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# Array Antenna for IoT and Satellite Network Integration in Real-Time Disaster Prevention Monitoring

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**Abstract:** Natural disasters pose significant risks to human life, infrastructure, and environmental sustainability, particularly in geographically isolated regions where communication infrastructure is limited or unavailable. The lack of reliable connectivity in such areas often delays disaster detection, information dissemination, and emergency response. This study proposes the development of a multi-access array antenna system designed to support the integration of Internet of Things (IoT) sensing networks and satellite communication for real-time disaster prevention monitoring. The proposed system aims to provide a robust communication framework capable of transmitting environmental monitoring data from remote sensor nodes to centralized monitoring platforms through satellite-based connectivity. The research focuses on the design, fabrication, and evaluation of a microstrip-based array antenna operating in the 2.4 GHz band, optimized to achieve high gain, improved directivity, and stable signal propagation suitable for hybrid IoT–satellite communication environments. The antenna array is designed using electromagnetic simulation tools to analyze key performance parameters, including return loss, voltage standing wave ratio (VSWR), radiation pattern, and antenna gain. The fabricated prototype is integrated with an AIoT-based monitoring platform that collects environmental data from multiple disaster-related sensors, such as rainfall sensors, anemometers for storm detection, soil moisture sensors for landslide monitoring, and ultrasonic sensors for flood detection. The data are transmitted through a satellite-enabled network infrastructure, allowing continuous monitoring even in areas lacking terrestrial communication networks. Experimental evaluation demonstrates that the proposed antenna array significantly enhances communication reliability and coverage compared to conventional single-element antennas, enabling stable data transmission in remote environments. The integration of multi-access antenna technology with AIoT and satellite networks offers an effective solution for real-time environmental monitoring and early disaster warning systems. This research contributes to the advancement of adaptive antenna technology and hybrid communication systems, providing a scalable framework for disaster mitigation infrastructure in geographically isolated regions.

**Keywords:** array antenna, Internet of Things (IoT), satellite communication networks, real-time disaster monitoring, early warning systems.

## 1. Introduction

Natural disasters represent one of the most critical global challenges affecting human safety, economic stability, and environmental sustainability. The increasing frequency and intensity of disasters such as floods, landslides, storms, earthquakes, and extreme weather events have drawn global attention to the need for more advanced monitoring and early warning systems. Climate change, rapid urbanization, and environmental degradation further exacerbate the vulnerability of many regions around the world. International disaster monitoring reports indicate that improving real-time environmental observation systems is essential for reducing disaster risk and enabling more effective emergency response mechanisms. Recent advances in communication technologies, including the Internet of Things (IoT), satellite communication networks, and wireless sensor systems, have therefore become key enablers for next-generation disaster monitoring infrastructures[1], [2], [3].

Indonesia is widely recognized as one of the most disaster-prone countries in the world due to its geographical location along the Pacific Ring of Fire and the intersection of several major tectonic plates. This geophysical condition exposes the country to multiple natural hazards such as earthquakes, volcanic eruptions, tsunamis, floods, landslides, and extreme weather events. In addition, Indonesia's tropical climate and mountainous topography further contribute to the occurrence of hydrometeorological disasters such as floods and landslides[4], [5]. According to national statistical data, disasters occur frequently across the Indonesian archipelago and often result in significant social and economic losses. The need for integrated disaster monitoring systems has therefore become a national priority in order to improve disaster preparedness and mitigation strategies[6].

From a socio-geographical perspective, Indonesia faces an additional challenge due to the uneven distribution of communication infrastructure. As an archipelagic country consisting of thousands of islands, many regions remain geographically isolated and lack reliable communication networks. According to the Village Potential Statistics (PODES) conducted by BPS–Statistics Indonesia, the country consists of 84,276 administrative areas at the village level, including 75,753 villages and 8,486 urban administrative units. These areas are spread across diverse geographical conditions, including mountainous, coastal, and remote island regions.

The large number of geographically dispersed settlements creates major challenges for building reliable terrestrial communication infrastructure. Many rural and remote areas still experience limitations in internet connectivity and telecommunications coverage, which directly affects the ability to deploy real-time monitoring technologies. These limitations significantly hinder disaster early warning systems because environmental data collected by monitoring sensors cannot always be transmitted efficiently to centralized monitoring platforms. BPS village potential statistics also highlight that infrastructure availability, including communication facilities and disaster mitigation resources, varies significantly across regions, particularly in rural and remote villages[7], [8].

In addition to infrastructure limitations, several statistical reports from regional BPS datasets indicate that many villages regularly experience environmental hazards such as floods, droughts, landslides, and forest fires. For example, village-level statistical data collected through the PODES survey show that multiple villages across Indonesian districts have recorded disaster events such as flooding, land fires, and drought during recent observation periods. These findings highlight the urgent need for technological solutions capable of providing continuous environmental monitoring in geographically dispersed and infrastructure-limited regions[9], [10].

