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Design of the Vehicle Geolocation Circuit with Satellite Communication

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Abstract

The incorporation of satellite communication into car geolocation systems is a noteworthy development in tracking technology, allowing precise position data to be obtained in real time, independent of geographical limitations. The main goal of this work is the design and execution of a car geolocation circuit that employs satellite communication to enhance tracking capabilities. The proposed system integrates GPS receivers, satellite modems, and microcontrollers to ensure smooth data transmission and reception. It utilizes satellite communication to achieve high-resolution localization. The circuit is designed for reliable operation in various environmental conditions, ensuring robust connectivity and accurate location data. By employing advanced methods in circuit design and signal processing, the design aims to address common issues in vehicle tracking, such as latency and signal degradation. The results demonstrate improved system resilience and GPS data transmission, making the technology valuable for fleet management, logistics, and private car tracking applications. Rigorous testing and optimization have produced a robust solution that significantly enhances GPS data transmission via communication satellites and system resilience through transmitter antenna. This groundbreaking technology holds immense potential for transforming fleet management, logistics, and personal vehicle tracking applications.

Keywords: GPS, Satellite Communication, Monitoring, Vehicle, Circuit Design**.**

1. Introduction

The integration of satellite communication into vehicle geolocation systems marks a significant advancement in tracking technology, enabling precise, real-time location data acquisition regardless of geographical constraints. This work focuses on the design and implementation of a vehicle geolocation circuit that leverages satellite communication to enhance tracking performance. The proposed system incorporates GPS receivers, satellite modems, and microcontrollers to ensure seamless data transmission and reception. By utilizing satellite-based communication, it achieves high-resolution positioning with improved reliability in diverse environmental conditions. The circuit is designed to maintain robust connectivity and accurate localization, addressing critical challenges such as signal degradation, latency, and intermittent coverage in traditional tracking systems. To overcome these challenges, advanced circuit design methodologies and signal processing techniques are employed, optimizing both data transmission efficiency and system resilience. The experimental results demonstrate enhanced GPS data transmission reliability, making the technology particularly suitable for applications in fleet management, logistics, and personal vehicle tracking. Rigorous testing and system optimization have resulted in a highly robust solution that significantly improves GPS data transmission via communication satellites, ensuring more reliable and uninterrupted tracking. This innovative approach holds immense potential for transforming real-time vehicle tracking, offering superior performance over conventional tracking systems. The advancements presented in this work pave the way for more resilient and accurate geolocation solutions, contributing to the evolution of intelligent transportation and logistics networks.

To address challenges such as signal degradation, latency, and intermittent coverage in traditional tracking systems, advanced circuit design methodologies and signal processing techniques are employed. The system incorporates error correction algorithms, adaptive power management, and efficient antenna designs to optimize data transmission efficiency and resilience. Additionally, real-time data processing and cloud-based integration facilitate comprehensive fleet management and analytics, offering insights into vehicle movement patterns and operational efficiency. Extensive testing under various environmental conditions has demonstrated the system's ability to deliver stable and accurate geolocation data, with improved signal integrity, reduced latency, and enhanced resilience. These advancements make the technology particularly suitable for applications in fleet management, logistics, emergency response, and personal vehicle tracking. Compared to conventional GPS tracking solutions, the proposed system offers superior accuracy, real-time responsiveness, and adaptability to challenging terrains. By bridging the gap between traditional GPS tracking and modern satellite communication, this work contributes to the evolution of intelligent transportation and logistics networks. The improvements introduced in this study pave the way for more resilient and precise geolocation solutions, with significant implications for real-time vehicle monitoring, autonomous navigation, and smart mobility systems.

