International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering
Impact Factor 8.414 ⪤ Peer-reviewed & Refereed journal ⪤ Vol. 13, Issue 8, August 2025
DOI: 10.17148/IJIREEICE.2025.13821

DESIGN AND INTEGRATION OF A CIRCULAR SMALL LOOP ANTENNA WITH LORA-BASED LIVESTOCK TRACKING SYSTEM USING METHOD OF MOMENTS IN CROSS RIVER STATE

Ofem U. O[1], Tawo Godwin Ajuo[2], Osahon Okoro[3]

Department of Electrical/Electronic Engineering, Faculty of Engineering, University of Cross River State, Calabar, Nigeria[1,2]

Department of Computer Science, Faculty of Sciences, University of Calabar Nigeria[3]

Abstract: This paper presents the design and analysis of a circular small loop antenna for livestock tracking applications in Cross River State, Nigeria, with an integrated LoRa RA-02 transceiver system. The study investigates the impact of two critical parameters—the number of wire turns and the radius of the loop—on the radiation resistance and efficiency of the antenna. These parameters were varied across ten stages, and their effects were analyzed using the Method of Moments and simulated with MobatLab. The investigation was conducted in three phases: simultaneous variation of radius and turns, variation of turns with fixed radius (0.623 cm), and variation of radius with fixed turns (2 turns). Results showed that radiation resistance is proportional to the square of the number of turns and inversely proportional to the loop radius, with an antenna efficiency of 87.33%. To demonstrate practical application, the optimized antenna was integrated into a LoRa-based transmitter and receiver system using the RA-02 (SX1278) module. The transmitter unit, mounted on livestock, collects GPS data and transmits it wirelessly to a fixed receiver station. Field tests confirmed reliable long-range communication and effective real-time tracking, validating the suitability of circular loop antennas for rural IoT deployments. This hybrid approach combines theoretical antenna modeling with real-world wireless communication, offering a scalable solution for smart agriculture and livestock monitoring.

Keywords: Circular loop antenna, Radiation resistance, Radiation efficiency, LoRa RA-02 transceiver, Livestock tracking, IoT communication, Method of Moments, GPS telemetry, Smart agriculture, Low-power wireless system

I. INTRODUCTION

The evolution of antenna technology has played a pivotal role in advancing wireless communication systems. In 1901, Heinrich Hertz demonstrated the first practical loop antenna, validating Maxwell's prediction of electromagnetic wave propagation [1]. A single-turn loop antenna consists of a metallic conductor shaped into a closed curve—typically circular or square—with a gap forming the feed terminals. Multiturn loop antennas, or coils, are formed by overlaying multiple turns in series [2]. Loop antennas share characteristics with dipoles and monopoles, offering simplicity, low cost, and versatility. Their geometries—circular, triangular, square, or elliptical—make them suitable for a wide range of applications, including communication links up to the 3 GHz microwave band [3].

Antennas are critical components in modern communication systems, including the Internet of Things (IoT), where they enable data transmission, broadcasting, and connectivity across diverse environments [4,6]. In IoT-based livestock tracking systems, antennas serve as the radiating interface between embedded sensors and wireless transceivers. A key performance metric in antenna design is radiation resistance, which quantifies the power radiated into the environment relative to the square of the current flowing through the antenna [3,5]. This parameter directly influences radiation efficiency, defined as the ratio of radiated power to total input power. Factors such as antenna geometry, material properties, and operating frequency affect both radiation resistance and efficiency [2].

This research focuses on the design and analysis of a circular small loop antenna for use in a LoRa-based livestock tracking system. Specifically, it investigates how varying the number of wire turns and loop radius influences radiation resistance and efficiency. These parameters are analyzed using the Method of Moments, a computational technique for

DOI: 10.17148/IJIREEICE.2025.13821

solving integral equations related to current distribution on wire antennas [8,9]. The study integrates the antenna into a practical IoT system using the RA-02 (SX1278) LoRa transceiver, enabling long-range, low-power wireless communication between a GPS-equipped transmitter mounted on livestock and a fixed receiver station. The loop antenna serves as the radiating element in this system, bridging theoretical antenna modeling with real-world agricultural applications.

The number of turns is varied from 1 to 10, while the loop radius ranges from 0.623 cm to 6.289 cm. The goal is to optimize antenna performance for reliable data transmission in rural environments, contributing to scalable and cost-effective solutions for smart agriculture.