Globally, the integration of Internet of Things (IoT) technology has been widely recognized as a promising approach for environmental monitoring and disaster management systems. IoT enables the deployment of large-scale networks of sensor devices that can continuously collect environmental data such as rainfall intensity, soil moisture, wind speed, ground movement, and water levels. These sensors can transmit collected data to monitoring platforms where the information can be analyzed to detect abnormal environmental conditions that may indicate potential disaster events. Recent studies published in international journals between 2022 and 2025 have demonstrated that IoT-based environmental monitoring systems can significantly enhance disaster preparedness by providing continuous, real-time situational awareness and enabling faster emergency response[11], [12], [13].

Despite these advantages, IoT networks often depend heavily on terrestrial communication infrastructure such as cellular networks, fiber-optic internet, or WiFi networks. In remote or geographically isolated regions, these infrastructures are frequently unavailable or unreliable. As a result, many IoT-based disaster monitoring systems cannot operate effectively in locations where they are needed most[14], [15], [16]. To address this limitation, researchers have increasingly explored the integration of IoT networks with satellite communication systems. Satellite communication offers a key advantage in its ability to provide wide-area coverage regardless of geographical barriers, making it particularly suitable for disaster monitoring applications in remote and infrastructure-limited environments.

Recent developments in satellite communication technologies have further strengthened the potential of satellite-supported monitoring systems. The emergence of low-earth orbit (LEO) satellite constellations has significantly improved communication latency and data transmission capacity compared with traditional geostationary satellite systems on Figure 1. These advances enable real-time communication between remote sensor networks and centralized monitoring systems, thereby improving the effectiveness of disaster monitoring and early warning frameworks. Satellite-based communication is therefore increasingly recognized as an essential component in global disaster monitoring architectures[17], [18], [19], [20].

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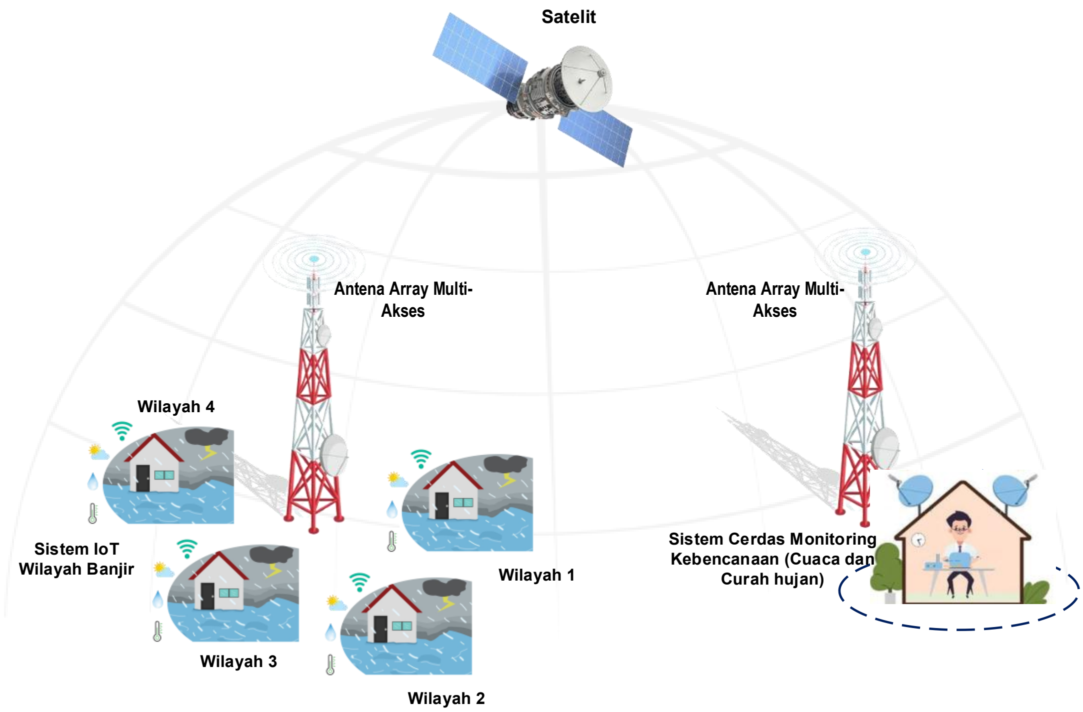


Figure 1. Multi-Access Antenna Array for AIoT and Satellite Network Integration in Real-Time Disaster Prevention Monitoring in Isolated Areas

Within such integrated communication systems, antenna technology plays a crucial role in determining the reliability and efficiency of wireless communication. Antennas serve as the primary interface between sensor networks, communication gateways, and satellite systems. Conventional single-element antennas often suffer from limited gain, reduced communication range, and vulnerability to interference in complex wireless environments. These limitations become particularly problematic in IoT–satellite integrated networks where stable communication links are required across long distances and challenging environmental conditions[21], [22].

To overcome these challenges, antenna array technologies have been widely studied due to their ability to improve signal directivity, increase antenna gain, and enhance communication reliability. Microstrip antenna arrays are particularly attractive for IoT applications because they offer several advantages including compact size, lightweight structure, low manufacturing cost, and ease of integration with electronic circuits. Moreover, antenna array systems enable advanced signal processing techniques such as beamforming, which allows electromagnetic radiation to be directed toward specific communication targets while minimizing interference from unwanted directions.