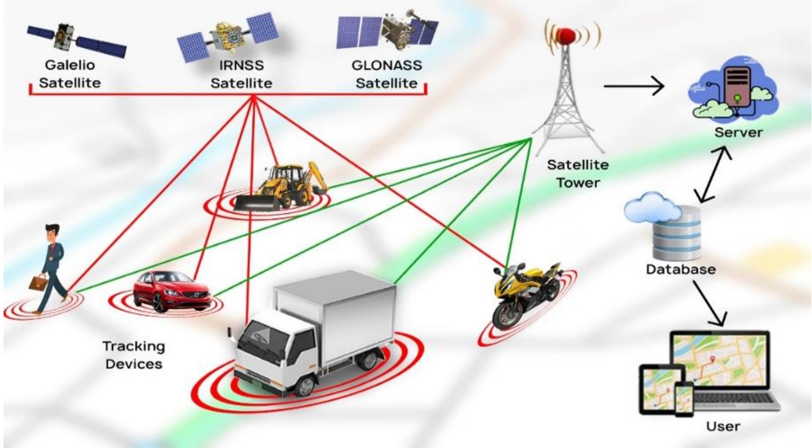


Fig.1. GPS tracking solutions with satellite communication.

2. GPS Circuit Material and methods

A GPS-based vehicle tracking system provides real-time location monitoring, enhancing the efficiency of service delivery. A GPS-equipped vehicle can determine its current position, track its route history, and record travel duration. This system utilizes geographic positioning and time data from Global Positioning System (GPS) satellites. It consists of an "on-board module" installed in the vehicle, which collects location data, and a monitoring system that processes and analyzes information from multiple vehicles. The on-board module includes a GPS receiver. A vehicle tracking system integrates an electronic device with dedicated software to continuously monitor the vehicle's position. It collects real-time data from the field and transmits it to a central operations unit. While modern tracking systems primarily rely on GPS technology, alternative automatic vehicle location methods can also be employed. Vehicle data can be accessed via electronic maps through the Internet or specialized software. Additionally, vehicle tracking systems are widely used for theft prevention and recovery. Law enforcement agencies can locate a stolen vehicle by tracking the signal emitted by the system. When used as a security measure, a vehicle tracking system can complement or replace a traditional car alarm. Some systems also enable remote vehicle control, allowing users to lock doors or disable the engine in emergency situations. Furthermore, the presence of a tracking system can contribute to reducing vehicle insurance costs. This system's design may be divided into two categories: software design and hardware design. Design and programming of software The Arduino IDE is a cross-platform Java tool for creating and debugging programs that supports the STK500 interface and the ATmega328 microcontroller. After initialization, the status of the GPS and GSM modules was examined. In addition to tracking GPS, the system accepted user commands to swap engines or communicate location. Authorized users received a URL, longitude, and latitude.

2.1. Algorithm Design for Implementing Source Code

The Algorithm illustrates a workflow using software design to coordinate hardware components, using complex symbols, GPS and GSM libraries from Arduino, and creating a system program using the Arduino IDE.

```
Algorithm: Vehicle Control via SMS
1. Start
2. Initialize Modules
3. Read SMS
4. If SMS content is "TRACK" then:
   a. Get vehicle location
   b. Send location via SMS
5. Else if SMS content is "OFF" then:
   a. Stop vehicle engine
6. Else if SMS content is "ON" then:
   a. Start vehicle engine
7. End
```

2.2. Hardware Implementation

This system integrates a a microcontroller and GPS module to retrieve position data, which is displayed on an Pc screen, and has been successfully tested, ensuring latitude and longitude positions are displayed on vehicles. In figure 2 presents the description of GPS Hardware Implementation in Vehicle Tracking.

