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Circularly Polarized Patch Array Antenna for GNSS Applications

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Abstract

GPS antennas are found in a myriad of applications in various industries such as tracking, location identification, surveying etc. These antennas are used to connect to GPS satellites and acquire GPS data to identify the current location. A circularly polarized, low profile, GPS patch array antenna is designed and successfully measured. The proposed antenna is designed as a better alternative to the present commercial antenna in our laboratory, which is weak and often fails in areas where less localization time and accuracy are appreciated. The commercial antenna is a small size (5 cm × 5 cm) with gain less than 3 dB and Right-Hand Circular Polarization (RHCP) around 1.575 GHz (axial ratio ≤ 2 dB). This paper proposes the design of a RHCP array of patch antenna that operates at GPS L_1 Band [1.563 - 1.587] GHz. The axial ratio of the proposed antenna is 0 dB while gain is 9.4 dB at working frequency of 1.575 GHz. Circular polarization is obtained by using a truncated corner technique. For the design and optimization of antenna, we use CST MWS software.

Keywords

Patch Array Antenna, RHCP, CP, Gain, Axial Ratio, GPS

1. Introduction

Due to the features of circular polarization, circular polarized (CP) antennas are very useful for various wireless systems such as satellite communications, global navigation satellite systems, mobile communications, wireless sensors, and direct broadcasting service television reception systems. The CP antenna is very effective in combating multi-path interferences or fading. The reflected radio signal from the ground or other objects will result in a reversal of polarization, that is, right-hand circular polarization (RHCP) reflections show left-hand circular polarization (LHCP). An RHCP antenna will have a rejection of a reflected signal which is LHCP, thus reducing the multi-path interferences from the reflected signals. The second advantage is that CP antenna can reduce the 'Faraday rotation' effect due to the ionosphere. The Faraday rotation effect causes a significant signal loss (about 3 dB or more) if linearly polarized signals are employed. Another advantage of using CP antennas is that no strict orientation between transmitting and receiving antennas is required. This is different from linearly polarized antennas which are subject to polarization mismatch losses if arbitrary polarization misalignment occurs between transmitting and receiving antennas. This is useful for mobile satellite communications where it is difficult to maintain constant antenna orientation. With CP, the strength of the received signals is fairly constant regardless of the antenna orientation. These advantages make CP antennas very attractive for many wireless systems.

The letter [1] deals with innovative design for a circularly polarized circular patch antenna featuring coplanar parasitic components. The design consists of a circular patch at the top surrounded by two annular rings and a ground plane with a lateral cross-slot at the bottom. A novel technique is introduced in [2] to reduce the size of circularly polarized (CP) patch antennas by utilizing parasitic shorting strips, which can be adjusted to control the frequency. The research examined different types of shorting strips, including rectangular, U-shaped, and meandering, and demonstrated the possibility of reducing the dimensions and back radiation of a patch antenna without sacrificing favorable CP and load matching properties. In [3], the proposed antenna is designed to be compact and suitable for Geo-positioning applications. It consists of a meandered ring patch that includes ground in a slotted manner and four parasitic patches. The patch is fed by two orthogonal T-shaped lines to achieve circular polarization. However, these techniques do not make it possible to increase the gain, which is very important for satellite communications.

High directional gain antennas offer a high degree of functionality and security in comparison to other signal transmission systems. These antennas feature a narrow radio beam, and this results in an improvement in the signal's strength [4] [5]. The letters [6]-[10] detail study and demonstration of a rigorous method which synthesizes the feeds weights by considering the strong cumulative coupling between antennas. These papers consist in considering the couplings to obtain the objective pattern. The work in [11] presents a compact 4-element GNSS antenna array design that achieves a mutual coupling level less than −20 dB. They have used a high isolation method to reduce the mutual coupling between the elements. In [12], a compact four element high isolation antenna array is presented for GNSS upper L-band application by using a defected ground structure (DGS) and a microwave absorber. These works have the capacity to amplify existing satellite signals. However, they are very complex and have high manufacturing costs.