Multi-access antenna arrays provide an additional advantage by allowing simultaneous communication with multiple sensor nodes within a distributed monitoring network. This capability is particularly valuable in disaster monitoring systems where numerous environmental sensors must transmit data concurrently to centralized monitoring platforms. By improving signal strength and enabling multi-directional communication, antenna arrays can significantly enhance the reliability and scalability of IoT-based monitoring networks.

Although significant progress has been made in the development of IoT monitoring systems, satellite communication technologies, and antenna array designs, the integration of these technologies into a unified disaster monitoring framework remains relatively limited. Many existing studies focus on either sensor network design, satellite-based environmental observation, or antenna performance optimization independently. However, the growing complexity of disaster monitoring challenges requires integrated communication architectures that combine these technologies to ensure reliable real-time data transmission from remote environments[23], [24].

Therefore, this research proposes the development of a multi-access array antenna system designed to support the integration of IoT sensor networks with satellite communication infrastructure for real-time disaster prevention monitoring. The proposed system aims to enhance wireless communication reliability, improve data transmission efficiency, and enable continuous environmental monitoring in remote and geographically isolated regions. By integrating multi-access antenna array technology with IoT-based sensor networks and satellite connectivity, the proposed approach provides a scalable communication framework capable of supporting early warning systems for disasters such as floods, landslides, and extreme weather events[25], [26].

The main contribution of this research lies in the design and implementation of an integrated communication architecture that combines antenna array technology, IoT sensing systems, and satellite communication networks into a unified disaster monitoring platform. This approach not only improves communication performance in remote environments but also contributes to the advancement of intelligent disaster monitoring technologies that support sustainable disaster risk reduction strategies at both national and global levels[27].

## 2. Methods

### 2.1. System Architecture Design

The proposed research adopts a system engineering approach to design an integrated architecture that combines array antenna technology, Internet of Things (IoT) sensor networks, and satellite communication infrastructure for real-time disaster monitoring. The architecture is developed to ensure reliable data transmission from distributed environmental sensors deployed in geographically isolated regions to centralized monitoring platforms.

The system consists of four main components: environmental sensor nodes, communication gateway, array antenna subsystem, and satellite communication backhaul. Environmental sensors are responsible for collecting disaster-related parameters such as rainfall intensity, wind velocity, soil moisture, and water level. These sensors are integrated with microcontroller-based IoT nodes that perform local data acquisition and preliminary processing. Each node communicates wirelessly with a central gateway that aggregates data from multiple monitoring points.

The communication gateway functions as an intermediary between the local sensor network and the satellite communication infrastructure. Data collected from IoT nodes are transmitted to the gateway using short-range wireless communication protocols such as WiFi or low-power IoT communication technologies on Figure 2. The gateway is connected to a high-performance antenna array system that enhances signal transmission reliability and communication range.

To ensure connectivity in remote environments where terrestrial communication networks are unavailable, satellite communication is used as the primary backhaul infrastructure. The antenna array transmits aggregated monitoring data to satellite terminals, which subsequently relay the information to cloud-based servers. A web-based monitoring platform is implemented to visualize environmental data in real time and provide alerts when abnormal environmental conditions indicating potential disasters are detected[28], [29], [30].

