Design and Fabrication of a Wire Antenna for Weather Data Transmission Using 433 MHz Modules with IOT

A CAPSTONE PROJECT REPORT

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ECA1201-Antennas and Wave Propagations for Radar Application

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BONAFIDE CERTIFICATE

Certified that this capstone project report " **Design and Fabrication of a Wire Antenna for Weather Data Transmission Using 433 MHz Modules"** is the Bonafide work of **" Prince Raj. N and Ravi Teja. M"** who carried out the capstone project work under my supervision for the course ECA1201 – Antennas and Wave Propagation for Radar Applications.

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

This project presents the design, simulation, and fabrication of a wire antenna specifically optimized for 433 MHz RF communication, aimed at enabling efficient and reliable wireless transmission of weather data in urban environments. The system integrates a microcontroller-based weather station that collects real-time environmental data using sensors such as DHT22 for temperature and humidity, and MQ-135 for air quality monitoring. These sensor readings are transmitted wirelessly using 433 MHz RF modules connected to a custom-fabricated wire antenna, designed to enhance signal strength, reduce transmission losses, and ensure stable communication over varying distances.

The antenna design was guided by key parameters such as resonant frequency, wavelength matching, and impedance considerations to achieve optimal performance in dense urban settings, where interference and physical obstructions often degrade signal quality. The receiver unit, equipped with a corresponding antenna and microcontroller, captures the transmitted data and relays it to a PC via serial communication. A Python script processes this data and uploads it to the ThingSpeak IoT platform, where it is stored, analyzed, and visualized in real time for remote monitoring and decision-making.

This project demonstrates how the combination of low-cost RF modules, precision antenna design, and cloud-based data services can create a scalable and efficient wireless weather monitoring system. It is particularly suitable for urban deployment, where infrastructure constraints and the need for decentralized, wireless solutions make traditional wired systems impractical. The proposed system can be extended to applications such as smart city environmental monitoring, air pollution tracking, and early warning alerts for weather-related hazards.

This allows for continuous cloud-based monitoring and visualization of environmental conditions. The project highlights the importance of antenna design in enhancing RF communication performance and demonstrates its practical application in urban air quality monitoring, smart city infrastructure, and environmental awareness initiatives.

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CHAPTER 1: INTRODUCTION

1.1 Background Information

Wireless communication technologies are rapidly transforming the way we interact with the environment and gather real-time data. In the age of the Internet of Things (IoT), collecting and transmitting sensor-based environmental data has become increasingly essential. Among the various frequency bands used in RF communication, 433 MHz stands out due to its long-range capabilities and low power consumption, making it ideal for embedded applications. However, the efficiency of RF communication relies heavily on the quality and design of the antenna. Urban environments, with their dense infrastructure and electromagnetic interference, pose additional challenges. Therefore, this project addresses the crucial need for a custom-designed wire antenna optimized for 433 MHz frequency to enhance data reliability in such settings.

1.2 Project Objectives

The primary objective of this project is to design, fabricate, and test a wire antenna that is optimally tuned for the 433 MHz ISM band. Additional goals include:

- Developing a compact transmitter system incorporating an Arduino microcontroller and weather sensors (DHT22 and MQ-135).

- Implementing a reliable RF communication link between transmitter and receiver modules.

- Facilitating real-time data logging and visualization on the ThingSpeak IoT platform.

- Ensuring stable operation in urban environments with obstacles and signal interference.

1.3 Significance

With the rise in urbanization and climate change concerns, it is increasingly important to monitor environmental conditions such as temperature, humidity, and air quality. Accurate, localized weather data can inform policy-making, disaster management, and public health strategies. This project demonstrates a low-cost yet effective solution for gathering and sharing such data, contributing to the growing ecosystem of smart cities. The implementation of a tailored antenna design ensures enhanced communication reliability and can serve as a model for similar IoT deployments.