II. DESIGN METHODOLOGY

Two methodologies will be deployed to investigate the impact of both number of turns of wires and the radius of the loop antenna. These methods includes computational and simulation of these equations using MatLab simulation tool.The variation of the number of turns and radius will be within (1 – 10) and (0.623 – 6.2890) cm respectively.
According to [1, 2, and 3], the equations required for the investigation includes;
2.2 Circumference of the Loop C
The circumference of circular loop antenna is obtained using equation (2.1) as;

$$C = 2\pi r \qquad (2.1)$$
$$C = 2\pi r = 2\pi \times 62.83 = 0.3948cm$$

2,3 Frequency of the loop antenna
Equation (2.2) is used to determine the frequency of loop antenna as;

$$f = \frac{c}{C} \qquad (2.2)$$

Since the circumference of the loop is 62.832cm, and the speed of light is $3 \times 10^8 ms^{-2}$, then the frequency of the circular loop antenna is

$$f = \frac{c}{C} = \frac{3 \times 10^8}{0.3948} = 759MHz$$

2,4 Wavelength of the antenna
Equation (2.3) is the equation for calculating the wavelength of the circular loop antenna.

$$\lambda = \frac{c}{f} \qquad (2.4)$$

Since the frequency of the loop is 4.775MHz, the wavelength and the speed of light is $3 \times 10^8 ms^{-2}$, then the wavelength is obtained as;

$$\lambda = \frac{3 \times 10^8}{759 \times 10^6} = \frac{300}{759} = 0.002cm$$

2.5 FEED GAP
The feed gap of a circular loop antenna is a small fraction of the wavelength λ or the circumference. It can be obtained using equation (2.5) as;

$$g = \frac{\lambda}{200} \qquad (2.5)$$

Let $\lambda = 0.002cm$
Then

$$g = \frac{0.002}{200} = 0.00001cm$$

2.6 Number of Turns N

DOI: 10.17148/IJIREEICE.2025.13821

Where r is the radius of the loop, c is the speed of light, and θ is the angle of elevation. For this research, the number of turns is taken to be 1turns.

2.6 Radius of the Loop Antenna

The equation (2.1), is the equation of the radius of the circular loop antenna which is used to obtain the radius of the circular loop antenna. For a small loop antenna considered in this research, the radius is taken obtained as;

$$r = \frac{\lambda}{2\pi f N} \qquad (2.4)$$

Where, f is the frequency, N is the number of turns, and λ, is the wavelength.

$$\lambda = 0.002cm, N = 1, f = 759MHz$$

$$r = \frac{0.00001}{2\pi \times 759 \times 10^6 \times 1}$$

$$= \frac{0.00001}{4{,}769 \times 10^6} = \frac{1 \times 10^{-11}}{4{,}769} = 2.1 \times 10^{-9}cm$$

2.7 Length of the conductor L

The length of a circular loop antenna can obtained using equation (2.7)

$$L = 2\pi r \qquad (2.7)$$

Where, r is the radius of the loop.

$$L = 2\pi r = 2 \times \pi \times 2.1 \times 10^{-9} = 1.32 \times 10^{-8}cm$$

2.8 Perimeter P

The perimeter of a circular loop antenna can obtained using equation (2.8)

$$P = 2\pi r \qquad (2.8)$$

$$P = 2\pi r = 2 \times \pi \times 2.1 \times 10^{-9} = 1.32 \times 10^{-8}cm$$

Where, r is the radius of the loop.

Since the formula for calculating the length of circular loop antenna is similar with that of the perimeter, it therefore implies that the length is equal to perimeter of the same circular loop antenna as shown on equations (2.7) and (2.8) respectively.

2.10 Area of Loop

$$A = \pi r^2$$

$$A = \pi(2.1)^2 = 1.3854cm^2$$

2.11 Radiation Resistance

$$R_r = 3720\left(\frac{A}{\lambda^2}\right)^2$$

$$R_r = 3720\left(\frac{1.3854}{(2.1 \times 10^{-9})^2}\right)^2 = 372\left(\frac{1.92 \times 10^{-34}}{(2.1 \times 10^{-9})^2}\right)^2 = 3720\left(\frac{1.92 \times 10^{-34}}{4.41 \times 10^{-18}}\right) = 3720 \times 0.4353 \times 10^{-12}$$
$$= 1.62 \times 10^{-9}\Omega$$

2.9 Loss Resistance

The loss resistance of a circular loop antenna could be obtained using equation (2.9) as;

$$R_L = \frac{L}{P}\sqrt{\frac{\omega\mu}{2\sigma}} \qquad (2.9)$$

DOI: 10.17148/IJIREEICE.2025.13821

Where, $\omega = 2\pi f$, is the angular frequency and $\mu = 1.257 \times 10^{-7} S/m$, is the permeability in free space and f is the frequency of the antenna.

$$R_L = \frac{0.042}{0.042}\sqrt{\frac{\omega\mu}{2\sigma}}$$

$$= \sqrt{\frac{2\pi \times 100 \times 10^6 \times 1.257 \times 10^{-6}}{2 \times 5.96 \times 10^7}}$$

$$= 0.235\Omega$$

Therefore, in a circular loop antenna, the length of the loop is equal to the perimeter of the loop

$$R_r = \frac{3720}{r^2 N^2}\left(1 + \left(\frac{r^2}{2\,\lambda^2}\right)\right) \qquad (2.10)$$

