

Polarization Reconfigurable Dipole Antenna for FM Band Radio Spectrum Monitoring System

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Received: May 04, 2026; Revised: Jul 10, 2026; Accepted: Jul 23, 2026

Abstract

This paper presents the design and implementation of a polarization reconfigurable dipole antenna operating in the FM radio frequency band (88–108 MHz) for low-cost radio spectrum monitoring applications. The proposed antenna consists of two orthogonal radiating arms integrated with an electronically controlled switching network that enables selection between two linear polarization states. Simulated results show that the antenna achieves $|S_{11}|$ below –10 dB across the entire FM band, with stable omnidirectional radiation patterns and realized gains of approximately 1.7 dBi and 1.8 dBi for the two polarization modes. A prototype was fabricated and measured to validate the design. Measured results confirm acceptable impedance matching over the frequency range of 93–102 MHz, covering the core FM broadcast channels, while maintaining omnidirectional radiation characteristics and effective polarization switching. The minor frequency shift observed in measurements is attributed to fabrication tolerances and environmental effects. Owing to its simple structure, low fabrication cost, and reliable performance, the proposed antenna is well-suited for large-scale deployment in automated FM-band radio spectrum monitoring systems.

Keywords: Dipole antenna, FM band, Radio spectrum monitoring, Polarization reconfiguration, RF switching network.

1. Introduction

Wireless communication technologies have advanced rapidly, accompanied by the widespread availability of low-cost radio frequency (RF) devices. This trend has led to increasingly dense spectrum utilization, giving rise to challenges such as electromagnetic (EM) interference and unauthorized frequency usage, which can degrade communication performance and disrupt regulated services. These issues highlight the need for effective spectrum regulation and continuous RF monitoring. In Thailand, spectrum management is overseen by the Office of the National Broadcasting and Telecommunications Commission (NBTC), which requires reliable and continuous inspection of RF activities to ensure regulatory compliance. Consequently, the development of cost-effective and scalable radio spectrum monitoring systems is essential for detecting interference, identifying illegal transmissions, and supporting efficient spectrum management [1]. Therefore, automated RF monitoring systems have become essential for enabling continuous and reliable spectrum surveillance and regulatory enforcement.

An automated RF monitoring system typically comprises several key components, as shown in Figure 1 [2–5], including RF sensing and monitoring equipment, a communication network for data transmission, and a centralized control and processing center. The RF sensing and monitoring equipment is responsible for receiving, measuring, and processing RF signals prior to transmitting the acquired data to the central control center through the communication network. Within this subsystem, the antenna serves as the primary receiving element for RF signals or EM waves and thus plays a critical role in determining the overall performance and reliability of the RF monitoring system. The communication network

provides the link between the RF monitoring subsystem and the central control center and may leverage either local infrastructure or services offered by commercial communication providers. The central command center oversees and supervises the operation of the entire RF monitoring system and serves as the primary unit for data processing and system coordination. It typically incorporates user interfaces that enable authorized personnel or regulatory organizations to control and manage radio frequency usage. The system's data storage includes collected RF measurements, system status information, and historical usage records. These data can be utilized for regulatory enforcement, legal evidence, and the development of analytical or intelligent algorithms to support spectrum management and decision-making.

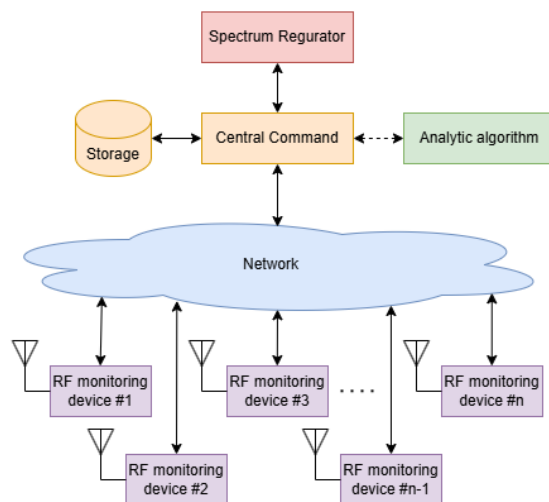


Figure 1. System architecture of an automated RF monitoring system.

As EM waves propagate from a transmitting station to an RF monitoring system, they are subjected to diverse and complex propagation environments. During transmission, various physical phenomena, including reflection, diffraction, refraction, and unknown properties of the transmitter, may occur due to interactions with surrounding objects and terrain. These effects can lead to variations in signal attenuation, polarization state, and propagation direction upon reception. Consequently, the characteristics of the received signal at the monitoring site are often unpredictable and environment-dependent. Therefore, the antenna becomes a critical component in enhancing the overall signal reception performance of the RF monitoring system. Since the polarization of the incident EM wave at the installation location cannot be known a priori and cannot be effectively compensated for through post-processing or system-level adjustments, the development of a polarization reconfigurable antenna is highly desirable. Such an antenna can adapt to varying polarization conditions, thereby improving reception reliability and robustness under practical deployment scenarios. It is noted that the antenna is required to exhibit an omnidirectional radiation pattern to effectively cover the monitoring area, while also supporting multiple polarization states [5],[6].