So, our goal is to design a high gain circularly polarized antenna. Following this introduction, the rest of the paper is organized as follows: the next section explains the design process and the simulated results of the proposed antenna. In section

3, we show the measured results. Finally, a conclusion is presented in the last section.

2. Antenna Design and Simulated Results

In this paper, the truncated corner technique is used to produce circular polarization with an axial ratio <3 dB. To increase gain and bandwidth of the proposed antenna, an array method with 2 × 2 elements is applied by arranging the antenna in parallel which relates to the microstrip line. The focus of this study is to produce microstrip antenna with circular polarization with axial ratio <3 dB, return loss <−10 dB and gain ≤10 dB which works at L_1 [1.563 - 1.587] GHz GPS band. The antenna is simulated on a Rogers RO4350B substrate with a permittivity value of 3.66 and a depth of 1.524 mm. PEC is used as a conducting material with a depth of 0.035 mm. The antenna is modelled, simulated and optimized numerically using CST MWS software. The performances are analyzed in terms of reflection coefficient, axial ratio and radiation patterns at the operating frequency 1.575 GHz.

2.1. Design of Square Patch Antenna with Truncated Corner

To produce circular polarization on a single element microstrip antenna, a truncated corner method is required. The truncated corner method is carried out by cutting the edge of a single element patch antenna so that it occurs on the edge effect of the microstrip antenna. The biggest current flowing on the microstrip antenna is on the edge of the patch so that if the part is deformed it will have an impact of shifting the working frequency and produce circular polarization. Figure 1 shows a single antenna developed with the truncated corner technique.

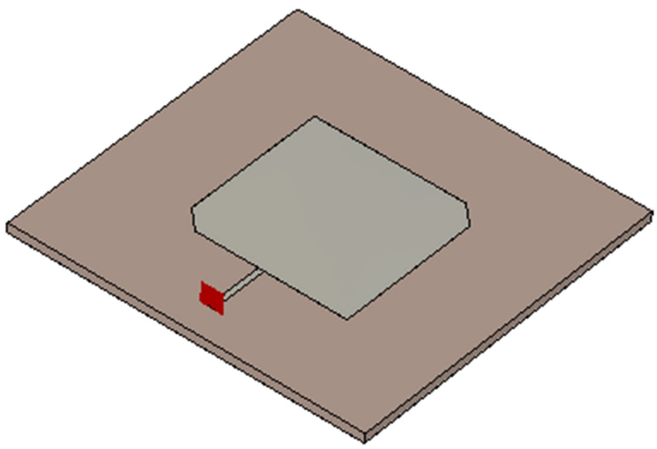

Figure 1. Design of the patch antenna with truncated corner.

The simulated reflection coefficient S_{11} is lower than −10 dB over the operating frequency bandwidth [1.563 - 1.587] GHz (Figure 2). The axial ratio of the proposed array antenna is shown in Figure 3 as a function of the theta angle at 1.575 GHz. It is less than 3 dB with a beamwidth of about 240˚ for good CP performance. The 3D radiation pattern of the proposed array at 1.575GHz obtained in simulation is shown in **Figure 4**. The array has a peak realized gain of 5.2 dB at the axis.