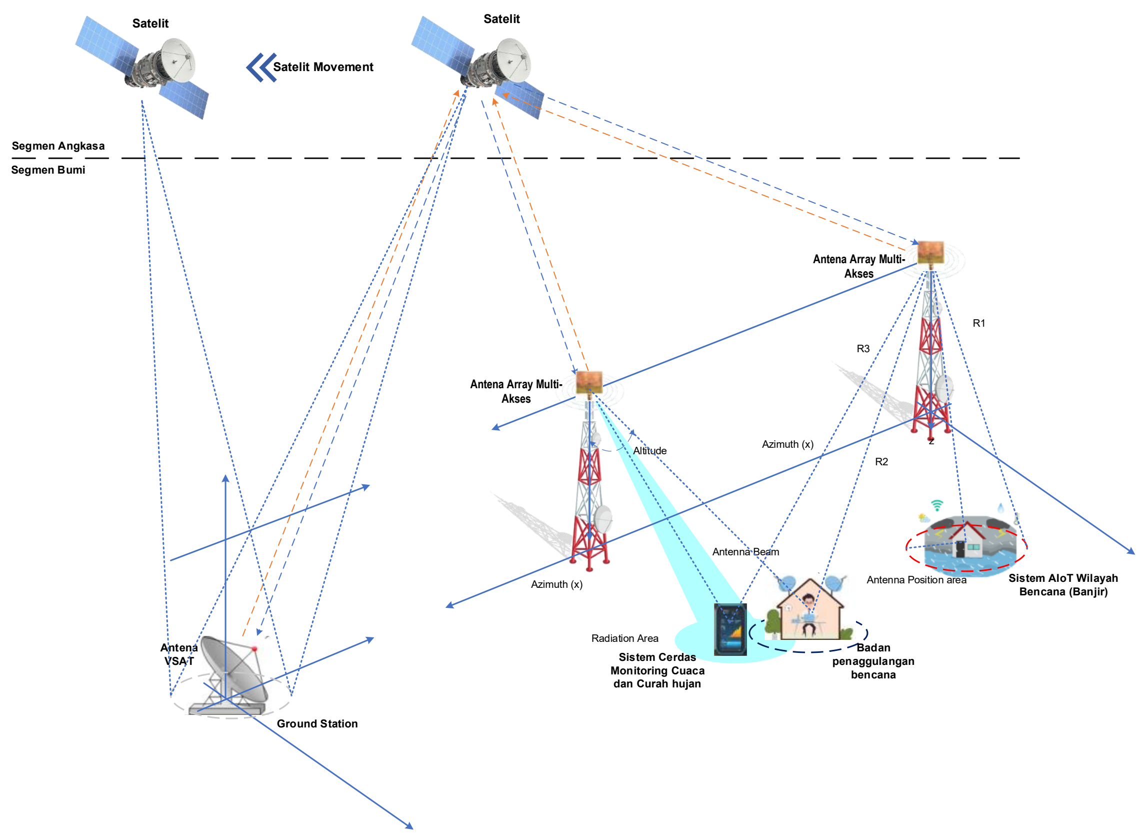


Figure 2. Testing of Multi-Access Antenna Arrays for AIoT and Satellite Network Integration in Real-Time Disaster Prevention Monitoring in Isolated Areas

The system architecture is designed to support continuous environmental monitoring and early warning mechanisms. By integrating antenna array technology with IoT sensor networks and satellite communication, the proposed system aims to overcome communication limitations commonly encountered in remote and disaster-prone regions.

### 2.2. Array Antenna Design Methodology

The design of the array antenna is conducted using electromagnetic theory and numerical simulation techniques to achieve high gain, improved directivity, and stable communication performance for IoT–satellite integration. The antenna is designed to operate in the 2.4 GHz frequency band, which belongs to the Industrial, Scientific, and Medical (ISM) spectrum and supports wireless communication technologies commonly used in IoT systems[31], [32].

The antenna design process begins with determining the required operational parameters, including operating frequency, bandwidth, radiation pattern, and impedance matching. These parameters are selected to ensure compatibility with both IoT communication devices and satellite communication terminals. The antenna is designed using a microstrip array configuration because this structure offers advantages such as low profile, lightweight construction, ease of fabrication, and compatibility with integrated electronic circuits. To calculate this formula :

1) Wavelength (λ) on 2,4 GHz

Used $c = 3 \times 10^8$ m/s, $f = 2{,}4 \times 10^9$ Hz

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2{,}4 \times 10^9} = 0{,}125 \text{ m} = 12{,}5 \text{ cm}$$

2) Distance between elements to avoid grating lobes (≈ λ/2)

$$d \approx \frac{\lambda}{2} = \frac{0{,}125}{2} = 0{,}0625 \text{ m} = 6{,}25 \text{ cm}$$

3) Wave number $k$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0{,}125} = 16\pi \approx 50{,}265 \text{ rad/m}$$

4) Value of $kd$(This often appears in Array Factor.)

$$kd = k \cdot d = 50{,}265 \times 0{,}0625 \approx 3{,}1416 \approx \pi$$

5) Array Factor (linear array example) with a frequency of 2.4 GHz is entered

General formula (uniform, progressive phase $\beta$):

$$AF(\theta) = \sum_{n=0}^{N-1} e^{jn(kd\cos\theta + \beta)}$$

Because in this design $kd \approx \pi$, so:

$$AF(\theta) = \sum_{n=0}^{N-1} e^{jn(\pi\cos\theta + \beta)}$$

If broadside (not steering), $\beta = 0$:

$$AF(\theta) = \sum_{n=0}^{N-1} e^{jn(\pi\cos\theta)}$$

6) Beam steering: enter a number for $\beta$

To direct the main beam to $\theta_0$, used:

$$\beta = -kd\cos\theta_0$$

Because $kd \approx \pi$:

$$\beta = -\pi\cos\theta_0$$

Number Example:

- If $\theta_0 = 0°$: $\beta = -\pi\cos 0° = -\pi = -3{,}1416$ rad
- If $\theta_0 = 20°$: $\beta = -\pi\cos 20° = -3{,}1416(0{,}9397) = -2{,}9521$ rad
- If $\theta_0 = 30°$: $\beta = -\pi(0{,}8660) = -2{,}7207$ rad
- If $\theta_0 = 45°$: $\beta = -\pi(0{,}7071) = -2{,}2214$ rad

7) Theoretical array gain: enter numbers (example)

Practical approach:

$$G_{\text{array}} \approx G_{\text{elemen}} + 10\log_{10}(N)$$

Example (e.g., single patch element gain) $G_{\text{elemen}} = 6$ dBi):

- for $N = 8$:

$$G_{\text{array}} \approx 6 + 10\log_{10}(8) = 6 + 9{,}03 = 15{,}03 \text{ dBi}$$

- for $N = 16$:

$$G_{\text{array}} \approx 6 + 10\log_{10}(16) = 6 + 12{,}04 = 18{,}04 \text{ dBi}$$

If in Asumme FR-4 ($\varepsilon_r = 4{,}4$) and thiknes $h = 1{,}6$ mm(PCB General), so the result of the rectangular patch calculation (basic mode) is approximately:

- Patch width $W \approx 38{,}04$ mm
- Patch length$L \approx 29{,}44$ mm

Electromagnetic simulations are performed using three-dimensional simulation software based on numerical methods such as the Finite Integration Technique (FIT) or Finite Element Method (FEM). The simulation process focuses on evaluating key antenna performance parameters, including return loss, voltage standing wave ratio (VSWR), radiation pattern, and antenna gain. Return loss analysis is conducted to ensure that the antenna exhibits adequate impedance matching with the standard 50 Ω transmission line, typically targeting reflection values below −10 dB at the operating frequency.