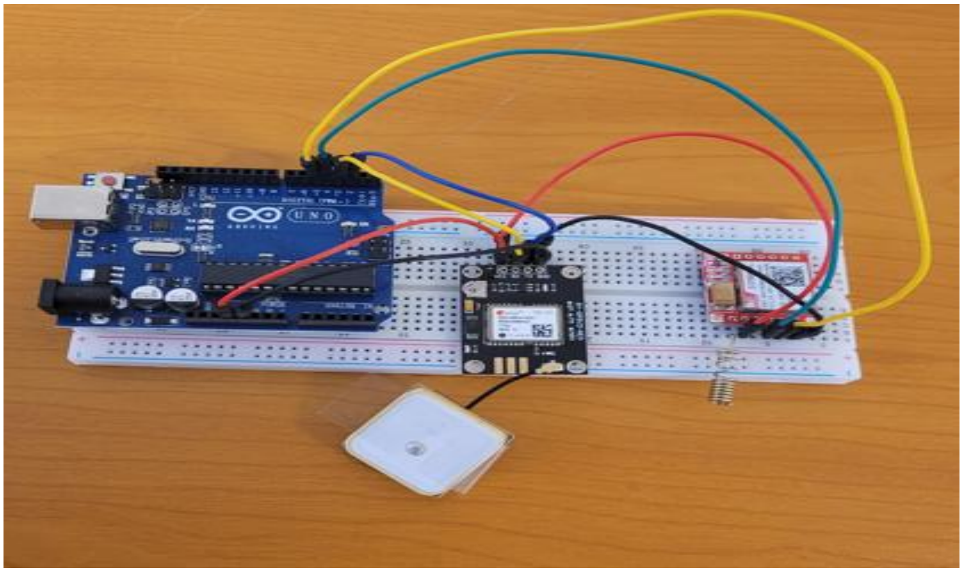
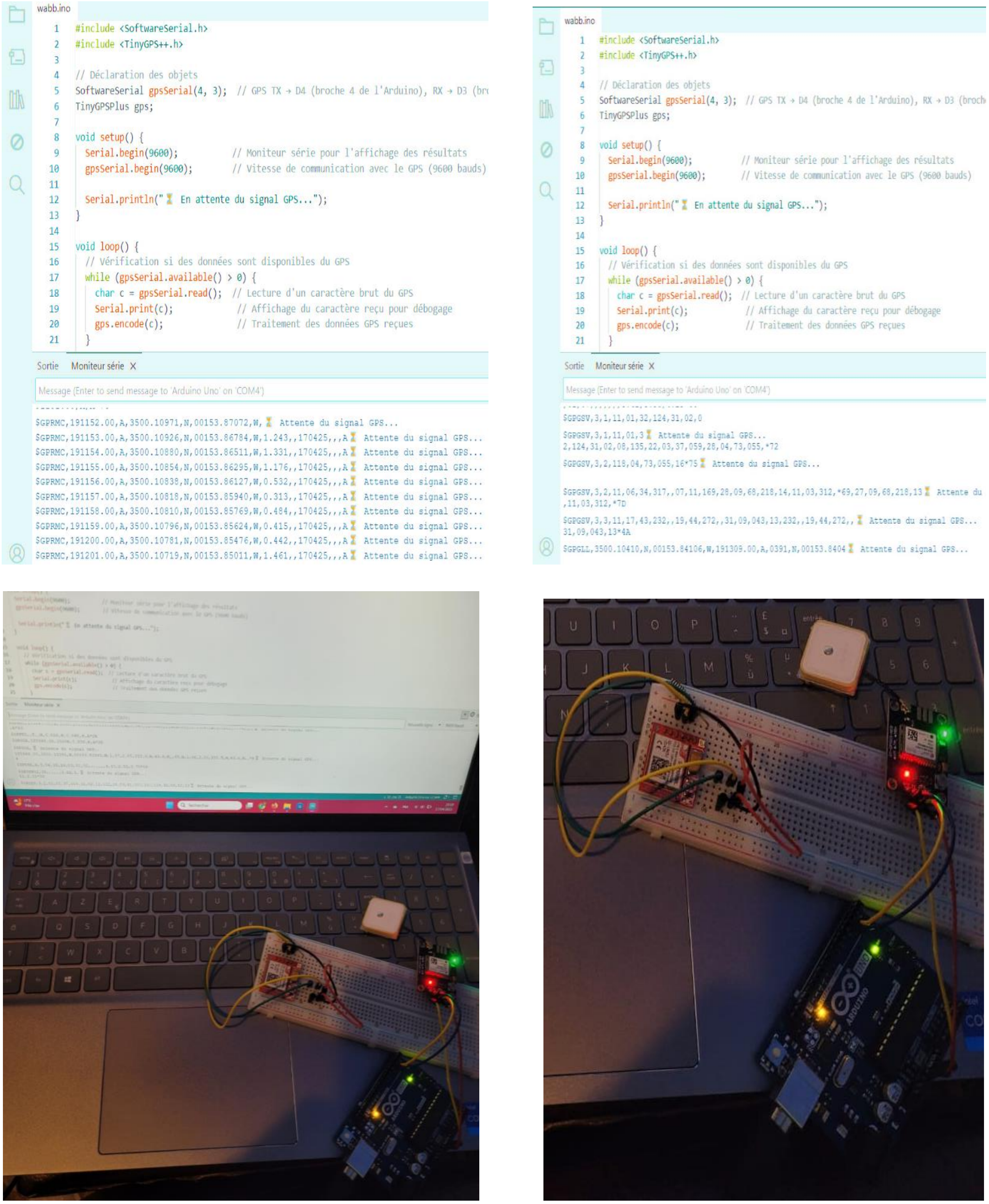