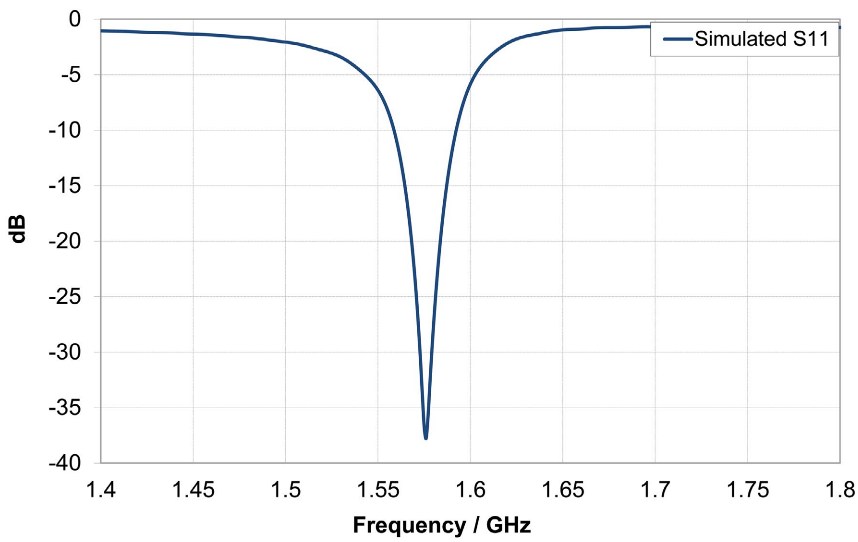

Figure 2. Simulated reflection coefficient S_{11}.

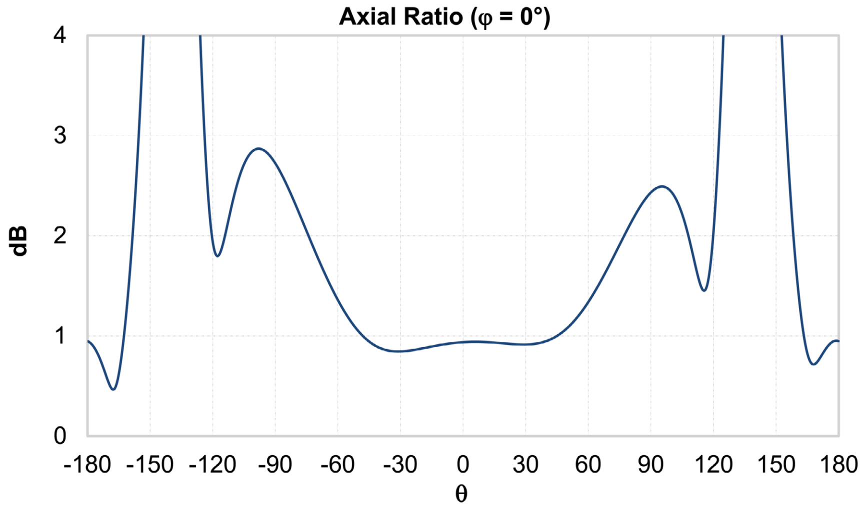

Figure 3. Simulated axial ratio at 1.575 GHz.

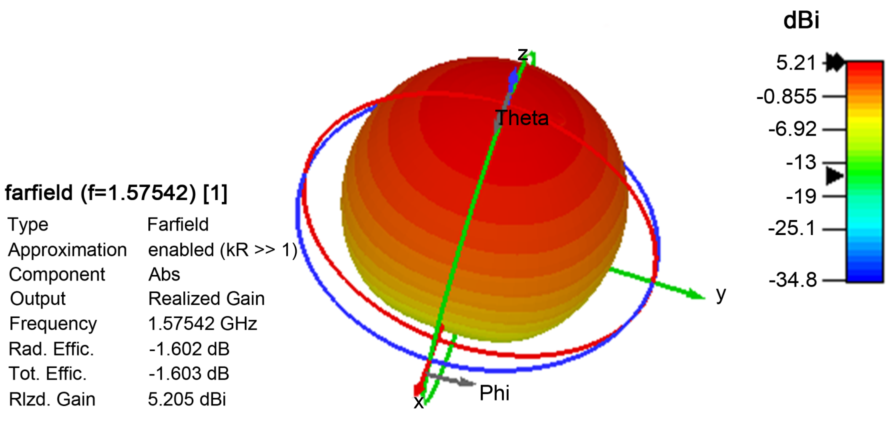

Figure 4. Simulated 3D radiation pattern (realized gain) at 1.575 GHz.

