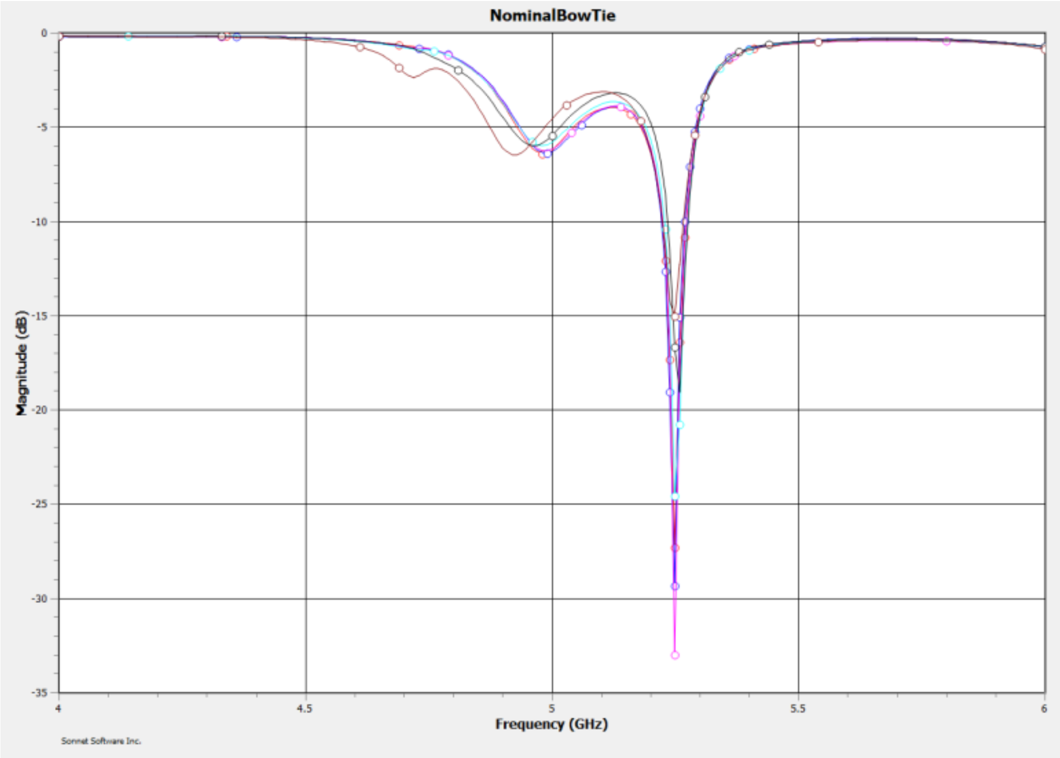

Figure 6. Magnitude/Frequency graph for all angle changes in points B

On Fig. 5 pink color represents 89° angle change and its simulation shows a change of the S11 parameter for 20.94%.

3. Measurments setup

Measurments results are done with the setup which is shown in Fig. 7. In setup it is used A-info LB8180 broadband horn antenna [13] as a reference antenna which have frequency range between 1-30GHz. Measurments are done calculating the gain from bow-tie antenna moving it with 5° steps, from -90° to 90° which is shown on Fig. 8.

Figure 7. Measurement setup

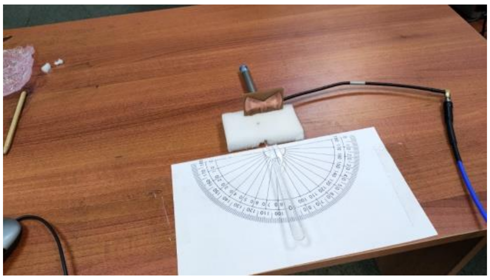

Figure 8. Bow-tie antenna with protractor for fine measurements

3.1. Conversion of S parameters

Measured results for S parameters are in the complex number form: z = a + jb, it the conversion from complex to magnitude phase field is needed. Formula to convert the complex number to the magnitude in decibels is:
$magnitude \ = 20 * \ log_{10}\sqrt{Re^2 + Im^2}$ [14]

3.2. Results from measurment setup

Comparison between simulation and testing diagrams is done in OriginPro [15] software which allows easy plots for all data that are tested in real time environment.
For the nominal antenna simulated results are better, because of the fabrication proces it have lost on S11 for about -70% but it still have a satisfying radiation pattern.