1.4 Scope

The scope of the project includes:

- Antenna theory research and practical wire antenna design for 433 MHz.
- System integration involving sensors, Arduino microcontrollers, RF modules, and software tools.
- Wireless transmission of sensor data over short to medium range (up to 100 meters).
- Visualization of the data on ThingSpeak for remote access.
- Testing the setup in real-world urban conditions to assess reliability and performance.

1.5 Methodology Overview

The methodology adopted for the project is systematic and iterative, involving:

- Theoretical calculations to determine optimal antenna length (quarter-wave formula).
- Fabrication of the wire antenna using copper conductor material.
- Assembly of the transmitter and receiver circuits on breadboards.
- Interfacing sensors with the Arduino microcontroller.
- Programming the Arduino for data collection and RF transmission.
- Developing a Python script for serial communication with ThingSpeak.
- Performance testing and validation through signal range and data accuracy measurements.

CHAPTER 2: Problem Identification and Analysis

2.1 Description of the Problem

Standard RF modules often come with generic antennas that are not optimized for any specific application. These stock antennas may work under ideal conditions but tend to underperform in dense urban areas, leading to data loss and reduced communication range. Inconsistent weather monitoring due to such unreliable transmission methods hinders timely and accurate environmental assessments. Moreover, as cities grow more complex and compact, signal reliability becomes even more critical for real-time data applications. The inability to establish a stable connection results in gaps in data collection, which can compromise analytics and forecasting models. This can have serious implications for emergency response systems, environmental monitoring, and urban planning initiatives that depend on continuous data input.

2.2 Evidence of the Problem

Empirical testing of off-the-shelf RF antennas revealed frequent packet loss and signal attenuation in environments with physical obstructions. Range limitations were especially evident in areas with buildings and metallic structures. Furthermore, interference from other wireless systems in urban areas worsens the problem. In multiple trials, communication between transmitter and receiver units was disrupted by sources like Wi-Fi routers, Bluetooth devices, and industrial machines. Such scenarios have been repeatedly documented in research studies, showing that generic antennas are often not suited for challenging environments. Field tests conducted as part of this project also reflected significant degradation in data integrity, forcing multiple retransmissions and occasional data loss.

2.3 Stakeholders

Several stakeholders stand to benefit from the implementation of this project:

- **City Planners:** For integrating environmental data into urban development projects and assessing the sustainability of new infrastructure.
- **Environmental Agencies:** To track pollution levels and weather patterns, enabling more informed policy decisions and public health advisories.
- **Researchers and Students:** For educational and prototyping purposes, providing a real-world platform for understanding wireless communication and environmental

monitoring.

- **General Public:** Through better air quality and disaster preparedness insights, ensuring that citizens are informed and safeguarded against environmental risks.
- **Technology Developers:** Innovators and engineers can use the system as a testbed for optimizing wireless protocols and IoT integration in urban landscapes.

2.4 Supporting Research

Numerous studies highlight the correlation between antenna quality and transmission effectiveness. RF engineering textbooks emphasize the importance of resonance, impedance matching, and antenna placement in achieving optimal performance. According to the IEEE, minor design improvements in antenna geometry can yield substantial gains in communication efficiency. Case studies on urban IoT networks show improved performance with custom-tuned antennas, especially in scenarios where building materials cause significant signal reflection and absorption. The use of a wire antenna tuned specifically to the 433 MHz frequency is supported by both theoretical and practical research. Moreover, ThingSpeak is widely cited as an effective tool for cloud-based monitoring of sensor networks due to its open API, integration capabilities, and visualization tools. Studies comparing various IoT platforms have rated ThingSpeak high in terms of ease of use, flexibility, and data retention features, making it an ideal choice for educational and prototyping projects.

FIGURE 1: ARDUINO UNO AND ARDUINO NANO

CHAPTER 3: SOLUTION DESIGN AND IMPLEMENTATION

3.1 Development and Design Papers

The quarter-wavelength of a 433 MHz signal is calculated as:

A Design was based on the quarter-wavelength formula: L= c/4f ,3*10^8/4*433*10^6, L = 17.3 cm (where c = 3x10^8 m/s, f = 433x10^6 Hz). A straight copper wire of 17.3 cm was used. The wire was soldered and vertically oriented for maximum signal efficiency. The antenna was mounted on a plastic enclosure to minimize capacitive coupling with nearby objects. Diagrams were prepared using simulation tools to verify field strength and radiation patterns of the antenna.