Based on the review of related literature, it is evident that antenna selection in RF monitoring systems varies according to the specific objectives of each system. For systems primarily focused on direction finding (DF) and source localization, DF antenna systems are commonly employed. Such systems typically combine multi-element directional antennas with omnidirectional antennas to enable both wide-area spectrum surveillance and accurate directional estimation. For example, one reported implementation utilizes three 5-element directional antenna systems in conjunction with 2 omnidirectional antennas, providing effective support for spectrum monitoring as well as directional signal processing [4]. In contrast, distributed and remote RF monitoring systems often adopt broadband omnidirectional antennas to ensure continuous coverage over wide frequency ranges and surrounding areas. A representative example is the use of the AX-71C disccone antenna, which offers broadband omnidirectional characteristics suitable for spectrum monitoring applications where directional localization is not the primary requirement [5]. For applications that require monitoring interference over large geographical areas with multiple simultaneous signal sources, antenna array systems are employed to enhance spatial discrimination and signal characterization. An illustrative case is a radio frequency interference (RFI) monitoring system that incorporates a 30-element antenna array, enabling simultaneous multi-channel and multi-polarization monitoring under real-world operating conditions [6]. Furthermore, some studies focus on the development

of integrated antenna systems designed to achieve extremely wide frequency coverage by combining different antenna types. For instance, a hybrid antenna configuration employing a log-periodic antenna for low-to-mid frequency bands together with a horn antenna for higher frequency bands has been proposed to provide comprehensive spectrum monitoring capability. Such systems also support polarization and directional adjustment to adapt to varying measurement environments [7]. Overall, the reviewed works demonstrate that antenna configurations in RF monitoring systems are closely aligned with system functionality, ranging from directional antenna systems for source localization, omnidirectional antennas for general spectrum surveillance, antenna arrays for spatially resolved monitoring, to integrated multi-antenna solutions for wideband applications. Nevertheless, these systems remain subject to uncertainties in signal polarization and propagation effects in practical environments, which motivates further research into antenna designs with enhanced polarization adaptability for automated RF monitoring systems.

To provide a clearer motivation for polarization reconfiguration in the specific context of FM-band monitoring, it is useful to consider practical deployment scenarios. In a typical urban or suburban environment, FM broadcast signals are predominantly transmitted with vertical polarization from licensed stations. However, these signals inevitably encounter obstacles such as buildings, hills, and moving vehicles, resulting in multipath reflections that can significantly alter the incident polarization state, often introducing substantial horizontal polarization components or even random elliptical polarization. Moreover, one of the primary objectives of spectrum monitoring is the detection of illegal, unauthorized, or interfering transmitters, which may employ arbitrary polarization orientations (e.g., horizontal, tilted, or circular) without adhering to any broadcast standard. If the monitoring antenna is fixed to a single polarization (e.g., vertical only), the polarization mismatch loss between the incident wave and the receiving antenna can range from 10 dB to over 20 dB depending on the polarization angle. This severe loss directly compromises the system's sensitivity, making it difficult to detect weak signals or low-power interference sources.

Therefore, this paper focuses on the design of a polarization reconfigurable dipole antenna compatible with the RF spectrum monitoring infrastructure for the FM radio band (87–108 MHz). To address these limitations, this work aims to develop a low-cost antenna solution that is easy to fabricate, install, and maintain, while being suitable for deployment in remote monitoring locations. The remainder of this paper is organized as follows. Related works on polarization-reconfigurable antennas are first reviewed. The structure and design concept of the proposed antenna are then presented in detail.

Subsequently, simulation and measurement results are discussed to validate the performance and applicability of the proposed antenna for FM-band radio spectrum monitoring. Finally, concluding remarks are provided.

2. Relate Work Of Polarization Reconfigurable Antenna

Extensive research is being carried out on polarization reconfigurable antennas, as shown in **Table 1**. Each research introduces difference method to reconfigure the polarization of the antenna. P. Saikia et al. [8] have experimented with creating a polarizable slotted microstrip antenna with a directional beam pattern. Its material is copper. The antenna polarization can be changed by adjusting the surface current flow controlled by a PIN diode at 2.4 GHz. It is suitable for 4G LTE and ISM applications. P. Guo et al. [9] have experimented to create a small polarization adjustable antenna which has a structure of 7 plate dipole antennas arranged in a circle with a back reflector between 4.21 and 5.32GHz. It can adjust polarization using a PIN diode on each sub-dipole antenna. Its material is copper. It is omnidirectional with 7.55 dBi. It is suitable for wireless communication technology. E. Tolín et al. [10] have created a compact, low-cost planar antenna in the UHF band for RFID reading. It can adjust polarization using a delay line controlled by a CMOS switch. Its material is copper. It is omnidirectional with 5.05 dB. H. Shi et al. [11] have experimented to create a continuously adjustable polarization planar antenna and radio waveguide assembly at 5 GHz. Its material is copper. It can adjust polarization using a phase-shift network using a variator. It is directional with 6 dBi. It is suitable for wireless communication technology. Z. Wu et al. [12] have experimentally built a compact, electronically controllable polarization slot antenna based on the metamaterial concept, which ranges from 5.2 to 6.4 GHz. It is directional with 3 dBi. It is suitable for wireless communication technology. H.L. Zhu et al. [13] have experimented to create a slot antenna that can adjust polarization by the principle of metamaterial between 3.3 and 3.7 GHz. Its material is copper. It is directional with 4.2 dBi. It is suitable for wireless communication technology. J. Ren et al. [14] have experimented to create an antenna that can adjust the wave propagation pattern and polarization by using the principle of dielectric parasitic adjustment on a monopole antenna. Its material is copper. It is designed to operate around 2.4 GHz. It is omnidirectional with 7.5 dBi. It is suitable for wireless communication technology. T. Zhang et al. [15] have experimented to create a frequency and polarization tunable antenna by changing the shape of the spiral antenna with liquid metal. It is operated between 1.5 and 2.5 GHz. It is omnidirectional, suitable for wireless communication technology. J. L. Valdes et al. [16] have experimented to create a polarization-tunable antenna with phase-