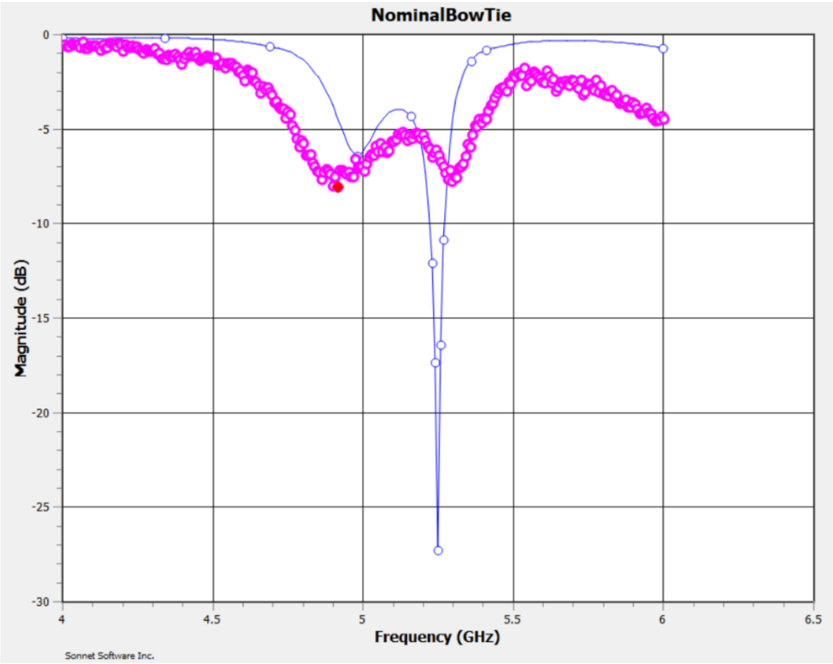

Figure 9. Simulated (blue), Tested (purple)

Best input match has achieved for **θ** = -30° and it have difference between simulated and tested results for -43%.

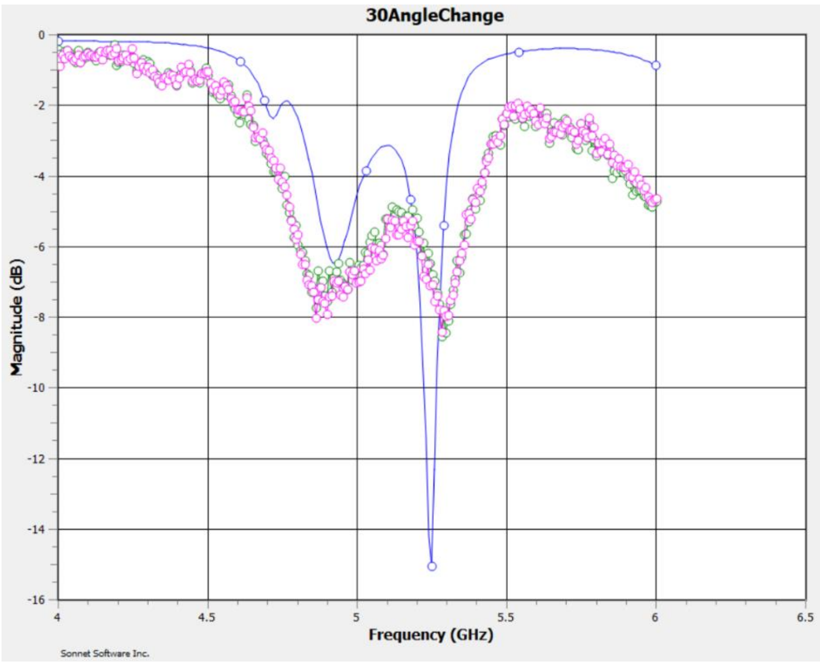

Figure 10. simulated (blue), tested (purple 30°), tested (green -30°)

Comparison of return loss for the fabricated and simulated antenna is on Fig. 11.

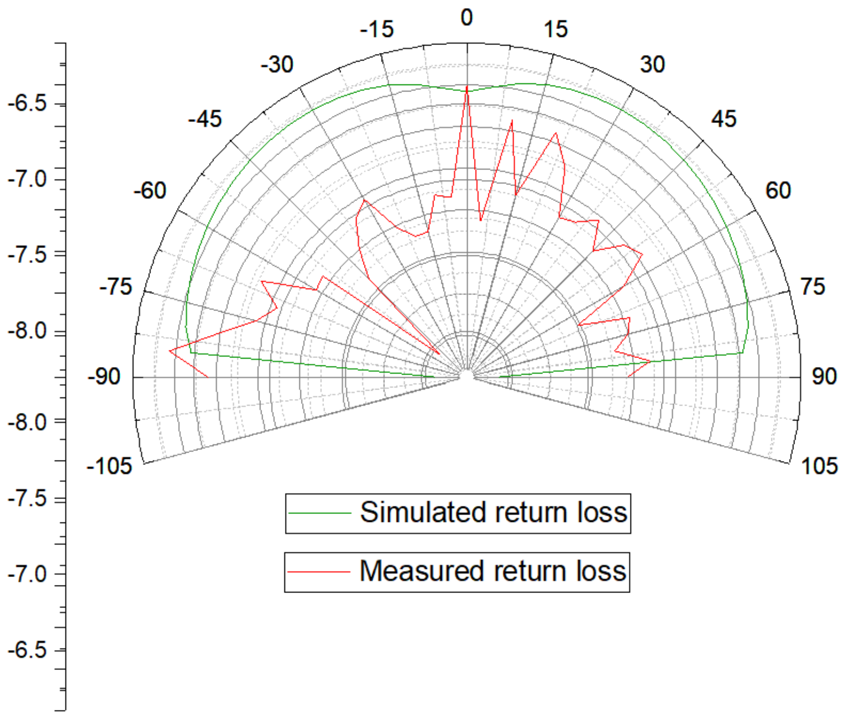

Figure 11. Simulated (green), fabricated (red)

Tested gain is shown on Fig. 12.