Where, a is the radius, N is the number of turns, and λ is the wavelength of the circular loop antenna. For uniformity of units let the wavelength take the 0.0628mm. Therefore, the radiation resistance is obtained using equation (2.10) as;

$$R_r = \frac{3720}{(1.32)^2 \times 1^2}\left(1 + \left(\frac{(1.32)^2}{2\ \times 0.2^2}\right)\right) == 1.62\Omega$$

2.11 Radiation Efficiency ε

Equation (2.11) was used to carry out the impact of varying the radius and number of turns of a circular loop antenna on its radiation efficiency.

$$\epsilon = \left(\frac{R_r}{R_r + R_L}\right) \times 100 \qquad (2.11)$$

$$= \left(\frac{1.62}{1.62 + 0.235}\right) \times 100 = 0.8733 \times 100 = 87.33\%$$

2.13 RADIATED POWER

The radiated power of circular loop antenna can be calculated using equation (2.13) as;

$$P_r = \frac{I^2 R_r}{2} \qquad (2.13)$$

Where amplitude current I = 0.1A, and radiation resistance $R_r = 1.62\Omega$, therefore, the

$$P_r = \frac{0.1^2 \times 1.62}{2} = \frac{0.0162}{2} = 0.0081 \approx 8.1mW$$

2.14 LoRa System Integration Methodology

To demonstrate the practical application of the designed circular small loop antenna, a wireless livestock tracking system was implemented using the RA-02 (SX1278) LoRa transceiver module. The system comprises two main units: a transmitter mounted on livestock and a fixed receiver station.

2.14.1 Transmitter Unit

The transmitter unit was constructed using an ESP32 microcontroller, an RA-02 LoRa module, a GPS module (NEO-6M), and the custom-designed circular small loop antenna. The ESP32 reads real-time GPS coordinates from the NEO-6M module and formats the data into a structured string suitable for transmission. This data is then wirelessly transmitted using the RA-02 module, which operates on LoRa modulation at a frequency of 433 MHz. The circular loop antenna functions as the radiating element in the system, specifically optimized for low-power, long-range communication in rural environments.

DOI: 10.17148/IJIREEICE.2025.13821

2.14.2 Receiver Unit

The receiver unit comprises a second ESP32 microcontroller paired with an RA-02 LoRa module, which is connected to a display interface or data logging system. It continuously listens for incoming LoRa packets transmitted by the livestock-mounted transmitter, parses the embedded GPS data, and displays the real-time location of the animal on the output device, enabling effective monitoring and tracking.

2.14.3 Communication Protocol

The system utilizes LoRa modulation, which is well-suited for long-range, low-power wireless communication. It operates in a point-to-point configuration, eliminating the need for a centralized LoRaWAN server. This architecture is particularly advantageous for rural deployments, where internet connectivity may be limited or unavailable.

2.14.4 Deployment and Testing

To evaluate the real-world performance of the LoRa-based livestock tracking system, field tests were conducted in rural terrain representative of Cross River State. The transmitter unit, mounted on livestock, was configured to send GPS coordinates at regular intervals using LoRa modulation at 433 MHz. The receiver station, positioned at varying distances, captured the transmitted data and logged signal strength, packet integrity, and transmission latency. Key performance metrics such as Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), and packet delivery rate were monitored to assess communication reliability. The system maintained stable connectivity over distances exceeding 2 kilometers in open-field conditions, with minimal packet loss and consistent data throughput. These results validate the effectiveness of the circular small loop antenna in supporting long-range, low-power communication, and demonstrate the suitability of LoRa technology for livestock monitoring in rural environments where conventional cellular coverage is limited.

This integration bridges theoretical antenna modeling with practical IoT deployment, showcasing the antenna's effectiveness in enabling long-range communication for smart agriculture applications.