shifting material around 29.5 GHz. It is a planar antenna with an omnidirectional beam pattern. Its material is Germanium Telluride. It's reconfigurable using a laser with phase change material. It gains is 4 dBi. It is suitable for millimeter wave applications

Table 1 presents a comparison of previously reported polarization reconfigurable antennas. Most existing designs operate in the microwave and millimeter-wave frequency ranges and employ planar, slot, metasurface, or multi-element antenna structures. For example, polarization reconfigurable microstrip and dipole-based antennas controlled by PIN diodes have been reported in the 2–5 GHz frequency range [8],[9], while compact planar antennas with CMOS switching techniques have been developed for UHF RFID applications around 865-868 MHz [10]. Other approaches utilize phase-shift networks or metasurface structures to enable polarization control in the 3–6 GHz band [11–13]. In addition, alternative techniques such as dielectric liquid tuning and liquid metal structures have been investigated to achieve polarization and frequency reconfigurability over wide frequency ranges [14],[15]. Furthermore, advanced materials such as phase-change materials have been explored to realize polarization reconfigurable antennas at millimeter-wave frequencies [16]. From this comparative review, several key research gaps can be identified. First, the majority of existing polarization-reconfigurable antennas summarized in **Table 1** are designed for microwave and millimeter-wave frequency bands (ranging from 2 GHz to 30 GHz) and are primarily intended for wireless communication systems, 4G/LTE, or RFID applications. Second, although a few designs operate at lower frequencies, such as the UHF RFID band around 865–868 MHz [10], they still rely on relatively complex feeding networks or delay lines to achieve polarization switching. Third, most of the reported configurations exhibit directional radiation patterns, which are unsuitable for radio spectrum monitoring applications that require omnidirectional coverage to detect signals arriving from arbitrary directions.

In contrast, the proposed antenna addresses these limitations by targeting the much lower VHF FM broadcast band (88–108 MHz), where the physical size and structural complexity of reconfigurable antennas pose significant design challenges. The novelty of our approach lies in the following aspects: i) a straightforward yet effective L-shaped dipole structure with two orthogonally arranged arms, which eliminates the need for complex phase-shift networks or metasurfaces; ii) the use of a simple RF switching network to selectively activate each arm, enabling reliable polarization switching with minimal insertion loss; iii) the achievement of stable omnidirectional radiation patterns for both polarization states, which is rarely reported in polarization-reconfigurable designs at this frequency band; and iv) the use of low-cost aluminum tubing as the radiating element, which significantly reduces fabrication and maintenance costs

compared to conventional copper-based microstrip or metasurface designs.

These features make the proposed antenna not only a novel solution for polarization reconfiguration at

VHF frequencies but also a highly practical and cost-effective candidate for large-scale deployment in automated FM-band radio spectrum monitoring systems.

Table 1. Comparison of polarization reconfigurable antenna designs.

Ref.	Frequency (MHz)	Antenna Structure	Material	Reconfigurable Circuit	Radiation Pattern	Gain (dBi)	Application
[8]	2130 and 2420	slotted microstrip	Copper	PIN diode and DC bias	Directional	-	4G LTE and ISM bands
[9]	4210 to 5320	Multi-Dipoles with artificial magnetic conductor reflector	Copper*	PIN diode and DC bias	Omni-directional	7.55	wireless communication technology*
[10]	865 to 868	Planar	Copper	Delay line controlled by CMOS switch	Omni-directional	5.05	RFID
[11]	4000 to 6000	Planar	Copper*	phase-shift network using variator	Directional	6	wireless communication technology
[12]	5200 to 6200	Slot	Copper*	Meta material controlled by PIN diode and DC bias	Directional	3	wireless communication technology
[13]	3300 to 3700	Slot	Copper	Meta material with motor	Directional	7.5	wireless communication technology*
[14]	2400	Monopole	Parasitic dielectric liquid	Liquid pumping system	Omni-directional	4.2	wireless communication technology*
[15]	600 to 25000	Spiral	Eutectic Gallium-Indium	Liquid pumping system	Omni-directional	-	wireless communication technology*
[16]	2800 to 3100	Planar	Germanium Telluride	LASER with Phase Change material	Omni-directional	-25 to 4	Millimeter wave application
This Paper	87 to 108	Dipole	Aluminum	RF switch	Omni-directional	1.7 to 1.8	FM radio monitoring

3. Designed and Simulated Results

The proposed antenna was designed to operate in the FM broadcast band, ranging from 88 to 108 MHz. The antenna structure consists of two identical radiating sections arranged orthogonally with respect to each other, forming two perpendicular arms capable of supporting two orthogonal linear polarization states, as shown in **Figure 2**. Each radiating section has an “L”-shaped configuration composed of two subsections. The subsection connected directly to the feed port is a straight conductor, while the second subsection forms the “L” extension to increase the effective electrical length of the antenna. A small gap is introduced between the two subsections of each arm. This gap plays an important role in the antenna operation because it allows the insertion of a switching

element used to control the current path along the antenna structure. By controlling the electrical connection across the gap using a switching network, the antenna can selectively activate one radiating arm while suppressing the other. As a result, the dominant current distribution is aligned along the selected arm, producing a corresponding linear polarization state.