Fig.2. GPS *Hardware Implementation In* Vehicle Tracking.

2.3.1. Measured Results

The geolocation system for vehicles using a GPS circuit has been successfully completed in fig.3, enabling accurate real-time tracking and monitoring of vehicle locations with reliable performance.



```
#include <SoftwareSerial.h>
#include <TinyGPS++.h>

// Déclaration des objets
SoftwareSerial gpsSerial(4, 3);  // GPS TX → D4 (broche 4 de l'Arduino), RX → D3 (br
TinyGPSPlus gps;

void setup() {
  Serial.begin(9600);          // Moniteur série pour l'affichage des résultats
  gpsSerial.begin(9600);       // Vitesse de communication avec le GPS (9600 bauds)

  Serial.println("⏳ En attente du signal GPS...");
}

void loop() {
  // Vérification si des données sont disponibles du GPS
  while (gpsSerial.available() > 0) {
    char c = gpsSerial.read();  // Lecture d'un caractère brut du GPS
    Serial.print(c);            // Affichage du caractère reçu pour débogage
    gps.encode(c);              // Traitement des données GPS reçues
  }
```

Message (Enter to send message to 'Arduino Uno' on 'COM4')

```
$GPRMC,191152.00,A,3500.10971,N,00153.87072,W,⏳ Attente du signal GPS...
$GPRMC,191153.00,A,3500.10926,N,00153.86784,W,1.243,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191154.00,A,3500.10880,N,00153.86511,W,1.331,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191155.00,A,3500.10854,N,00153.86295,W,1.176,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191156.00,A,3500.10838,N,00153.86127,W,0.532,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191157.00,A,3500.10818,N,00153.85940,W,0.313,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191158.00,A,3500.10810,N,00153.85769,W,0.484,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191159.00,A,3500.10796,N,00153.85624,W,0.415,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191200.00,A,3500.10781,N,00153.85476,W,0.442,,170425,,,A⏳ Attente du signal GPS...
$GPRMC,191201.00,A,3500.10719,N,00153.85011,W,1.461,,170425,,,A⏳ Attente du signal GPS...
```

```
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// Déclaration des objets
SoftwareSerial gpsSerial(4, 3);  // GPS TX → D4 (broche 4 de l'Arduino), RX → D3 (broch
TinyGPSPlus gps;

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  gpsSerial.begin(9600);       // Vitesse de communication avec le GPS (9600 bauds)

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void loop() {
  // Vérification si des données sont disponibles du GPS
  while (gpsSerial.available() > 0) {
    char c = gpsSerial.read();  // Lecture d'un caractère brut du GPS
    Serial.print(c);            // Affichage du caractère reçu pour débogage
    gps.encode(c);              // Traitement des données GPS reçues
  }
```

Message (Enter to send message to 'Arduino Uno' on 'COM4')

```
$GPGSV,3,1,11,01,32,124,31,02,0

$GPGSV,3,1,11,01,3⏳ Attente du signal GPS...
2,124,31,02,08,135,22,03,37,059,28,04,73,055,*72

$GPGSV,3,2,118,04,73,055,16*75⏳ Attente du signal GPS...


$GPGSV,3,2,11,06,34,317,,07,11,169,28,09,68,218,14,11,03,312,*69,27,09,68,218,13⏳ Attente du
,11,03,312,*7D

$GPGSV,3,3,11,17,43,232,,19,44,272,,31,09,043,13,232,,19,44,272,,⏳ Attente du signal GPS...
31,09,043,13*4A

$GPGLL,3500.10410,N,00153.84106,W,191309.00,A,0391,N,00153.8404⏳ Attente du signal GPS...
```

Fig3. Integrated GPS Hardware Development Setup.