2.2. Design of Array Antenna of 4 Patches with Truncated Corner

After obtaining a single element microstrip antenna design that has circular polarization, the next step is to optimize the gain of the microstrip antenna. In this study, the gain optimization by using an array technique with planar model. The optimization is done in stages from the condition of an array of 2 × 2 elements. The design of proposed microstrip antenna with array technique 2 × 2 element can be seen in Figure 5. To determine the performance of the antenna that has been designed, the next step is to simulate the proposed antenna.

The simulated reflection coefficient S_{11} is lower than −10 dB over the operating frequency bandwidth [1.563 - 1.587] GHz (Figure 6). The axial ratio of the proposed array antenna is shown in Figure 7 as a function of the theta angle at 1.575 GHz. It is less than 3 dB with a beamwidth of about 130˚ for good CP performance. The 3D radiation pattern of the proposed array at 1.575 GHz is shown in Figure 8. The array has a peak realized gain of above 9.4 dB and a radiation efficiency of 0.75 %.

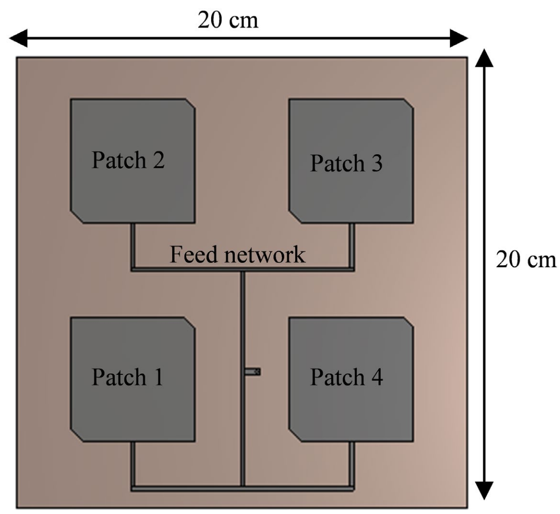

Figure 5. Design of the proposed array antenna with the feed network.

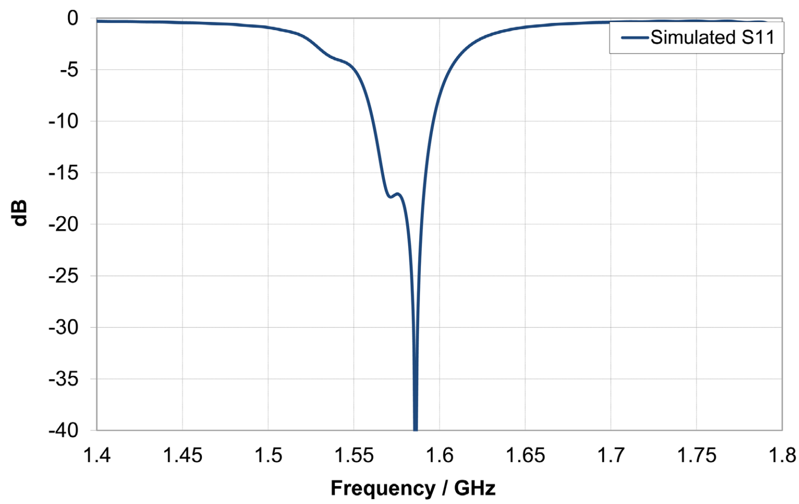

Figure 6. Simulated reflection coefficient S_{11} of the patch array.