The antenna is constructed using aluminum tubing to provide a mechanically robust and lightweight structure suitable for outdoor deployment. Aluminum was selected due to its low cost, good electrical conductivity, and ease of fabrication. These properties make the antenna appropriate for large-scale implementation in distributed radio spectrum monitoring stations. The overall geometry of the proposed antenna is illustrated in **Figure 2**, and the detailed design parameters are summarized in **Table 2**. The antenna consists of two main arms

separated by an angle of 90° , allowing polarization switching between two orthogonal orientations. Each arm is divided into subsections whose lengths are optimized to achieve resonance within the FM broadcast band. The dimensions were determined through iterative electromagnetic simulations to ensure good impedance matching and stable radiation characteristics across the operating frequency range. To verify the electromagnetic performance of the proposed design, full-wave simulations were carried out [17]. The simulated return loss, radiation patterns, and gain characteristics of the antenna are presented in the following section. These results are used to evaluate the effectiveness of the proposed structure in achieving polarization reconfiguration while maintaining omnidirectional coverage for FM-band radio spectrum monitoring applications.

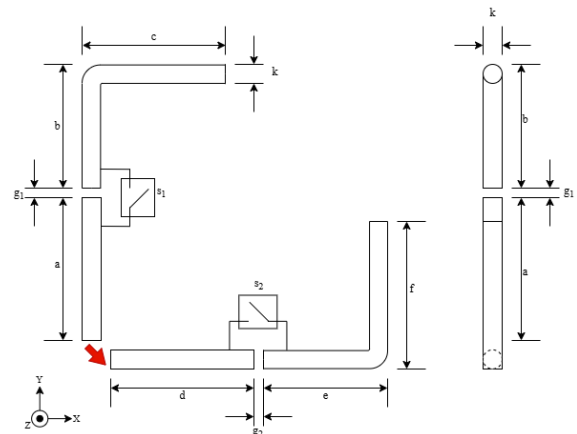


Figure 2. The structure of a polarization reconfigurable dipole antenna.

Table 2. Parameters of a polarization reconfigurable dipole antenna.

Antenna Parameters	Descriptions	Physical Size (mm)
a	Length of the lower radiating sections connected to the feed region.	400
d	Length of the lower radiating sections connected to the feed region.	400
b	Length of the vertical radiating sections forming the main antenna arms.	400
e	Length of the vertical radiating sections forming the main antenna arms.	400
c	Length of the horizontal end sections forming the L-shaped extensions.	415
f	Length of the horizontal end sections forming the L-shaped extensions.	415
g_1	Switching gap between antenna segments for polarization control.	5
g_2	Switching gap between antenna segments for polarization control.	5
k	Diameter of the aluminum tube used as the radiating conductor.	30
S_1	The switching network is used to activate the vertical radiating arm for vertical polarization.	
S_2	The switch network is used to activate the horizontal radiating arm for horizontal polarization.	

The prototype employs DC-controlled RF relays (or coaxial jumpers) across gaps g_1 and g_2 . In the ON state, the relay is modeled as a near-ideal short circuit ($R_{\text{ON}} \sim 0.1 \, \Omega$); in the OFF state, it provides high isolation (>60 dB). Closing S1 (while S2 is open) activates the vertical arm for vertical polarization, whereas closing S2 activates the horizontal arm for horizontal polarization. Although relay switching is slower than PIN diodes, this is not a limitation for spectrum monitoring, where polarization selection occurs during system setup or calibration. This approach offers ultra-low insertion loss (~ 0.05 dB), superior isolation, and simplified biasing, making it well-suited for the low-cost proof-of-concept prototype.

The electromagnetic performance of the proposed polarization reconfigurable dipole antenna was evaluated using full-wave simulations performed with CST Studio Suite [17]. The simulated results include the input reflection coefficient, radiation pattern, and realized gain of the antenna for both polarization configurations. **Figure 3** shows the simulated reflection coefficient ($|S_{11}|$) of the proposed antenna for vertical and horizontal polarization modes. The results indicate that the antenna achieves good impedance matching over the entire FM broadcast band from 88 MHz to 108 MHz. For both polarization states, the simulated $|S_{11}|$ remains below -10 dB within the operating frequency

range, confirming that the antenna is properly matched to the feed and capable of efficiently receiving signals across the FM band.