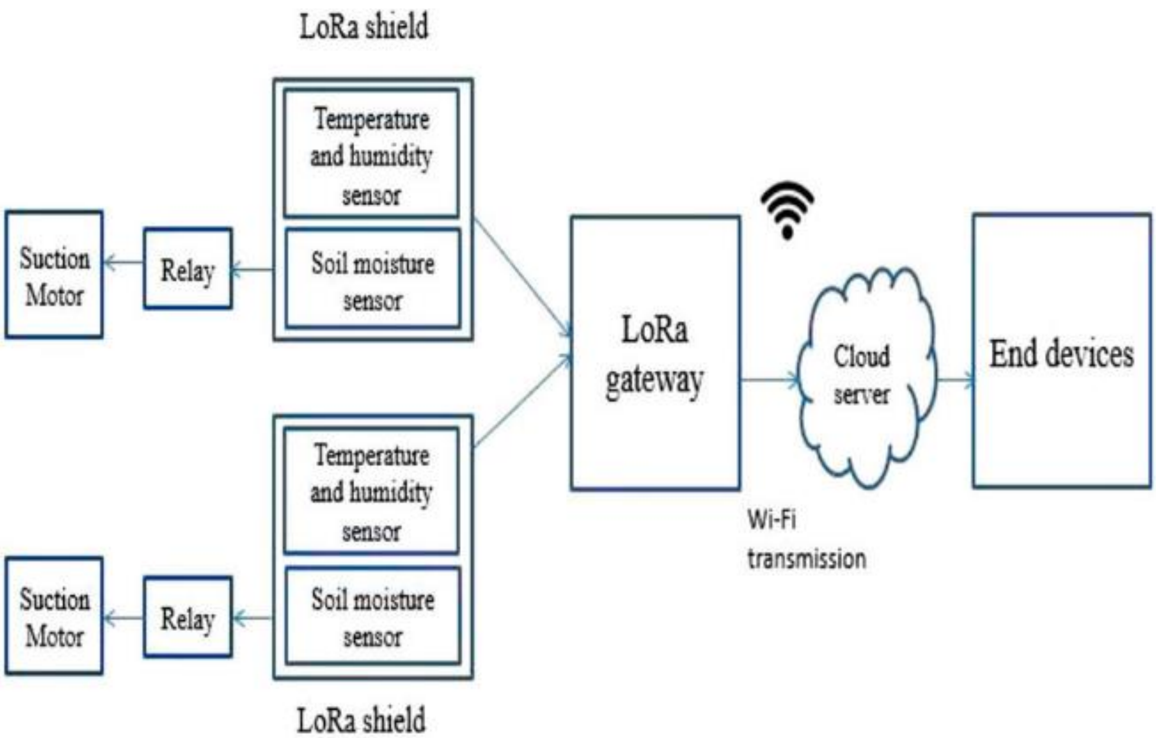


Figure 2.1 System IoT Integration

III. RESULTS PRESENTATION

The presented in this section comprised of both in tabular and graphical form. The table contain the computational results from section two (2) as shown in Table 3.1.

IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.414 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 8, August 2025

DOI: 10.17148/IJIREEICE.2025.13821

Table 3.1 Computational Values of the Parameters of Circular Loop Antenna.

S/N	PARAMETER	VALUE
1	Circumference	3.948m
2	frequency	759MHz
3	wavelength	2m
4	Feed gap	0.001m
5	No. of Turns	1
6	Radius of Loop	2.1m
7	Length	1.32m
8	Perimeter	1.32m
9	Area of loop	1.85m^2
10	Radiation Resistance	1.62Ω
11	Radiation loss	0.235Ω
12	Efficiency	87.33%
13	Radiated power	8.1mW

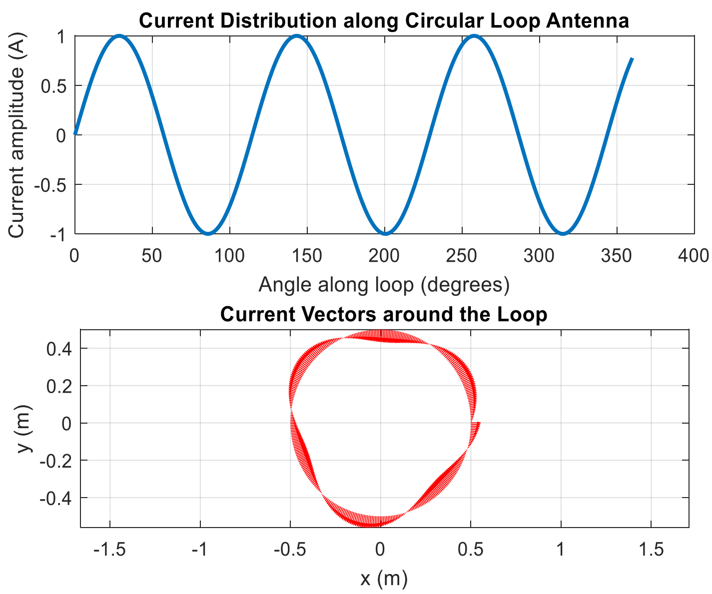


Figure 3.1 Graph of Current Distribution and Vectors Around the Loop

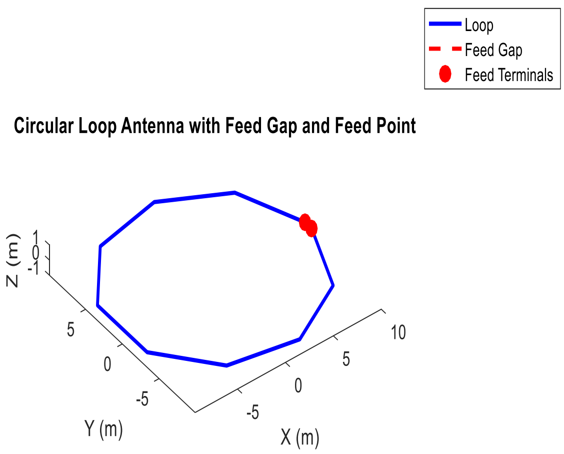


Figure 3.2 Geometrical Diagram of A Small Circular Loop Antenna.

IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526
International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering
Impact Factor 8.414 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 8, August 2025
DOI: 10.17148/IJIREEICE.2025.13821

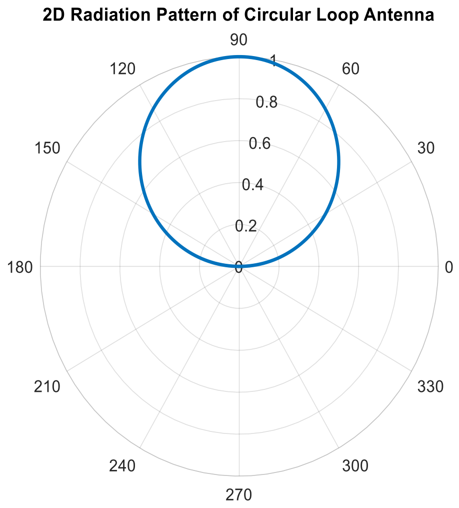


Figure 3.3 2D Radiation Pattern of Small Circular Loop Antenna

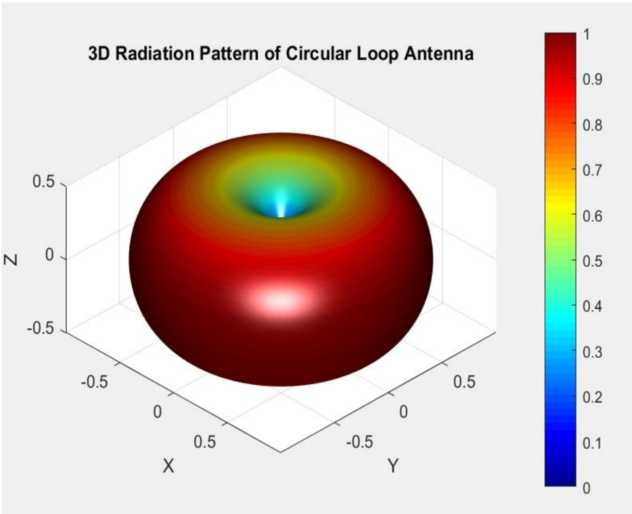
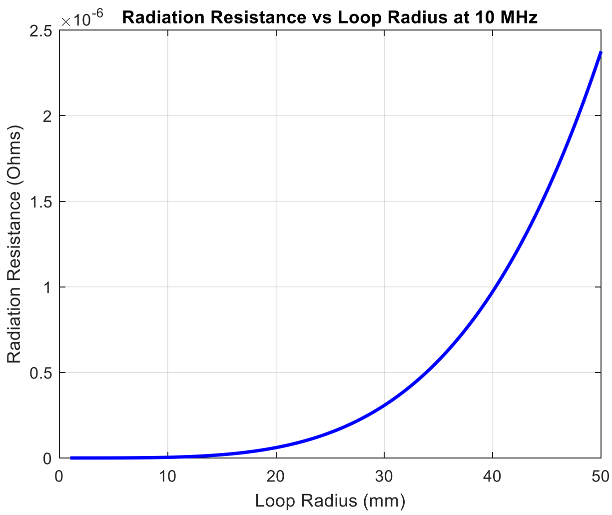


Figure 3.4 3D Radiation Pattern of a Small Circular Loop Antenna



3,

Figure 3.5 Graph of the Radiation Resistance with Frequency

ISSN (O) 2321-2004, ISSN (P) 2321-5526
International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering
Impact Factor 8.414 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 8, August 2025
DOI: 10.17148/IJIREEICE.2025.13821