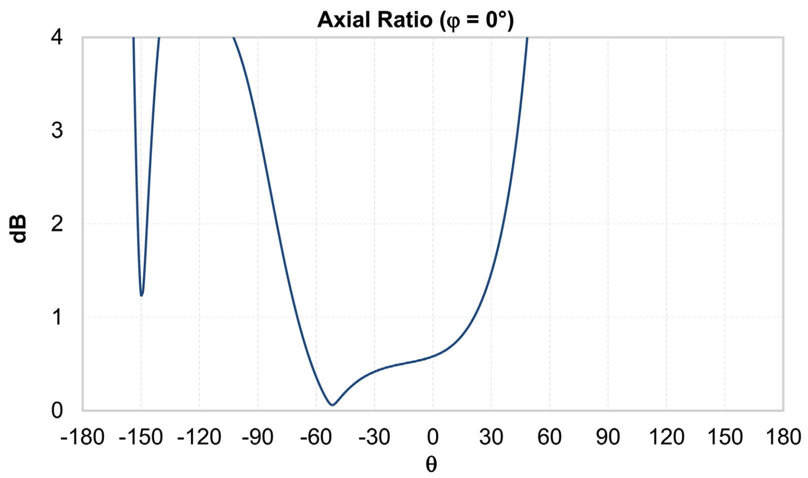

Figure 7. Simulated axial ratio of the patch array at 1.575 GHz.

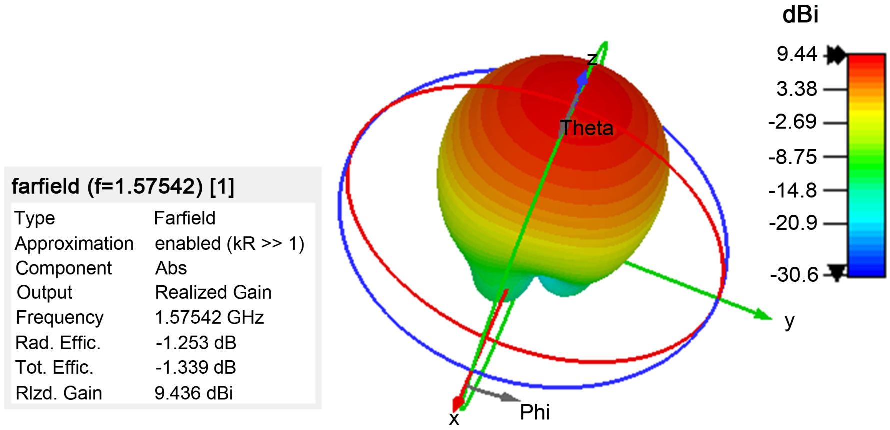

Figure 8. Simulated 3D radiation pattern (realized gain) of the patch array at 1.575 GHz.

Figure 9 shows that the antenna propagates Right Hand Circular Polarization (RHCP) to identify the type of circular polarization. It can be observed that the Right-Hand Circular Polarization (RHCP) gain is approximately 30 dB higher than the Left-Hand Circular Polarization (LHCP) gain at broadside direction.

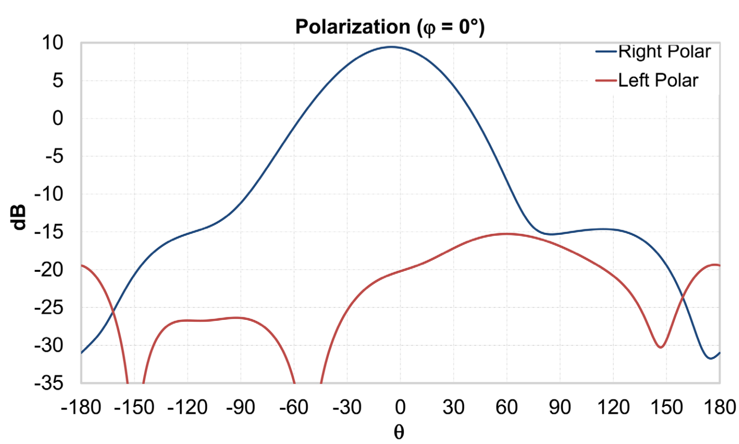

Figure 9. Simulated realized gain (right and left polarization) of the patch array at 1.575 GHz.

The antenna's surface currents can also show circular polarization performance. In Figure 10, the subplot corresponds to the current distribution when the phase is 0˚, 90˚, 180˚ and 270˚. It's shown that 1.575 GHz, the antenna generates RHCP mode.