The simulated radiation patterns of the antenna at the center frequency of 97.5 MHz are presented in **Figure 4**. The radiation characteristics are illustrated in both the xy -plane and xz -plane for the two polarization modes. It can be observed that the antenna maintains an omnidirectional radiation pattern in the horizontal plane, which is desirable for radio spectrum monitoring applications where signals may arrive from various directions. When the switch S1 is activated, the current distribution is primarily concentrated along the vertical radiating arm, producing vertical polarization. Conversely, when the switch S2 is activated, the dominant current flows along the horizontal arm, resulting in horizontal polarization. This behavior confirms that the switching mechanism effectively redirects the surface current to the desired radiating arm while the orthogonal arm remains electrically inactive. **Figure 5** presents the simulated realized gain of the antenna as a function of frequency for both polarization modes. The antenna exhibits relatively stable gain performance across the operating band. The maximum realized gain is approximately 1.7 dBi for the vertical polarization mode and approximately 1.8 dBi for the

horizontal polarization mode. The difference in gain between the two polarization states is mainly attributed to the asymmetrical geometry and current distribution introduced by the switching configuration of the antenna arms. Overall, the simulation results demonstrate that the proposed antenna provides

adequate impedance bandwidth, stable omnidirectional radiation characteristics, and effective polarization reconfiguration over the entire FM broadcast band. These features make the antenna suitable for deployment in low-cost distributed radio spectrum monitoring systems.

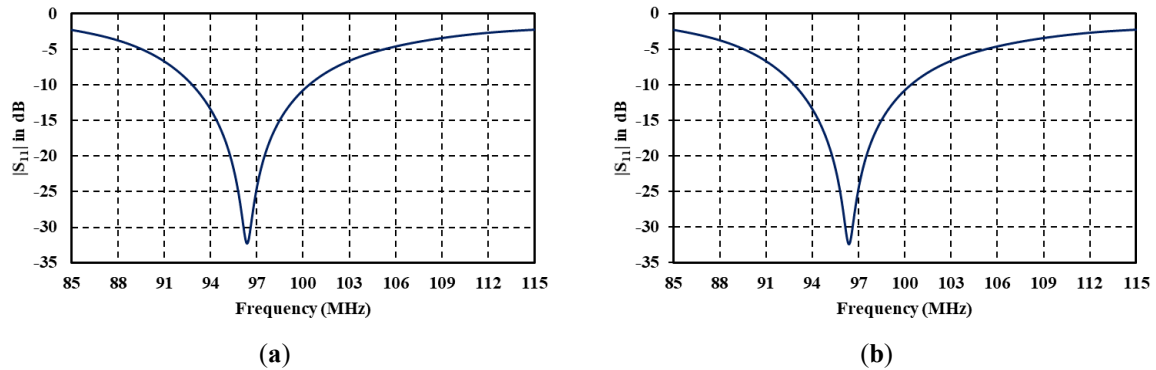


Figure 3. Simulation of $|S_{11}|$ of the polarization reconfigurable dipole antenna. (a) Vertical polarization (b) Horizontal polarization.

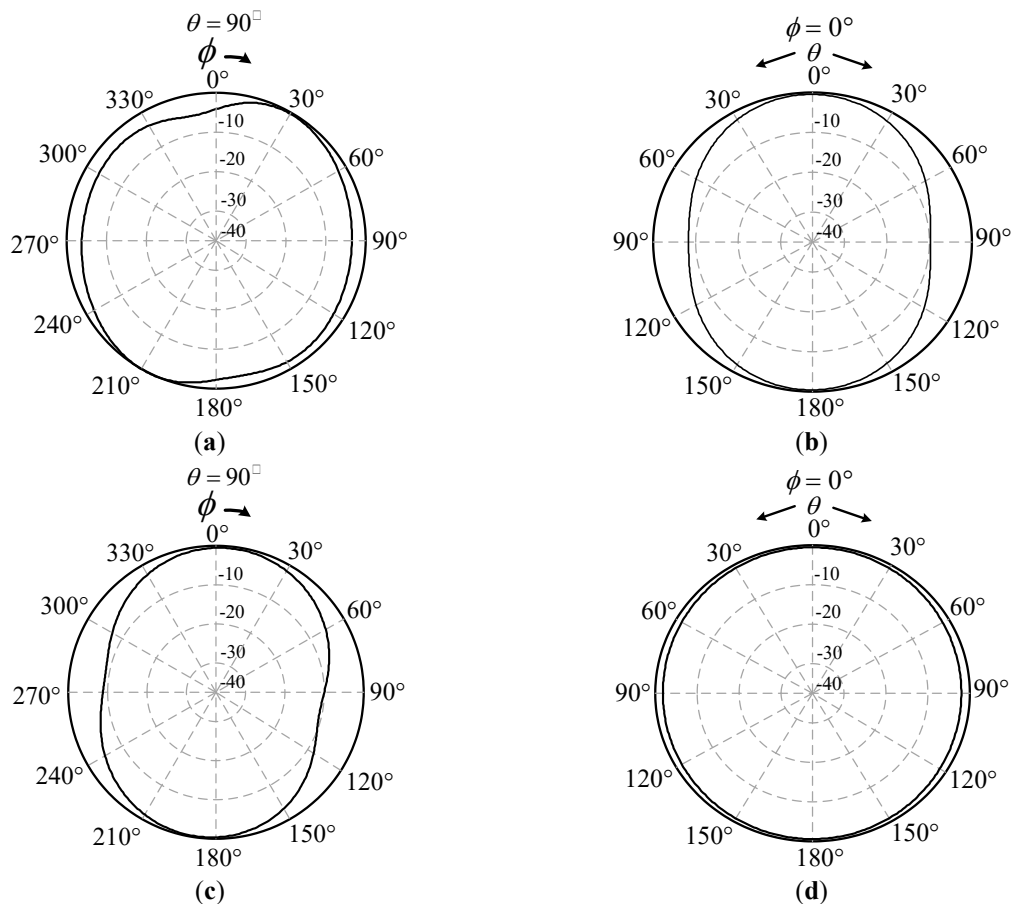


Figure 4. Simulation of the radiation pattern of the polarization reconfigurable dipole antenna at the frequency of 97.5 MHz (a) xy-plane (Vertical polarization) (b) xz-plane (Vertical polarization) (c) xy-plane (Horizontal polarization) (d) xz-plane (Horizontal polarization)