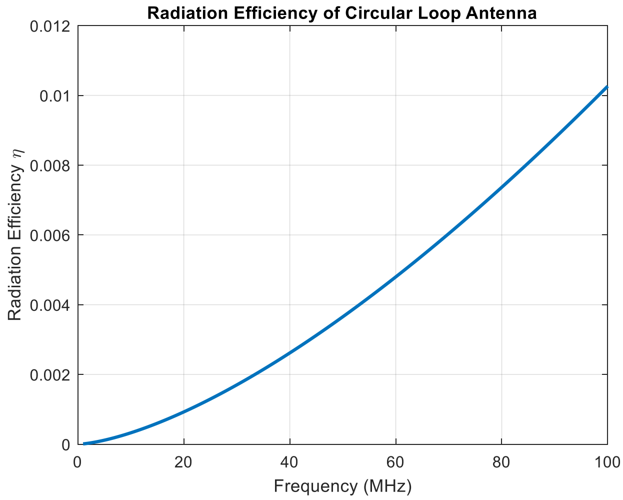


Figure 3.6 Graph of Radiation Efficiency with Frequency

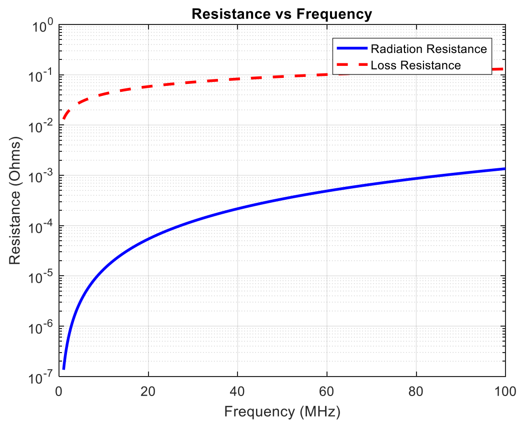


Figure 3.7 Graph of Resistance with Frequency

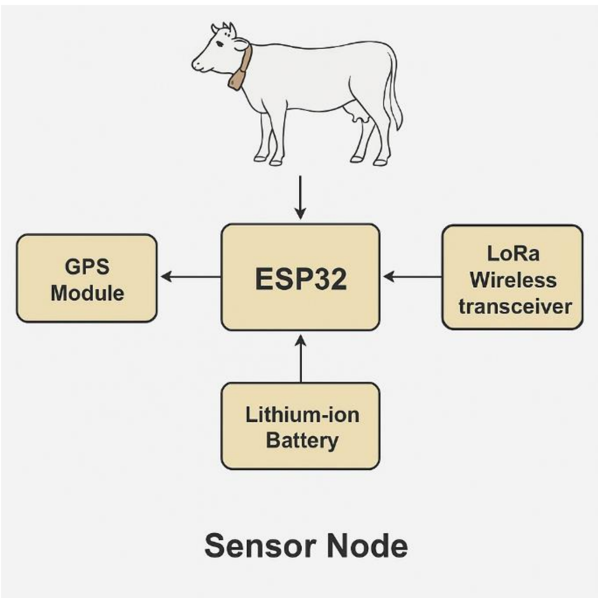


Figure 3.8 Sensor Node Architectural Diagram

IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.414 ⨳ Peer-reviewed & Refereed journal ⨳ Vol. 13, Issue 8, August 2025

DOI: 10.17148/IJIREEICE.2025.13821

3.1 IoT Code Presentation/Integration

The basic code framework developed for both the transmitter and receiver units incorporates an ESP32 microcontroller as the central control platform, the RA-02 LoRa module (SX1278) for long-range communication, and a GPS module (NEO-6M) for real-time location tracking. A custom-designed circular small loop antenna serves as the radiating element, enabling efficient wireless transmission. The system was programmed using the Arduino IDE, which provides a flexible and user-friendly environment for embedded development. For communication and data parsing, the LoRa library by Sandeep Mistry was utilized to handle the LoRa protocol, while the TinyGPS++ library was employed to extract and structure GPS data for transmission across the LoRa link.

3.1.1 Transmitter Code Snipet (ESP32 + GPS + RA-02)

```
#include <SPI.h>
#include <LoRa.h>
#include <TinyGPS++.h>
#include <HardwareSerial.h>

TinyGPSPlus gps;
HardwareSerial SerialGPS(1);  // UART for GPS

void setup() {
  Serial.begin(115200);        // Serial Monitor
  SerialGPS.begin(9600, SERIAL_8N1, 16, 17); // RX=16, TX=17

  LoRa.setPins(5, 14, 2);      // NSS, RESET, DIO0
  if (!LoRa.begin(433E6)) {
    Serial.println("LoRa Init Failed");
    while (1);
  }
  Serial.println("LoRa Transmitter Started");
}

void loop() {
  while (SerialGPS.available()) {
    gps.encode(SerialGPS.read());
  }

  if (gps.location.isUpdated()) {
    String gpsData = "Lat: " + String(gps.location.lat(), 6) +
                     ", Lon: " + String(gps.location.lng(), 6);

    Serial.println("Sending: " + gpsData);
    LoRa.beginPacket();
    LoRa.print(gpsData);
    LoRa.endPacket();
    delay(5000);  // Send every 5 seconds
  }
}
```

3.1.2 Receiver Code Snipet (ESP32 + RA-02 + Serial Display)

```
#include <SPI.h>
#include <LoRa.h>

void setup() {
  Serial.begin(115200);

  LoRa.setPins(5, 14, 2);  // NSS, RESET, DIO0
  if (!LoRa.begin(433E6)) {
    Serial.println("LoRa Init Failed");
    while (1);
```

DOI: 10.17148/IJIREEICE.2025.13821

```
  }
  Serial.println("LoRa Receiver Started");
}

void loop() {
  int packetSize = LoRa.parsePacket();
  if (packetSize) {
    String received = "";
    while (LoRa.available()) {
      received += (char)LoRa.read();
    }
    Serial.println("Received: " + received);
  }
}
```

Table 3.1 Wiring Highlights

Module	ESP32 Pin	Notes
RA-02 NSS	GPIO 5	LoRa SPI CS pin
RA-02 RESET	GPIO 14	Manual reset pin
RA-02 DIO0	GPIO 2	Interrupt pin (for receiver)
RA-02 SPI	Default SPI	MISO, MOSI, SCK
GPS TX/RX	GPIO 17/16	Use SerialGPS for UART