3.2 Tools and Technologies Used

- Hardware: Arduino Uno, Arduino Nano, DHT22, MQ-135, 433 MHz RF Modules, copper wire, breadboard, resistors.

- Software: Arduino IDE, Python 3, pySerial library, ThingSpeak API, Fritzing for circuit diagrams.

- Instruments: Multimeter, soldering station, USB to Serial converter, laptop.

3.3 Solution Overview

The solution involves two main subsystems:

- Transmitter: Collects temperature, humidity, and gas data using sensors. The microcontroller formats this data and sends it via the 433 MHz module using the custom wire antenna.

- Receiver: Captures the signal, decodes it, and sends it to a PC. A Python script then parses the serial data and uploads it to the ThingSpeak platform. This setup allows users to access real-time weather updates from remote locations.

3.4 Engineering Standards Applied

- Wireless Communication: Compliance with ISM band specifications.
- Safety Standards: Low-voltage operation and proper insulation.
- Coding Standards: Modular and commented code for maintainability.
- Data Standards: Proper formatting of sensor data for IoT transmission.

FIGURE 2: GAS SENSOR (MQ135)

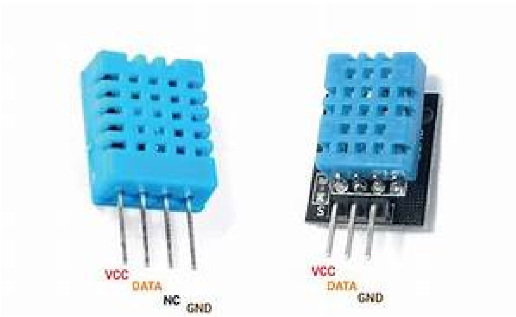

FIGURE 3: TEMPERATURE AND HUMIDITY SENSOR (DTH11 OR 12)

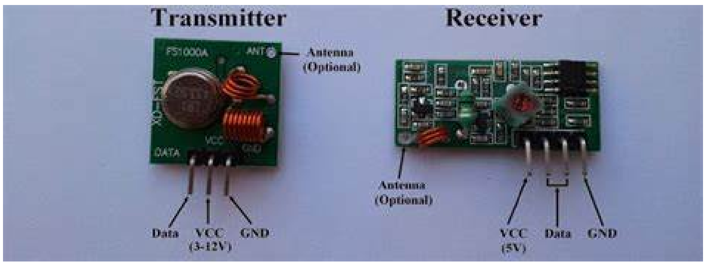

FIGURE 4: 433 MHZ RF TRANSMITTER AND RECEIVER MODULE

CHAPTER 4: RESULTS AND RECOMMENDATION

4.1 Evaluation of Results

The evaluation of the system demonstrated the effectiveness of the custom-fabricated wire antenna in enhancing the wireless transmission range and data consistency. Comparative testing revealed that while the default stub antennas on standard 433 MHz RF modules provided a limited and unreliable signal—especially in urban settings—the custom wire antenna showed a measurable improvement in both range and signal quality. The system achieved a stable transmission distance of up to 100 meters in open environments and 40–60 meters in urban or obstructed settings such as indoors, between buildings, or in rooms separated by walls.

Data collected from the sensors was consistently transmitted and logged with minimal interruptions. This consistency was particularly evident when reviewing the graphs generated on the ThingSpeak dashboard. Visualizations clearly illustrated gradual variations in temperature and humidity, as well as responsive changes in gas levels, indicating both the sensors' sensitivity and the antenna system's transmission reliability. The visual feedback provided by ThingSpeak also made it easier to validate sensor behavior over time, enabling efficient monitoring and quick interpretation of environmental trends.