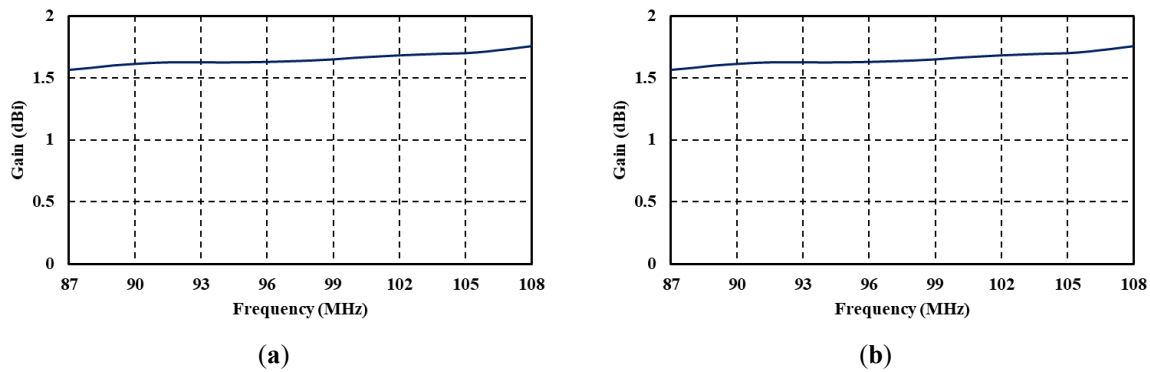


Figure 5. Simulation of the gain versus operating frequency of the polarization reconfigurable dipole antenna. (a) Vertical polarization (b) Horizontal polarization.

4. Measured Results

To validate the simulated performance, a prototype of the proposed polarization reconfigurable dipole antenna was fabricated and experimentally evaluated as shown in **Figure 6**. The antenna was constructed using aluminum tubing according to the design parameters summarized in **Table 2**. The switching elements were implemented using RF switches to enable polarization selection between the two orthogonal radiating arms. The antenna was tested to verify its impedance matching and radiation characteristics within the FM broadcast band. The input reflection coefficient of the fabricated antenna was measured using a vector network analyzer, while the radiation characteristics were evaluated in an open-area test environment. During the measurements, the antenna polarization was controlled by activating the corresponding switch to select either the vertical or horizontal radiating arm. The measured results are presented and compared with the simulated results to verify the performance of the proposed antenna for FM-band radio spectrum monitoring applications.

The measurement setup was arranged in an open-area test site to approximate realistic deployment conditions. The antenna under test (AUT) was mounted on a non-metallic mast at a height of 1.5 meters above the ground to minimize reflections from the ground plane. A standard broadband reference dipole antenna was employed as the transmitting antenna and was positioned at a distance sufficient to satisfy the far-field criterion ($R \geq 2D^2/\lambda$, where D is the maximum dimension of the AUT and λ is the free-space wavelength at 97.5 MHz). The input reflection coefficient ($|S_{11}|$) was measured using a calibrated vector network analyzer (VNA). During radiation pattern measurements, the AUT was rotated in the azimuth plane using a turntable, while the transmitting antenna remained fixed, allowing the reception pattern of the AUT to be recorded. The same procedure was repeated for both polarization states by toggling the RF switches $S1$ and $S2$.

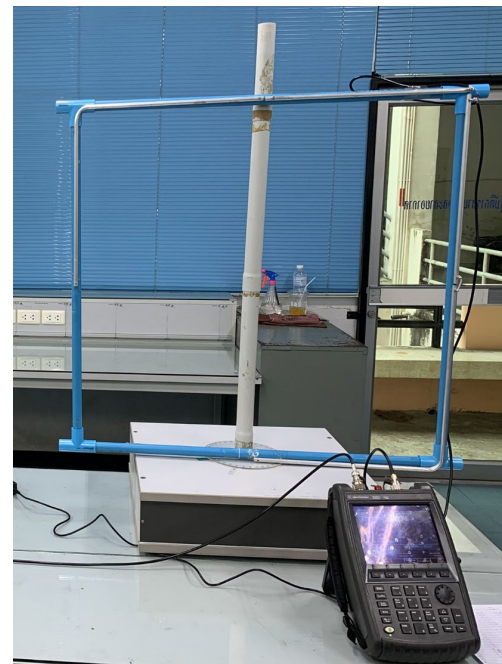


Figure 6. The Prototype of the polarization reconfigurable dipole antenna.