3. GPS Antenna Design

To enhance GPS performance, we have proposed a novel antenna structure featuring circular polarization presents in fig.4. This design aims to improve signal reception quality and robustness, making it more reliable for GPS applications.

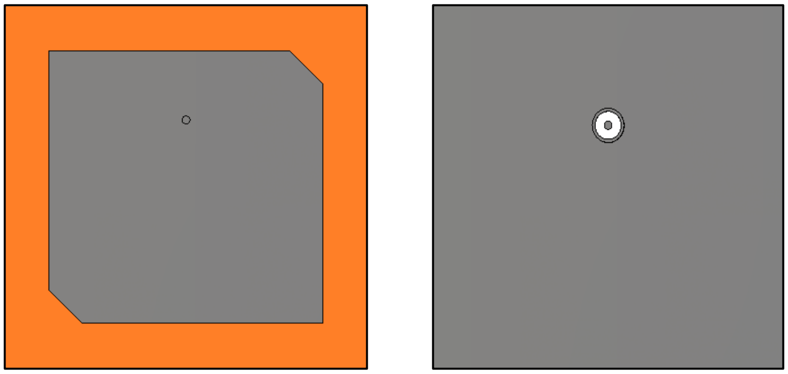

Fig.4.GPS Antenna design proposed.

3.1. Theory and calculation

The initial stage in designing a circularly polarized microstrip patch antenna is to determine its dimensions. To compute the size of the patch antenna resonating at 1.5 GHz, given a substrate with a dielectric constant of 4.3 and a thickness of 1.6 mm, the following equations are applied. The given equation represents the width (W) of patch for a microstrip antenna, calculated based on several parameters:

$$W = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad (1)$$

With:

- ✓ C: Speed of light in a vacuum (approximately 3×1083 \times 10^83×108 m/s).
- ✓ f_0: Resonant frequency of the antenna (in Hz).
- ✓ ε_r: Relative permittivity of the substrate used for the antenna.

The given equation represents the **effective length correction** for a rectangular patch antenna:

$$L = L_{eff} - 2\Delta L \qquad (2)$$

With:

- ✓ L_{Eff}: Effective length of the patch, which considers the influence of the dielectric substrate.
- ✓ ΔL: Extension of the effective length due to fringing fields at the edges of the patch.

This equation 3 determines the effective length of the patch, which is slightly longer than the actual physical length due to fringing effects. It accounts for wave propagation in the dielectric material, ensuring accurate resonance at the desired frequency.

$$L_{eff} = \frac{C}{2 f_0 \sqrt{\varepsilon_{reff}}} \qquad (3)$$

With:

- ✓ c: Speed of light in a vacuum (approximately 3×1083 \times 10^83×108 m/s).
- ✓ f_0: Resonant frequency of the antenna (in Hz).
- ✓ L_{eff}: Effective length of the patch
- ✓ ε_{eff}: Effective relative permittivity of the substrate.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \qquad (4)$$

$$\Delta L = 0.412h\left[\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} - 0.8\right)}\right] \qquad (5)$$

The antenna parameters are initially determined using theoretical formulas and further optimized using advanced simulation software. The final dimensions of the designed antenna are presented in Table 1.

Table 1. Design Parameters of the Proposed GPS Antenna

Items	***Optimal Value [mm]***
Length of patch	44.52
Width of patch	44.52
Length of square substrate	60
Feeding point in x-axis	8
Feeding point in y-axis	0
Inner Radius	1.3
Outer Radius	3

4. Simulation and Results

The parameters study affects the antenna's efficiency and overall performance, highlighting its potential to improve the compactness and effectiveness of circularly polarized (CP) antennas for GPS applications. The proposed antenna is designed to optimize critical performance parameters (see fig.5), such as return loss, gain, Voltage Standing Wave Ratio (VSWR), axial ratio, and radiation pattern.