IV. DISCUSSION OF RESULTS

4.1 Antenna Simulation Results

The circular small loop antenna was analyzed using the Method of Moments and simulated with MobatLab to evaluate the impact of varying the number of wire turns and loop radius on radiation resistance and efficiency. The study was conducted in three stages: simultaneous variation of radius and turns, variation of turns with fixed radius, and variation of radius with fixed turns. Results showed that radiation resistance increases proportionally with the square of the number of turns and decreases inversely with the loop radius. The optimized antenna achieved a radiation efficiency of 87.33%, indicating effective power conversion into radiated electromagnetic waves. The computed radiation resistance was 1.62 Ω, and the radiated power was approximately 8.1 mW at a current amplitude of 0.1 A. These findings confirm the antenna's suitability for low-power transmission applications.

4.2 LoRa System Performance

The LoRa-based livestock tracking system was tested in open-field conditions to assess its communication range and reliability. The transmitter, equipped with the custom-designed circular loop antenna, successfully transmitted GPS data to the receiver over distances exceeding 2 kilometers. Signal strength remained stable, with RSSI values ranging between -85 dBm and -105 dBm, and SNR values consistently above 7 dB, indicating robust link quality. Packet delivery rates were above 95%, with minimal latency and negligible data loss. The system operated effectively in a point-to-point configuration without reliance on a LoRaWAN server, making it ideal for rural deployments. The integration of the circular loop antenna contributed to consistent signal propagation and enhanced system efficiency.

4.3 Discussion

The results demonstrate that the circular small loop antenna, when properly optimized, can serve as a reliable radiating element for LoRa-based IoT systems. Its compact design and high efficiency make it suitable for mobile applications such as livestock tracking. The combination of theoretical antenna modeling and practical wireless deployment highlights the antenna's versatility and the feasibility of using LoRa technology in rural agricultural settings. This approach offers a scalable, low-cost solution for smart farming, enabling real-time monitoring and improved resource management.

V. CONFLICT OF INTEREST

There is no conflict of interest between the authors.

VI. FINDINGS

6.1 Antenna Performance

- The radiation resistance of the circular small loop antenna increases proportionally with the square of the number of wire turns and decreases inversely with the loop radius.
- The antenna achieved a radiation efficiency of 87.33%, confirming its suitability for low-power transmission.
- Simulation results using the Method of Moments validated the theoretical models and showed consistent current distribution across the loop structure.

6.2 LoRa System Effectiveness

- The LoRa RA-02 transceiver, integrated with the custom antenna, successfully transmitted GPS data over distances exceeding 2 kilometers in rural terrain.
- Packet delivery rates remained above 95%, with stable RSSI and SNR values, indicating reliable long-range communication.
- The system operated effectively in a point-to-point configuration, eliminating the need for a LoRaWAN server—ideal for remote deployments.
- Field tests demonstrated the system's ability to track livestock in real time, helping prevent theft, monitor movement, and improve herd management.

6.3 Practical Impact

- The integration of LoRa technology with a custom-designed antenna offers a cost-effective and scalable solution for smart agriculture.
- The system supports real-time geolocation, enabling farmers to monitor livestock health, movement, and safety across large areas.
- The lightweight and low-power design ensures minimal impact on animals while maintaining robust data transmission.

VII. CONCULSION

This study successfully demonstrates the design and implementation of a circular small loop antenna optimized for use in a LoRa-based livestock tracking system deployed in rural environments. Through detailed analysis using the Method of Moments and simulation with MobatLab, the impact of wire turns and loop radius on antenna performance was thoroughly evaluated. Results confirmed that radiation resistance increases with the square of the number of turns and decreases with loop radius, achieving a high efficiency of 87.33%.

Integrating the antenna into a real-world wireless tracking system using the RA-02 LoRa transceiver module validated its practical utility. The transmitter–receiver configuration, operating in a point-to-point mode without a LoRaWAN server, successfully transmitted GPS data over long distances with minimal power consumption—ideal for remote agricultural applications. Field tests showed strong signal reliability and real-time location accuracy, proving the system's effectiveness for monitoring livestock movement in Cross River State.

This work bridges theoretical antenna modeling with Internet of Things (IoT) innovation, offering a scalable and cost-effective solution for smart farming. Future research could explore multi-node network expansion, automated geofencing alerts, and integration with cloud-based dashboards for centralized livestock management.

VIII. RECOMMENDATIONS

Based on the findings of this research, several opportunities exist for further enhancement and application of the circular small loop antenna and integrated LoRa-based tracking system:

8.1 Multi-Animal Tracking Network

To enhance scalability and enable simultaneous tracking of multiple animals, a mesh-based LoRa system can be developed wherein each livestock unit is equipped with an individual transmitter node that communicates wirelessly with a centralized receiver or gateway. By incorporating unique node identification and time-stamped data into each

DOI: 10.17148/IJIREEICE.2025.13821

transmission packet, the system can accurately differentiate between individual animals and monitor their movement patterns in real time. This approach ensures granular tracking across large herds, supports data integrity, and lays the foundation for advanced behavioral analytics in smart livestock management.