The measured reflection coefficient ($|S_{11}|$) of the fabricated antenna is shown in **Figure 7** for both polarization modes. It can be observed that the antenna maintains acceptable impedance matching across the FM broadcast band from 93 MHz to 102 MHz. For both polarization configurations, the measured $|S_{11}|$ is generally below -10 dB over most of the operating band, which is in good agreement with the simulated results. Minor discrepancies between simulation and measurement can be attributed to fabrication tolerances, connector losses, and the influence of the measurement environment. Although the measured impedance bandwidth is slightly narrower than the simulated full-band coverage, the antenna still provides adequate performance for practical FM-band monitoring applications, where the most congested and critical channels lie within this frequency range.

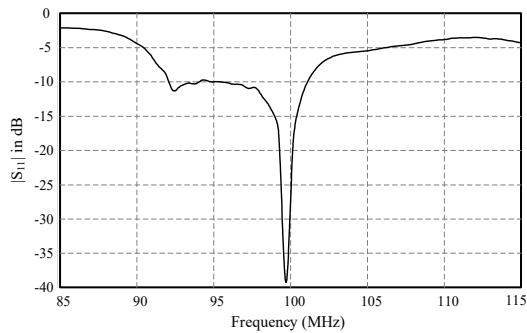


Figure 7. Measurement of $|S_{11}|$ of the polarization reconfigurable dipole antenna.

The measured radiation patterns of the antenna at 97.5 MHz are presented in **Figures 8–9**. The results demonstrate that the antenna preserves an omnidirectional radiation characteristic in the horizontal plane for both polarization modes. This behavior is consistent with the simulated results and confirms that the proposed antenna is suitable for receiving signals from arbitrary directions in radio spectrum monitoring applications. When switch S_1 is

activated, the antenna produces vertical polarization, whereas activating switch S_2 results in horizontal polarization. The measured radiation patterns confirm that the polarization switching mechanism operates as intended. In addition, **Figure 8** shows the measured radiation patterns at 100 MHz to further verify the antenna performance across the operating band. The results indicate that the radiation characteristics remain stable over the FM frequency range, with no significant distortion in the radiation pattern. This demonstrates the broadband performance of the proposed antenna.

Overall, the measured results are in good agreement with the simulated results in terms of impedance matching and radiation characteristics. The slight differences observed between the measured and simulated results are mainly due to practical implementation factors such as fabrication imperfections, the presence of feeding cables, and environmental reflections during measurement. These results confirm that the proposed antenna is capable of providing reliable polarization reconfiguration and omnidirectional coverage for FM-band radio spectrum monitoring applications.

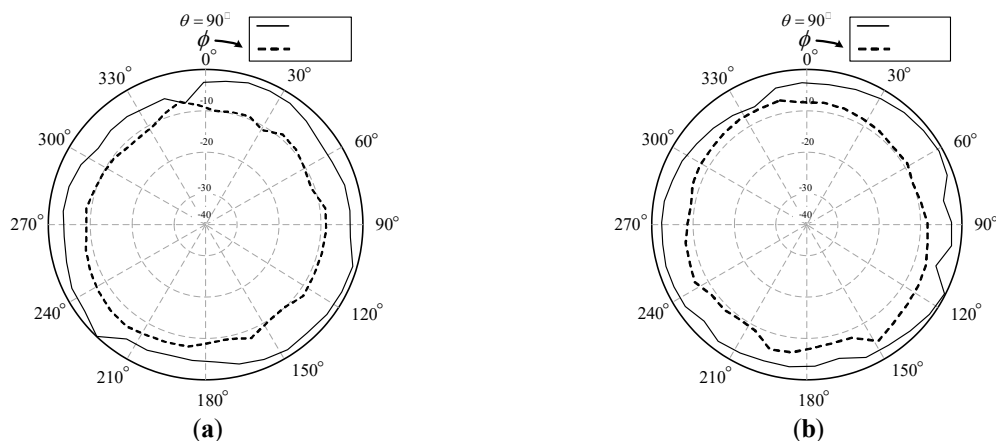
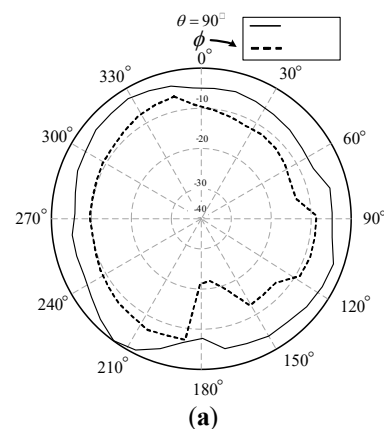


Figure 8. Measurement of the radiation pattern of the polarization reconfigurable dipole antenna at the frequency of 97.5 MHz (a) xy -plane (Horizontal polarization) (b) xy -plane (Vertical polarization)

To quantitatively evaluate the polarization reconfiguration performance, the realized gain for both co-polarization (desired polarization state) and cross-polarization (orthogonal polarization state) was extracted from the measured radiation patterns. **Figure 8** shows the measured gain values at the boresight direction ($\theta = 90^\circ$) for both operating states at the center frequency of 97.5 MHz. When switch S_1 is activated to select vertical polarization, the co-polarized gain reaches approximately 1.7 dBi, while the cross-polarized gain is suppressed to below -13.2 dBi, yielding a polarization isolation of approximately 14.9 dB. Similarly, when switch S_2 is activated for horizontal polarization, the co-polarized gain is approximately 1.8 dBi with a cross-polarized gain of -12.5 dBi, corresponding to a polarization isolation of 14.3 dB. These results confirm that the proposed switching mechanism effectively selects the desired polarization state while maintaining low cross-

polarization levels, thereby ensuring reliable polarization diversity for spectrum monitoring applications.