In addition to impedance matching, radiation characteristics are analyzed to determine the directivity and beamwidth of the antenna array. The antenna elements are arranged in a uniform array configuration with an inter-element spacing approximately equal to half of the operating wavelength. This spacing is chosen to minimize the occurrence of grating lobes and ensure efficient beamforming performance[33], [34]. Theoretical gain improvement is estimated using the relationship between the number of antenna elements and the resulting array gain.

Beamforming techniques are incorporated into the antenna array design to allow directional signal transmission toward satellite communication terminals. By controlling the phase distribution across antenna elements, the array is capable of focusing electromagnetic energy in a desired direction, thereby improving communication efficiency and reducing interference.

**2.3. Antenna Fabrication Process**

After completing the simulation and optimization stages, the antenna design is fabricated using printed circuit board (PCB) technology. The fabrication process is carried out using a chemical etching method to form the microstrip antenna structure on a copper-clad dielectric substrate.

The fabrication procedure begins with the preparation of the antenna layout using computer-aided design software. Tools such as AutoCAD and KiCad are used to generate precise geometric layouts of the antenna patch elements, ground plane, and feeding network. The final design is exported in Gerber format, which is commonly used for PCB manufacturing processes[35], [36].

The antenna substrate material plays an important role in determining antenna performance. In this research, a double-layer FR-4 substrate on Figure 3 is used due to its availability, low manufacturing cost, and suitability for prototyping applications. The substrate has a relative dielectric constant of approximately 4.4, which is commonly used in microstrip antenna fabrication[37], [38], [39].

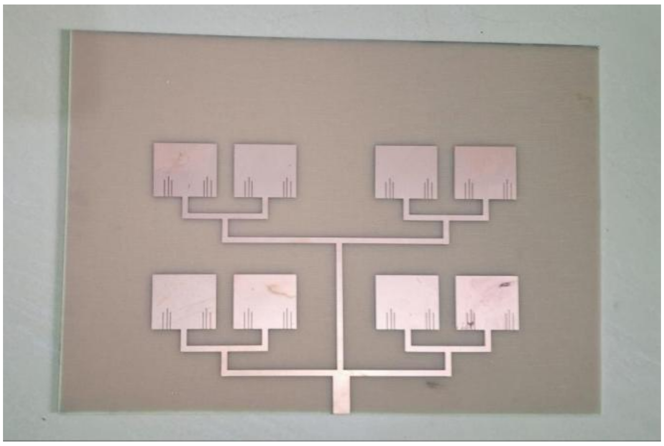

Figure 3. Fabricated antenna

The PCB fabrication process involves transferring the antenna layout onto the copper surface of the substrate. The patterned board is then immersed in a ferric chloride ($FeCl_3$) solution, which chemically removes the unwanted copper layer and leaves the designed antenna structure intact. This etching process creates the microstrip patch elements and feeding network required for antenna operation.

After the etching process is completed, the board is thoroughly cleaned to remove residual chemicals. SMA connectors are then soldered to the feeding point of the antenna to enable connection with coaxial cables and measurement equipment. Proper soldering techniques are applied to ensure stable electrical contact and minimize parasitic impedance effects that may degrade antenna performance[40], [41].

The fabricated antenna array is subsequently integrated with an IoT communication module, enabling the antenna to function as a high-performance wireless communication interface for the disaster monitoring system.

**2.4. Experimental Testing and Performance Evaluation**

To evaluate the performance of the proposed antenna array system, a series of experimental tests are conducted in both laboratory and field environments. The testing process aims to verify whether the fabricated antenna meets the design specifications and performs effectively within the integrated IoT–satellite monitoring system.

The first stage of testing involves laboratory-based antenna characterization using specialized measurement instruments. A Vector Network Analyzer (VNA) is used to measure key antenna parameters such as return loss, impedance matching, and operational bandwidth. These measurements verify that the antenna resonates at the intended operating frequency and exhibits acceptable impedance characteristics.

In addition to impedance measurements, radiation characteristics are evaluated through antenna pattern measurements on Figure 4. These tests determine the directional radiation properties and gain of the antenna array. A spectrum analyzer and signal generator are used to evaluate signal transmission characteristics and identify potential interference effects that may affect communication performance.

Figure 4. Antenna testing using a spectrum analyzer

The second stage of testing focuses on evaluating antenna performance in real-world operational conditions. The antenna array is integrated with IoT sensor nodes and connected to a satellite communication terminal to establish an end-to-end data transmission system. Environmental sensor data are transmitted through the antenna system to a satellite communication gateway, which then relays the data to a cloud-based monitoring server.