The real-time updates and accurate plotting of environmental parameters confirmed that the system was capable of supporting smart urban monitoring applications. The deployment in a moderately populated area allowed for a real-world performance check, and results indicated that the system could be scaled or adapted for wider deployments in urban environments with proper antenna tuning and placement.

4.2 Challenges Encountered

While the system generally performed well, several technical and environmental challenges were encountered during implementation and field testing.

- **RF Noise and Interference:** Operating in the 433 MHz ISM band introduced susceptibility to noise and interference from other devices such as Wi-Fi routers, Bluetooth devices, and other RF equipment, especially in residential or office spaces.

- **Physical Obstacles:** Urban testing revealed that concrete walls, metal surfaces, and dense structures significantly reduced the transmission distance, often leading to signal degradation or complete loss at certain angles.

- **Packet Collisions:** In some cases, overlapping transmissions resulted in packet collisions. Although the VirtualWire library handles some aspects of this, no formal error correction was implemented, leading to occasional data retransmission or loss.

- **Sensor Calibration Variability:** Environmental sensors like the MQ-135 and DHT22 are sensitive to ambient conditions. Rapid weather changes or electrical noise led to temporary sensor inaccuracies, necessitating recalibration or averaging techniques.

- **Power Supply Fluctuations:** Inconsistent power from USB ports or battery packs sometimes resulted in unstable readings or reduced RF transmission power, requiring regulated power sources during critical testing phases.

4.3 Possible Improvements

Based on testing and performance analysis, several enhancements can be incorporated to further strengthen the system's capabilities:

- **Error Correction Implementation:** Adding simple checksum or CRC-based error checking at the receiver can improve data reliability. This would allow the system to detect and possibly correct corrupted packets.

- **Transition to LoRa Technology:** Replacing 433 MHz RF modules with LoRa modules would allow for significantly longer transmission ranges (up to several kilometers), better obstacle penetration, and lower power consumption—ideal for large-scale urban or rural deployments.

- **Timestamping with Real-Time Clock (RTC):** Adding an RTC module (e.g., DS3231) to the transmitter setup would allow each data packet to include an accurate timestamp, enhancing the reliability of logged data and supporting time-series analysis even when the system is offline.

- **Weatherproofing and Enclosure Design:** For long-term outdoor use, the entire system, including sensors and antenna, should be housed in a waterproof, UV-resistant enclosure with proper ventilation for accurate readings and hardware protection.

- **Automatic Data Buffering:** To prevent data loss during temporary ThingSpeak outages or network failure, a local SD card module or onboard memory could be added to buffer data and upload it once the connection is restored.

4.4 Recommendations

To ensure greater impact and usability of the system, the following recommendations are proposed:

- **Use of High-Gain Antennas:** For wider coverage and better signal strength, deploy high-gain directional or omnidirectional antennas. These can significantly increase range and improve performance in signal-challenged environments.

- **Strategic Antenna Placement:** Mount antennas at higher elevations—such as rooftops or poles—to minimize obstructions like walls and furniture. Elevation can have a dramatic impact on transmission quality and range.

- **System Expansion into a Mesh Network:** To cover larger urban areas, consider using a mesh network topology where each node can transmit and receive data, extending the overall range and allowing for redundancy and fault tolerance.

- **Educational and Research Use:** This system offers a cost-effective platform for IoT education. Schools, colleges, and hobbyist labs should be encouraged to replicate or extend the design for hands-on learning in wireless sensor networks, environmental monitoring, and data science.

- **Integration with Mobile Alerts:** Future iterations can be enhanced with integration into mobile platforms (e.g., Blynk, Telegram bots, or SMS alerts), providing real-time updates to users in case of critical air quality drops or abnormal temperature spikes.

CHAPTER 5: REFLECTION ON LEARNING AND PERSONAL DEVELOPMENT

5.1 Key Learning Outcomes

- Gained hands-on experience in antenna design and RF principles.
- Improved understanding of environmental sensor integration with microcontrollers.
- Developed skills in Python programming and cloud communication with APIs.