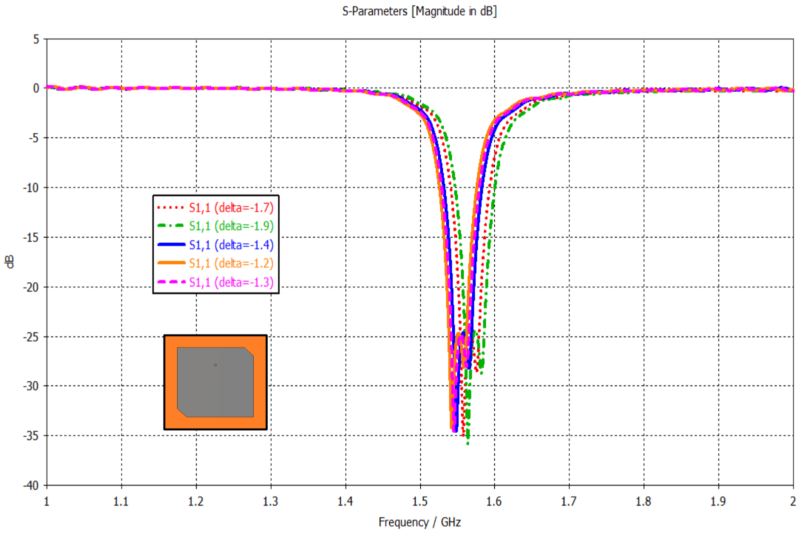

Fig.5.optimisation the parameters of antenna design.

The figure 6 represents the S-parameters (S11) in dB versus frequency in GHz for a GPS antenna. The S11 parameter, also known as the return loss, indicates how much power is reflected back from the antenna due to impedance mismatch. The deep notch in the curve around 1.558 GHz suggests the antenna is well-matched at this frequency, which aligns with the GPS L1 band (1.57542 GHz). The minimum S11 value, which appears below -25 dB, indicates excellent impedance matching, meaning most of the power is transmitted rather than reflected. This confirms the antenna's suitability for GPS applications, ensuring efficient radiation and minimal signal loss.

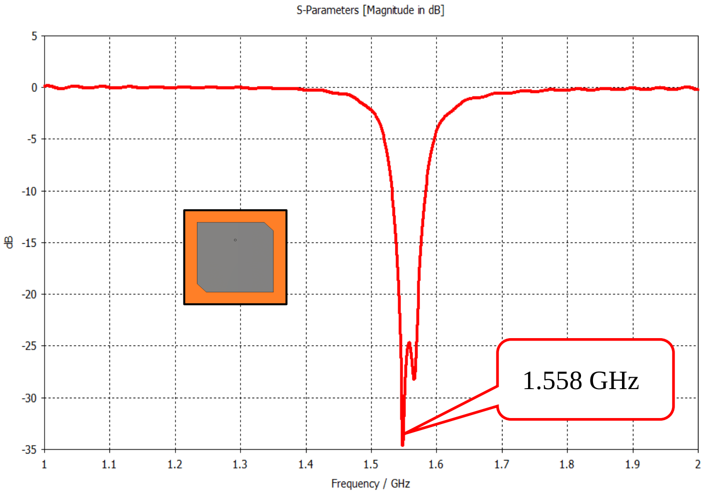

Fig.6.Return loss of GPS antenna

The quality of the circular polarization is described by the axial ratio (AR), which is a crucial metric for evaluating the antenna's polarization properties, especially for circularly polarized antennas. An ideal AR value denotes perfect circular polarization. The proposed antenna has an axial ratio of 1.345 presented in fig5, indicating good circular polarization, with a lower AR value indicating more efficient polarization.