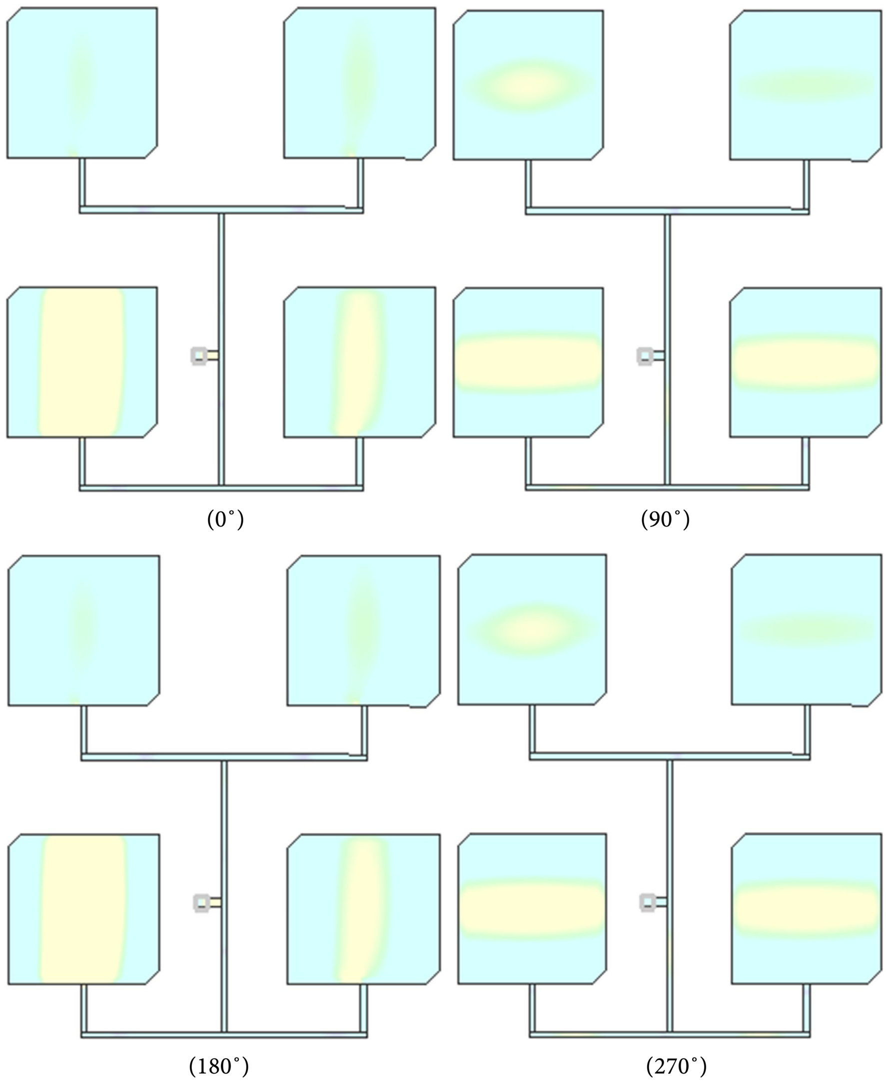

Figure 10. Simulated surface current distribution of the patch array at 1.575 GHz.

3. Measured Results

The antenna was manufactured as can be seen in Figure 11. The measurement of S_{11} was achieved by using a portable VNA. Figure 12 shows the comparison between simulated (blue curve) and measured (red curve) return loss. A slight discrepancy of 17 MHz can be observed compared to the simulation, but it represents only 1% of the frequency shift that can be due to manufacture and permittivity tolerance.

Several retro-simulations are made to know the difference between measurement and simulation results (S_{11}). After these retro-simulations (variation of permittivity, patch sizes), we found that the difference between the simulation and measurement results comes from the tolerance of permittivity as shown in Figure 12. We note that the green curve in Figure 12 is closest to the measurement (red curve). This curve shows the S_{11} when the permittivity of the antenna is equal to 3.59 (−1.9%).