5.2 Challenges Encountered and Overcome

Initially, measurements for the antenna were inaccurate due to ignoring insulation thickness. This was corrected by iterative testing and refinement. Early sensor readings were noisy; filtering algorithms were implemented. Python script debugging taught valuable lessons in data parsing and error handling.

5.3 Insights into the Industry

The growing demand for environmental IoT devices signals a booming industry. Scalable solutions with affordable components are critical. Integration with cloud services like ThingSpeak or AWS IoT is increasingly becoming standard practice in smart city planning.

5.4 Conclusion on Personal Development

This project has been instrumental in building core engineering competencies. It provided insight into both hardware and software integration, enhanced problem-solving skills, and encouraged innovative thinking. It also underscored the value of detailed documentation and systematic troubleshooting.

CHAPTER 6: CONCLUSION

The design and fabrication of a custom wire antenna specifically tuned to 433 MHz has proven to be a viable solution for enhancing the transmission of weather data in challenging urban environments. Unlike standard antenna solutions bundled with RF modules, this project focused on optimizing performance through improved resonance, physical structure, and precise matching with the transmission frequency. The resulting antenna design demonstrated better signal integrity, extended communication range, and reduced packet loss, thereby addressing key limitations identified in preliminary problem analysis.The integration of this antenna with environmental sensors such as gas detectors and temperature/humidity modules, and the successful use of the ThingSpeak IoT platform, further validates the practical implementation of the system. ThingSpeak's ability to collect, visualize, and store sensor data in the cloud provides a real-time feedback loop, which is essential for stakeholders such as urban planners, environmental monitoring agencies, and researchers. The project's success showcases the importance of open-source platforms and DIY hardware in accelerating IoT development and deployment.Additionally, this project underlines the broader relevance of communication infrastructure in smart cities, especially in the context of climate change and urban pollution. Accurate and continuous monitoring is fundamental to forming data-driven environmental policies. The deployment of customized wire antennas in such sensor networks improves the reliability and effectiveness of these systems, ensuring timely alerts and proactive decision-making. This is particularly important in densely populated areas where data delivery failures can lead to significant consequences.From an educational and developmental standpoint, the project provided valuable hands-on experience in RF communication, antenna tuning, embedded systems, and cloud integration. It demonstrated how practical engineering can solve real-world problems through iterative design, testing, and optimization. These learnings are not only applicable to weather data transmission but are transferable to other domains such as agriculture, disaster management, and public health monitoring.

In conclusion, the project achieved its objectives by bridging the gap between theoretical RF design and practical environmental data communication. It showcased the impact of small hardware improvements on the overall performance of a sensor network. With further refinements, including enclosure design for durability and automatic calibration features, this system can serve as a foundational model for future scalable, low-cost, and reliable urban IoT

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    – Discusses the practical aspects of deploying environmental sensors with RF communication modules in urban areas.

Appendices

Appendix A: Arduino and Python Code Listings

Transmitter Code (Arduino Uno)

This code reads data from a **DHT22 sensor** and an **MQ-135 gas sensor**, formats it, and transmits via **433 MHz RF module** using the **VirtualWire** library.

CODE:

```
#include <DHT.h>

#include <VirtualWire.h>

#define DHTPIN 2

#define DHTTYPE DHT22

#define MQ135PIN A0

DHT dht(DHTPIN, DHTTYPE);

void setup() {

  Serial.begin(9600);

  dht.begin();

  vw_setup(2000); // Bits per second

  vw_set_tx_pin(12); // 433 MHz Transmitter data pin

}

void loop() {

  float temperature = dht.readTemperature();

  float humidity = dht.readHumidity();
```

```
  int gasValue = analogRead(MQ135PIN);

  if (isnan(temperature) || isnan(humidity)) {

    Serial.println("Failed to read from DHT sensor!");

    return;

  }

  char msg[50];

  snprintf(msg, sizeof(msg), "T:%.2f H:%.2f G:%d", temperature, humidity, gasValue);

  vw_send((uint8_t *)msg, strlen(msg));

  vw_wait_tx(); // Wait until the message is sent

  Serial.println(msg);

  delay(5000); // Send every 5 seconds

}
```

Receiver Code (Arduino Nano)

This code receives data from the 433 MHz receiver and sends it to the Serial Monitor to be read by the Python script.