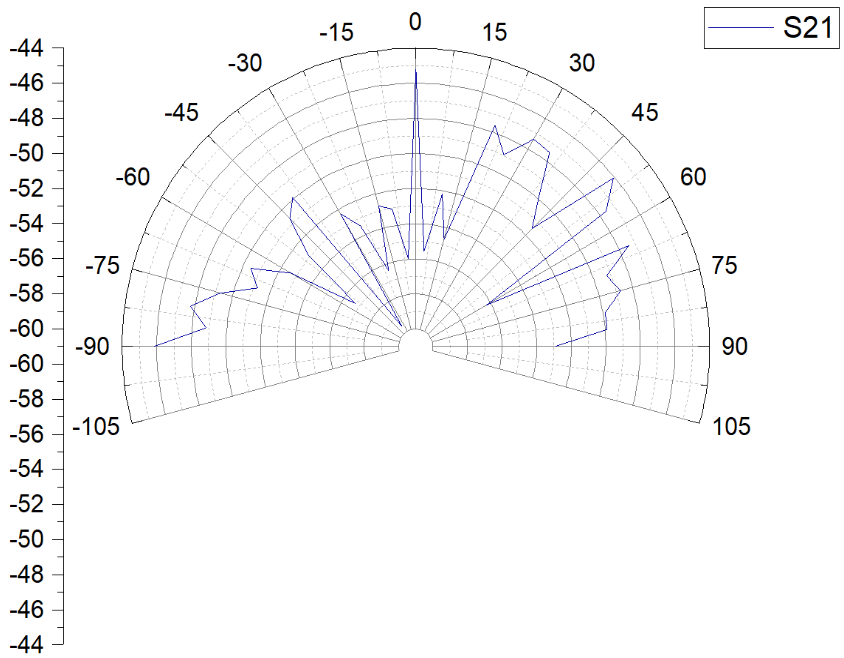

Figure 12. Gain measured (S21)

4. Fabrication

A simulated bow-tie antenna for 5G networks has been fabricated with CNC machine with FR-4 material. Port was soldered with 1mm diameter and it have 50 Ω resistance. It was observed in this paper if there any inconsistencies between simulation and fabrication levels the gain and input match can be decreased or if the port is not soldered properly it can affect the performance of the microstrip patch antenna.

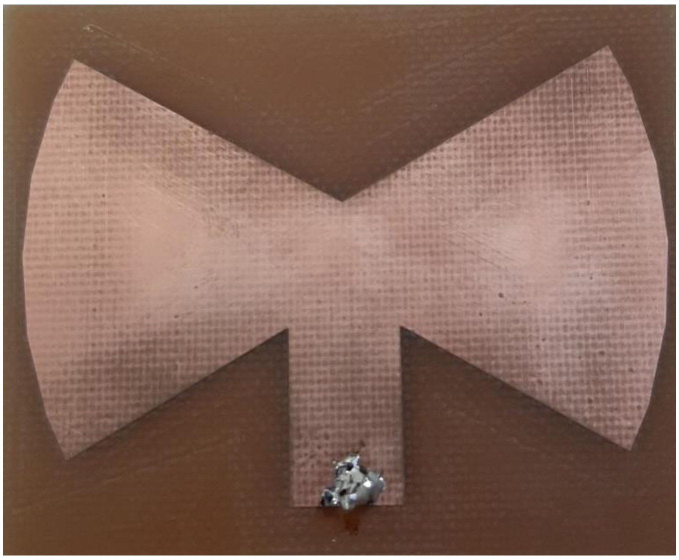

Figure 13. Fabricated bow-tie microstrip patch antenna

5. Conclusion

We can observe by changing the angles in point A we can improve radiation pattern and return loss, for example changing angle on point A for 123° decreases S11 by 44.92% and increases radiation pattern by 5.6%. For changing angles in points B, we have a variety of results. Three angle changes (89°, 93°, 97) shows radiation pattern improvements (E-phi) while changing angles for 70° and 83° showing good results where radiation pattern is lower than nominal but still above the 7dB for E-theta and less than -3 for the E-phi. Simulation and fabricated antenna have inconsistencies because of the fabrication process and soldering port so it can be observed that best return loss is achieved for θ = -30° and best gain is achieved for θ = -55° and its value is -56.71 dB, with frequency of 5.25GHz.

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