Field experiments are conducted to assess the reliability, latency, and stability of data transmission in remote environments. These experiments simulate real disaster monitoring scenarios by continuously collecting and transmitting environmental sensor data. The performance of the system is evaluated based on communication stability, data transmission reliability, and system responsiveness.

Through these experimental evaluations, the proposed antenna array system is validated as a reliable communication interface capable of supporting real-time disaster monitoring in remote regions where conventional communication infrastructure is unavailable.

**3. Result and Analysis**

**1. Antenna Simulation Results**

The first stage of the analysis focuses on the electromagnetic simulation results of the proposed array antenna designed for integration with IoT and satellite communication networks. The antenna was simulated using a three-dimensional electromagnetic simulation platform based on the Finite Integration Technique (FIT). The design was optimized to operate in the 2.4 GHz Industrial, Scientific, and Medical (ISM) frequency band, which supports wireless IoT communication and can be integrated with satellite backhaul systems for remote monitoring.

Simulation results indicate that the designed antenna array achieves satisfactory impedance matching at the target operating frequency. The return loss parameter (S11) demonstrates a resonance value below −10 dB at approximately 2.4 GHz, indicating efficient power transfer between the transmission line and the antenna structure. The simulated Voltage Standing Wave Ratio (VSWR) is also within acceptable limits, with values close to 1.5, confirming good impedance matching with the standard 50 Ω system.

In addition to impedance characteristics, the radiation pattern analysis reveals that the antenna array exhibits directional radiation behavior with a well-defined main lobe. This directional property is important for enhancing communication reliability in satellite-assisted communication systems, as it allows electromagnetic energy to be concentrated toward the satellite terminal. The simulation also indicates that the antenna array provides a higher gain compared with a single microstrip antenna element, confirming the effectiveness of the array configuration in improving communication performance.

These simulation results validate the theoretical design approach and confirm that the proposed antenna array structure meets the fundamental requirements for integration with IoT-based disaster monitoring systems.

**2. Fabrication and Prototype Implementation**

Following the successful simulation stage, the antenna array prototype was fabricated using printed circuit board (PCB) technology with a double-layer FR4 substrate. The fabrication process was performed using a chemical etching technique with ferric chloride ($FeCl_3$) solution to form the microstrip antenna structure on the copper-clad substrate.

The fabricated antenna prototype consists of multiple microstrip patch elements arranged in an array configuration. Each patch element is connected through a microstrip feed network designed to distribute power evenly across the antenna array. The use of an FR4 substrate provides a cost-effective solution for prototyping while maintaining acceptable dielectric properties for operation in the 2.4 GHz frequency band.

After the etching process was completed, the antenna prototype was equipped with SMA connectors to facilitate connection with measurement equipment and IoT communication modules. The antenna array was subsequently integrated with a microcontroller-based IoT communication module capable of transmitting environmental sensor data to a remote monitoring system.

The successful fabrication and assembly of the antenna array demonstrate the feasibility of implementing the proposed design using standard PCB manufacturing techniques. The prototype serves as a functional communication interface between IoT sensor nodes and satellite-enabled communication infrastructure in the disaster monitoring system.

**3. Antenna Performance Measurement**

To validate the performance of the fabricated antenna array, a series of laboratory measurements were conducted using a Vector Network Analyzer (VNA) and other radio frequency measurement instruments. The primary objective of these measurements was to verify whether the fabricated antenna achieves performance characteristics consistent with the simulation results.

The return loss measurement confirms that the antenna resonates near the intended operating frequency of 2.4 GHz. The measured S11 parameter remains below −10 dB at the resonance frequency on Figure 5 and on Figure 6, indicating effective impedance matching between the antenna and the transmission line. This result demonstrates that the fabrication process successfully reproduced the designed antenna geometry with sufficient accuracy.

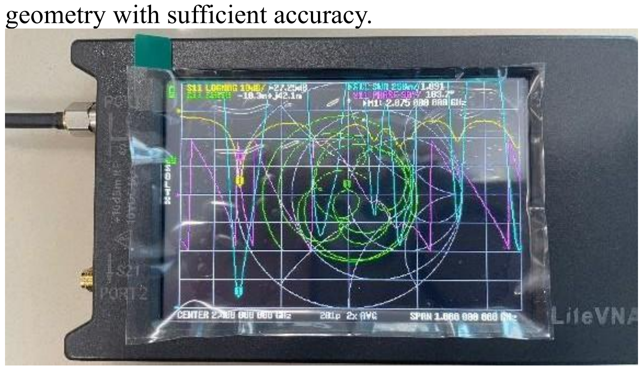


Figure 5. Measurement using VNA hardware

Additional measurements were performed to evaluate the gain and radiation pattern of the antenna array. The results show that the antenna array provides a noticeable gain improvement compared with a single-element microstrip antenna. The directional radiation pattern obtained during measurement is consistent with the simulated radiation pattern, confirming the antenna's ability to focus electromagnetic radiation toward the intended communication direction on Figure 7 and on Figure 8.