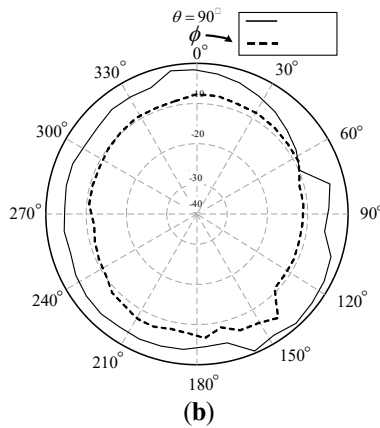


Figure 9. Measurement of the radiation pattern of the polarization reconfigurable dipole antenna at the frequency of 100 MHz (a) xy -plane (Horizontal polarization) (b) xy -plane (Vertical polarization)

To provide a more comprehensive assessment of the proposed antenna, this section presents a critical comparison of its performance against previously reported polarization-reconfigurable antenna designs summarized in **Table 1**. The comparison focuses on four key aspects: operating frequency, impedance bandwidth, gain, radiation pattern, and structural complexity.

In terms of operating frequency, most existing designs, such as those reported in [8],[9] and [11–16], operate in the microwave (2–6 GHz) or millimeter-wave (28–31 GHz) ranges. Only the design in [10] operates at a relatively lower UHF band (865–868 MHz). The proposed antenna uniquely targets the VHF FM broadcast band (88–108 MHz), which presents distinct design challenges due to the much larger physical dimensions of the radiating elements. This makes our work one of the few reported polarization-reconfigurable antennas specifically tailored for low-frequency spectrum monitoring applications.

Regarding gain performance, the proposed antenna achieves a measured realized gain of approximately 1.7–1.8 dBi, which is comparatively lower than several microwave-band designs, such as [9] (7.55 dBi), [14] (7.5 dBi), and [11] (6 dBi). However, this is an expected trade-off inherent to electrically small dipole structures operating at VHF frequencies, where physical aperture size is constrained by the wavelength. More importantly, unlike many of the aforementioned designs that exhibit directional radiation patterns, the proposed antenna maintains stable omnidirectional coverage in the horizontal plane for both polarization states. This characteristic is critical for radio spectrum monitoring, where signals may arrive from unknown or arbitrary directions a requirement that directional antennas cannot adequately fulfill. Among the works listed in **Table 1**, only [9],[10],[14],[15], and [16] offer omnidirectional patterns; however, those designs rely on complex multi-element structures, delay lines, liquid pumping systems, or phase-change materials, which significantly increase fabrication complexity and cost.

In terms of structural complexity and cost, the proposed antenna employs a straightforward L-shaped aluminum dipole configuration with a simple RF switching network, which offers several practical advantages over existing approaches. For instance, compared to metasurface-based designs [12],[13] and multi-dipole arrays with artificial magnetic conductors [9], our design eliminates the need for intricate periodic structures and complex biasing networks. Compared to liquid-based reconfiguration mechanisms [14–15], which require external pumping systems that are difficult to maintain in remote monitoring stations, our all-metallic structure is mechanically robust and weather-resistant. Compared to the UHF planar design in [10], our aluminum tubing construction is more suitable for outdoor deployment and offers better structural integrity.

However, the proposed design also has certain limitations. As observed in the measured results, the impedance bandwidth is somewhat narrower (93–102 MHz) than the simulated full-band coverage, which is attributed to fabrication tolerances and environmental reflections during measurement. The polarization isolation of approximately 14.3–14.9 dB, while adequate for receiving applications, is lower than that of highly directional designs. Nevertheless, for the specific application of FM-band spectrum monitoring where the primary requirement is reliable reception of incident signals rather than high-gain directional transmission these trade-offs are acceptable and justified by the substantial reductions in cost, weight, and system complexity.

In summary, while the proposed antenna does not aim to compete with microwave-band designs in terms of peak gain or fractional bandwidth, it addresses a clearly identified gap in the literature: a low-cost, structurally simple, and omnidirectional polarization-reconfigurable antenna for the VHF FM band. Its practical advantages make it a highly suitable candidate for large-scale distributed deployment in automated spectrum monitoring infrastructures.

5. Conclusions

This paper presented the design of a polarization reconfigurable dipole antenna for FM-band radio spectrum monitoring applications. The proposed antenna operates across the entire FM broadcast band (88–108 MHz) and employs two orthogonal radiating arms with RF switching elements to achieve polarization reconfiguration between two linear polarization states. Simulation results show that the antenna provides good impedance matching with $|S_{11}|$ below -10 dB across the operating band while maintaining an omnidirectional radiation pattern. The simulated realized gain is approximately 1.7 dBi and 1.8 dBi for the two polarization modes. These characteristics make the antenna suitable for receiving FM signals in radio spectrum monitoring systems. Experimental measurements were carried out to validate the simulated performance. The measured

results confirm that the antenna provides good impedance matching and omnidirectional radiation characteristics over the frequency range of 93–102 MHz, which covers the essential portion of the FM broadcast band. The proposed design thus offers a low-cost and practical solution for distributed radio spectrum monitoring systems.

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