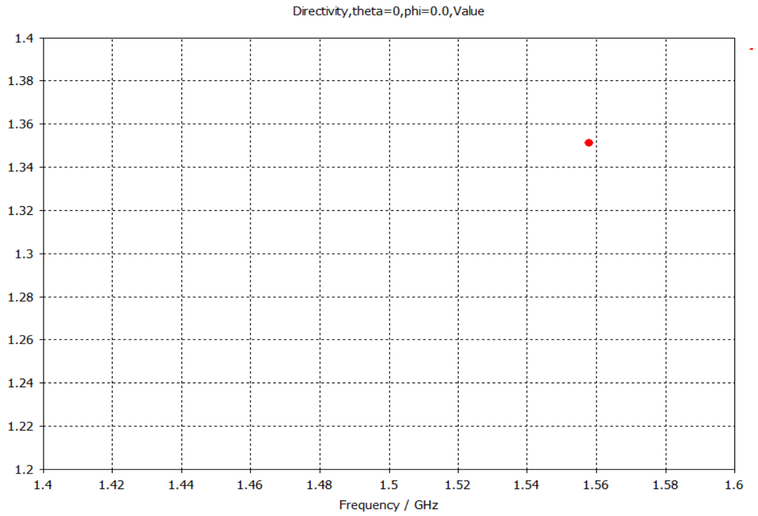

Fig.7. Axio Ratio of GPS antenna

The radiation pattern depicted in Figure 8 of the GPS antenna exhibits a broad main lobe centered at 0°, with a gain of approximately 3.45 dB, ensuring strong signal reception from satellites. The angular width of around 98° indicates a wide coverage area, essential for maintaining connectivity. The side lobe level of -6.4 dB suggests minimal interference from undesired directions. The nearly identical patterns in the Phi = 0° and Phi = 90° planes confirm uniform circular polarization, which is crucial for consistent signal reception regardless of the receiver's orientation.

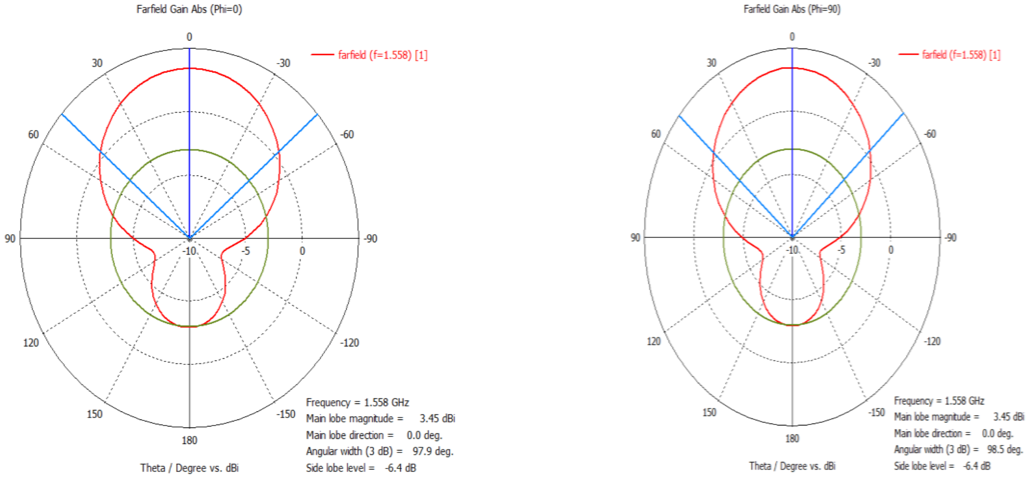

Fig.8. Polare Radiation pattern of GPS Antenna Proposed.

6. Conclusions

This paper presents a robust and efficient vehicle security solution by integrating GPS tracking with remote engine control via satellite communication. By leveraging real-time location data and SMS-based alerts, it offers an effective theft prevention mechanism while ensuring seamless user interaction. The combination of GPS technology, SIM network services, and internet accessibility enhances both security and reliability, making it a valuable advancement in modern vehicle protection systems. In the future, this system can be further enhanced by incorporating advanced technologies such as artificial intelligence (AI) and machine learning to predict potential security threats based on movement patterns and unusual activities. Additionally, integrating real-time data analytics and cloud storage would enable more efficient monitoring and historical tracking of vehicle locations. Future developments could also include compatibility with IoT-based smart security systems, allowing automated responses and improved user control. Expanding network coverage through satellite communication would further enhance reliability, ensuring uninterrupted tracking even in remote areas. These improvements would contribute to a more intelligent, efficient, and secure vehicle protection system.

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