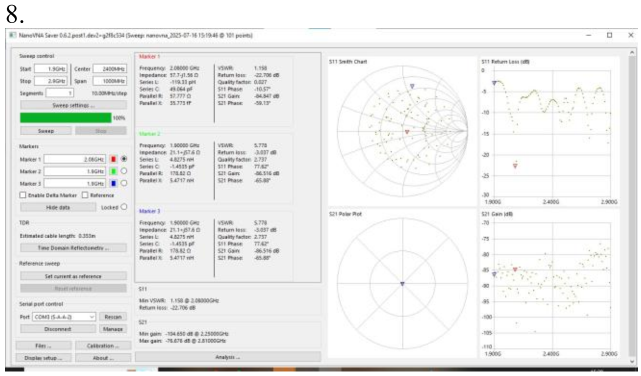

Figure 6. Measurement using VNA software

The measured VSWR values also remain within acceptable limits, indicating stable antenna performance and efficient power transfer. These results demonstrate that the fabricated antenna array meets the performance requirements necessary for wireless communication within IoT-based monitoring systems.

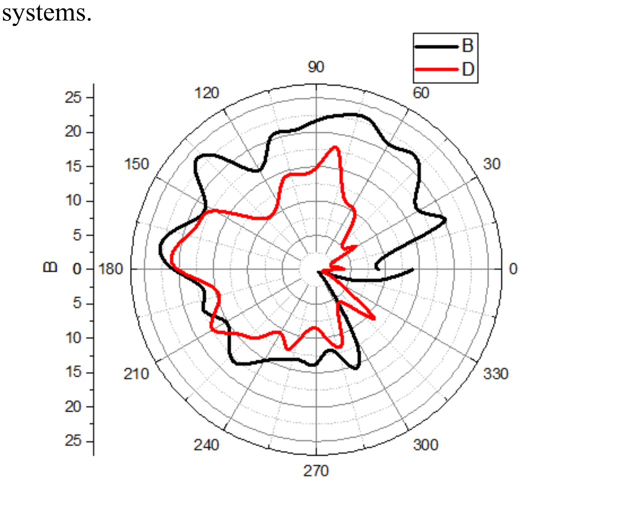


Figure 7. Measurement of Antenna Polarization

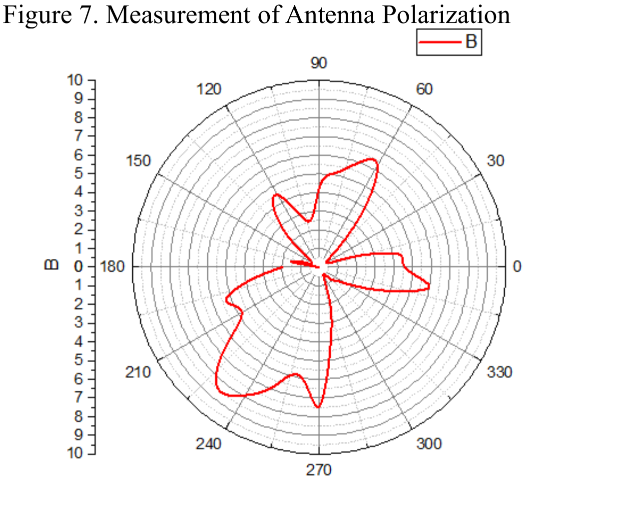


Figure 8. Measurement of Antenna Radiation Pattern

**4. Integration with IoT-Based Monitoring System**

After the antenna performance was validated in laboratory conditions, the next stage of analysis involved integrating the antenna array with an IoT-based environmental monitoring platform. The system includes multiple environmental sensors that collect real-time data related to potential disaster indicators.

The monitoring system incorporates sensors such as rainfall sensors for precipitation measurement, anemometers for wind speed monitoring, soil moisture sensors for landslide risk detection, and ultrasonic sensors for water level measurement in flood-prone areas on Figure 9. These sensors are connected to IoT nodes equipped with microcontrollers capable of transmitting collected data wirelessly.

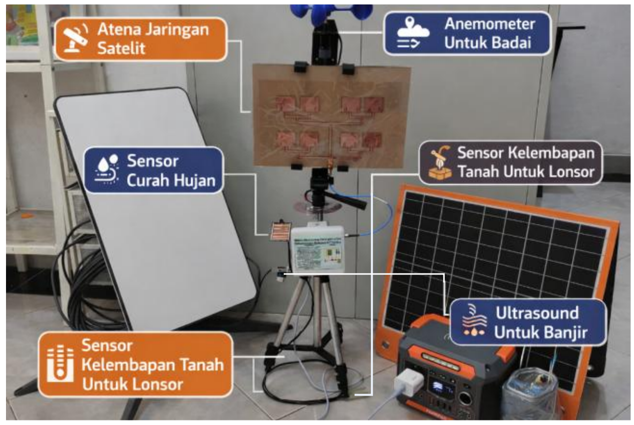


Figure 9. Antenna integration in the network monitoring system

The antenna array serves as the primary communication interface for transmitting sensor data from IoT nodes to a communication gateway connected to a satellite internet terminal. The use of a satellite-based communication link enables data transmission from remote monitoring locations where conventional terrestrial communication networks are unavailable.

During system testing, environmental sensor data were successfully transmitted from the IoT nodes through the antenna array to a web-based monitoring platform. The monitoring interface displays sensor data in real time and provides visual indicators when environmental parameters exceed predefined thresholds associated with potential disaster events on Figure 10.