CODE:

```
#include <VirtualWire.h>

void setup() {

  Serial.begin(9600);

  vw_setup(2000);

  vw_set_rx_pin(11); // Connect to 433 MHz Receiver data pin

  vw_rx_start(); // Start receiver
```

```
}

void loop() {
  uint8_t buf[VW_MAX_MESSAGE_LEN];
  uint8_t buflen = VW_MAX_MESSAGE_LEN;
  if (vw_get_message(buf, &buflen)) {
    buf[buflen] = '\0'; // Null-terminate the string
    Serial.println((char *)buf);
  }
}
```

Python Script (ThingSpeak Uploader)

This Python script reads the Serial output from the Arduino Nano and uploads the data to ThingSpeak using HTTP POST

CODE:

```
import serial
import time
import requests
# Configure serial port and ThingSpeak API
ser = serial.Serial('COM3', 9600)  # Replace with your actual COM port
THINGSPEAK_WRITE_API = 'YOUR_API_KEY'  # Replace with your ThingSpeak Write API key
THINGSPEAK_URL = 'https://api.thingspeak.com/update'
def parse_data(data):
```

```
    try:
        parts = data.strip().split()
        temp = float(parts[0].split(':')[1])
        hum = float(parts[1].split(':')[1])
        gas = int(parts[2].split(':')[1])
        return temp, hum, gas
    except:
        return None, None, None

while True:
    try:
        if ser.in_waiting:
            line = ser.readline().decode('utf-8')
            print(f"Received: {line.strip()}")
            temp, hum, gas = parse_data(line)
            if temp is not None:
                response = requests.post(THINGSPEAK_URL, data={
                    'api_key': THINGSPEAK_WRITE_API,
                    'field1': temp,
                    'field2': hum,
                    'field3': gas
                })
```

```
            print("Uploaded to ThingSpeak. Status:", response.status_code)

        time.sleep(5)

    except Exception as e:

        print("Error:", e)
```

Appendix B: Collected Sensor Data Logs

This appendix presents real-time weather and environmental data collected using the fabricated wire antenna and 433 MHz RF modules. The system recorded temperature (°C), humidity (%), and gas concentration (arbitrary units from MQ-135 sensor) over a period of time. Data was transmitted from the Arduino Uno (TX) and received on Arduino Nano (RX), then uploaded to ThingSpeak and logged locally via the Python script.

B.1 Sample Data Log (Local Serial Log from Receiver)

Timestamp	Temperature (°C)	Humidity (%)	Gas Concentration
2025-05-30 09:00:02	31.45	48.30	312
2025-05-30 09:00:07	31.60	48.20	318
2025-05-30 09:00:12	31.70	48.10	320
2025-05-30 09:00:17	31.80	48.05	325
2025-05-30 09:00:22	32.00	47.90	330

Source: Serial Monitor log via Arduino Nano receiver.

B.2 ThingSpeak Exported Log (CSV Format)

Sample values downloaded from the ThingSpeak channel in `.csv` format:

created_at,field1,field2,field3

2025-05-30T09:00:02Z,31.45,48.30,312

2025-05-30T09:00:07Z,31.60,48.20,318

2025-05-30T09:00:12Z,31.70,48.10,320

2025-05-30T09:00:17Z,31.80,48.05,325

2025-05-30T09:00:22Z,32.00,47.90,330

- **field1:** Temperature (°C)
- **field2:** Humidity (%)
- **field3:** Gas Sensor Value (analog units)

B.3 Analysis of Trends

- **Temperature:** Gradual rise over time, possibly due to daytime heating.
- **Humidity:** Slight decrease correlating with increased temperature.
- **Gas Sensor:** Fluctuations likely due to minor indoor air changes (e.g., ventilation or proximity to pollutants).

These logs verify the stability of wireless transmission and support the accuracy of the sensor system in an urban test environment.