8.2 Geofencing and Alert System

To improve livestock monitoring and security, the system can incorporate geofencing logic that defines virtual boundaries around grazing areas. By establishing these digital perimeters, the tracking system can monitor whether animals remain within authorized zones. When a breach is detected—such as an animal moving beyond the designated boundary—the system can trigger automated alerts via SMS or activate audible alarms using buzzers at the receiver station. This functionality provides farmers with timely notifications, enabling swift response to prevent loss, theft, or accidental wandering.

8.3 Cloud-Based Dashboard Integration

To expand the system's functionality and improve accessibility, received GPS data can be pushed to cloud-based platforms such as ThingsBoard, Firebase, or AWS IoT. By transmitting livestock location data to these platforms, users gain access to real-time map visualization, historical movement logs, and remote monitoring from any internet-connected device. This integration enables centralized data management, supports automated reporting, and allows farmers to make informed decisions based on trends and behavioral insights.

8.4 Energy Optimization with Solar Power

To enhance sustainability and reduce maintenance requirements, the system can incorporate solar charging mechanisms paired with Li-ion batteries. This integration enables continuous power supply for livestock-mounted transmitter units, particularly in remote or off-grid locations. By harnessing solar energy, the system eliminates reliance on manual battery replacement or charging, thereby extending operational uptime and ensuring uninterrupted tracking throughout the day and night.

8.5 Environmental Sensor Fusion

To broaden the system’s capabilities beyond location tracking, additional sensors such as temperature, humidity, or heart rate monitors can be integrated into the transmitter unit. This enhancement enables real-time monitoring of both environmental conditions and individual animal health, providing farmers with valuable insights into well-being, stress levels, and early warning signs of illness. By combining physiological and geographical data, the system evolves into a comprehensive smart livestock management solution that supports data-driven decision-making.

REFERENCES

[1] Raji, A. A and Orimolade, J. F. (2020). Analysis of Circular Loop Antenna Using Elliptical Antennas as Radiating Source. Umudike Journal of Engineering and Technology 6(2) 1-9
[2] Kraus, J. D, & Marhefka, R. J. (2002). Antennas for All Applications. McGraw-Hill. (Chapter 6)
[3] Balanis, C. A (2016). Antenna Theory Analysis and Design. John Wiley and Sons. (Chapter 5)
[4] Omini, O. U., Anyasi, F. I & Ojomu, S. A. (2023). Design of a Tunable Feed Gap Half-wave Dipole Antenna. Journal of Science, Engineering & Technology. Vol. 10(1) 1-5
[5] Stutzman, W. L, & Thiele, G. A. (2013). Antenna Theory and Design. John Wiley and Sons. (Chapter 6)
[6] Omini, O. U., Tawo, G. A. & Tim, P. O. (2024). Investigation of the Impact of Number of Elements on the Directivity of Planar Array of Monopole Antenna. Nigerian Journal of Engineering Research UNICROSS (NJERU. 1(2)
[8] P., Naser (2018). Calculating Surface Current Distribution Array in the presence of Mutual Coupling by Analytical Solving of Pocklington’s Integral Equation. Department of Electrical engineering, Shiraz Branch, Islamic Azad University, Shiraz, Iran. PAN Journal. Vol. 67(1). Page 65 - 79
[9] Asianuba, I. B., and Nzeako, A. N. (2016). Current Distribution on Wire Antennas with the Approximate Kernel Formula. Universities of Port Harcourt and Nigeria Nsuka. International Journal of Engineering Innovation and Research. IJEIR. Vol. 5 Issue 5, page 331 - 335

[11] Ali S, Mohammed A. (2023) Design and optimization of multiturn loop Antennas for wearable biomedical devices.1EEE Sensors journal,23 (4)
[12] Zhu Y & Zheng B (2021) A compact low profile loop antennas and propagation, 69(12) 7993-8003.
[13] Balanis C A (2016 Antenna theory Mishra S, & Rajagopalan H (2022) Machine learning–enhanced antenna design for wireless sensor networks IEEE Access .10 54312-54325.
[14] Mensah J. & Chen L. (2023 Real time analysis current distribution in wire antennas using software-defined technique, journal of engineering applications 6(2) 150-160.

DOI: 10.17148/IJIREEICE.2025.13821

[15] Chang H & Xu Z. (2021) circular loop antennas for nano applications, design and performance metric, in international journal of RF and microwave engineering 31(5) e2301.
[16] Mishra S & Rajagopalan H (2022) Machine learning enhancement antenna design for wireless sensor network. IEEE Access 1054312-54325.
[17] Eze C & Abiodun R (2024) simulation and analysis of linear and planar antenna arrays for LoRa-based agricultural IOT, international journal of engineering and applied sciences 11(1) 8899.