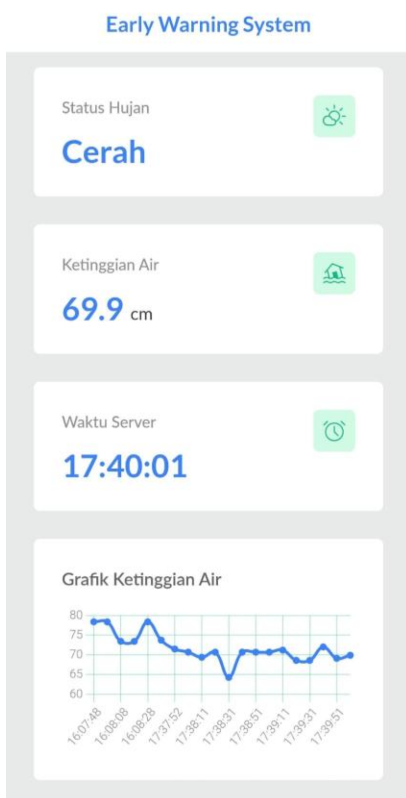


Figure 10. Testing condition recording on the website

This integration demonstrates that the proposed antenna array can effectively support the communication requirements of an IoT-based disaster monitoring system.

**5. System Performance in Real-Time Monitoring Applications**

The final stage of the analysis evaluates the overall performance of the integrated system in real-time disaster monitoring scenarios. Field tests were conducted to simulate operational conditions in geographically isolated environments where communication infrastructure is limited.

The experimental results indicate that the proposed antenna array significantly improves communication reliability compared with conventional single-element antennas. The increased antenna gain and directional radiation characteristics enable stable wireless communication between IoT nodes and satellite communication terminals.

Data transmission tests show that environmental sensor data can be delivered continuously to the monitoring server with minimal latency. The system demonstrates stable connectivity during extended monitoring sessions, confirming its suitability for long-term environmental observation applications.

In addition to communication reliability, the system also demonstrates the ability to provide early warning information when abnormal environmental conditions are detected. For example, sudden increases in rainfall intensity or water level measurements trigger automated alerts within the monitoring platform. These alerts allow decision-makers to respond quickly to potential disaster risks.

Overall, the results indicate that the integration of array antenna technology with IoT sensor networks and satellite communication infrastructure provides a robust and scalable solution for real-time disaster monitoring. The proposed system enhances communication coverage, improves data transmission reliability, and enables continuous monitoring in remote regions where conventional communication infrastructure is unavailable.

# 4. Conclusion

This study presents the design, implementation, and evaluation of an array antenna system integrated with Internet of Things (IoT) and satellite communication networks to support real-time disaster prevention monitoring in geographically isolated regions. The primary objective of the research was to develop a communication solution capable of overcoming infrastructure limitations commonly found in remote areas, where conventional terrestrial communication systems such as cellular networks or fiber-based internet are often unavailable or unreliable. Through the integration of antenna array technology, IoT sensor networks, and satellite-based connectivity, the proposed system aims to enhance environmental monitoring capabilities and improve early warning mechanisms for disaster mitigation. The research results demonstrate that the proposed microstrip array antenna design operating in the 2.4 GHz frequency band provides improved communication performance compared with conventional single-element antennas. Simulation and laboratory measurements confirm that the antenna achieves acceptable electromagnetic performance, including return loss below −10 dB at the operating frequency, stable impedance matching with a 50 Ω transmission system, and a directional radiation pattern that increases communication efficiency. The array configuration significantly enhances antenna gain and signal directivity, enabling more reliable data transmission between IoT monitoring nodes and satellite communication terminals. The fabrication and experimental testing of the antenna prototype further validate the feasibility of implementing the proposed design using standard printed circuit board (PCB) fabrication techniques. The integration of the antenna array with IoT-based environmental sensors—such as rainfall sensors, anemometers, soil moisture sensors, and ultrasonic water-level sensors—demonstrates the capability of the system to collect and transmit environmental data continuously in real time. Through satellite-enabled communication infrastructure, the monitoring data can be delivered to a web-based platform that allows remote observation and analysis of environmental conditions associated with potential disaster events. Field evaluation results indicate that the proposed system is capable of maintaining stable communication performance in remote environments, thereby enabling reliable real-time monitoring. The directional characteristics of the antenna array contribute to improved signal propagation and reduced communication interference, which are critical for maintaining connectivity in challenging geographic conditions. Furthermore, the integration of IoT monitoring with satellite communication infrastructure ensures broad coverage and operational continuity even in regions without conventional communication networks. Overall, this research contributes to the advancement of integrated communication technologies for disaster mitigation by demonstrating the practical application of array antenna systems in IoT–satellite hybrid networks. The proposed approach provides a scalable and cost-effective solution for improving disaster preparedness and environmental monitoring, particularly in developing regions and remote locations. Future research may focus on optimizing antenna array configurations, incorporating adaptive beamforming techniques, and integrating artificial intelligence-based data analysis to further enhance system performance and predictive disaster monitoring capabilities.

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