(a) (b)

Figure 11. Fabricated antenna: (a) patch array and feed network, (b) ground plane and SMA connector.

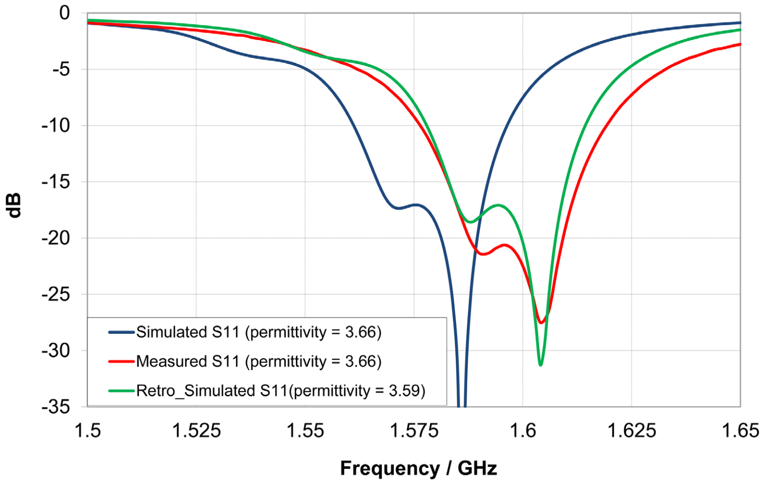

Figure 12. Simulated and measured return loss of the patch array.

The manufactured prototype is then used in the GNSS receiver system (Figure 13) to capture satellite signals with high sensitivity. The signals received are first amplified by a Low Noise Amplifier LNA (powered via a Bias Tee), which is directly connected to the antenna to improve signal quality and reduce noise. The amplified signals are then fed into a USRP (Universal Software Radio Peripheral) card, which serves as the RF front-end for digitizing and processing the signals. The USRP is connected to a PC where a configuration file is used to control the signal acquisition and perform positioning calculations, enabling flexible and software-defined GNSS reception.

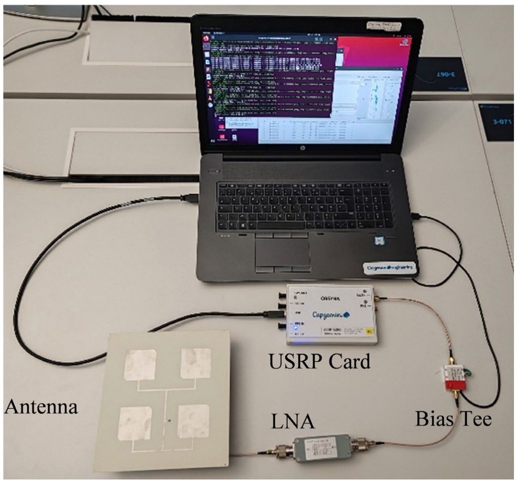

Figure 13. GNSS receiver.

4. Conclusion

In this paper, microstrip antenna with Right-Hand Circular Polarization (RHCP) optimized with array techniques has been presented. For the patch array, the feed network has been designed and optimized to work at 1.575 GHz. In terms of performances, very good results were obtained (S_{11}, axial ratio, gain). Based on the results obtained from the simulation process, the proposed antenna has a return loss of −17 dB, an axial ratio of 0.4 dB and gain of 9.4 dB at the working frequency of 1.575 GHz. The achieved prototype presents performances like those obtained in simulation. The differences observed in terms of S_{11} can be explained by the fact that it is impossible to accurately determine the characteristics of the used substrates especially in terms of relative permittivity. Several retro-simulations are made to know the difference between the results of measurement and simulation. We note that the antenna substrate has a permittivity value close to 3.59. This antenna can be used to receive GPS signals in GNSS receiver.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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