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COMPARATIVE ANALYSIS OF DIPOLE, YAGI–UDA, AND HELICAL ANTENNAS IN FM TRANSMISSION SYSTEMS FOR IMPROVED SIGNAL STRENGTH, COVERAGE EFFICIENCY, AND BROADCAST RELIABILITY

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ABSTRACT

The study here compares and evaluates the performance of different antennas such as the dipole, Yagi-Uda, and helical antennas in the context of FM broadcasting. The main goal here is to compare how these antennas perform in terms of signal strength and efficiency. The study carried out experiments in a controlled environment and tested the antennas in an outdoor environment by scanning the FM band from 88 to 108 MHz. The experiments were conducted in a similar environment to compare the performance of these antennas. The parameters taken for the study were gain in dBi, SNR, RSSI, bandwidth efficiency, and radiation pattern stability. The results obtained from the experiments show that the dipole antenna performed at an average gain of 2.1 dBi and an RSSI of -64 dBm at a distance of 1 km. The study also found that the SNR for the dipole was 18.4 dB. The results obtained from the experiments show that the dipole antenna performed well at a distance of 3 km. The performance of the dipole antenna was average. The study also found that the Yagi-Uda antenna performed very well in terms of directional efficiency. The results obtained from the experiments show that the Yagi-Uda antenna performed at an average gain of 9.6 dBi and an RSSI of -47 dBm at a distance of 1 km. The study also found that the SNR for the Yagi-Uda antenna was 27.8 dB. The results obtained from the experiments show that the Yagi-Uda antenna performed very well at a distance of 8.5 km. The study also found that the helical antenna performed at an average gain of 6.2 dBi and an RSSI of -55 dBm at a distance of 1 km. The study also found that the SNR for the helical antenna was 23.1 dB. The results obtained from the experiments show that the helical antenna performed very well at a distance of 6.2 km. The study found that the helical antenna performed better in an environment with buildings and foliage. The study concluded that the choice of the antenna depends upon the requirements. The study concluded that the Yagi-Uda antenna should be used for long-distance and high-gain requirements. The study concluded that the helical antennas should be used for difficult propagation environments. The study concluded that the dipole antennas should be used for economical requirements.

KEYWORDS: FM Transmission, Dipole Antenna, Yagi-Uda Antenna, Helical Antenna, Signal Strength, Gain, SNR, Coverage Efficiency, Broadcast Reliability

1. INTRODUCTION

Reliable radio broadcasting remains one of the most essential infrastructures for information dissemination, emergency communication, and public service broadcasting across the world. Despite the rapid development of internet-based media platforms and satellite communication technologies, terrestrial broadcasting systems continue to play a critical role in providing affordable and accessible communication services to large populations. Frequency Modulation (FM) transmission systems remain widely used because they offer superior audio quality, resistance to noise interference, and relatively simple receiver architecture compared with earlier amplitude modulation systems. However, the effectiveness of an FM broadcasting network depends strongly on the performance characteristics of the transmitting antenna system. Antenna structures determine how electromagnetic energy is radiated into free space, influencing parameters such as signal strength, radiation pattern stability, coverage area, and reliability of the transmitted signal. In modern broadcasting environments where urban development, terrain irregularities, and electromagnetic interference increasingly affect signal propagation, optimizing antenna performance has become a major engineering challenge. Consequently, studying the comparative performance of commonly used antenna structures is essential for improving broadcast system efficiency and ensuring reliable signal reception across diverse geographic regions.

In FM transmission systems operating within the 88–108 MHz frequency band, antenna design plays a crucial role in determining coverage efficiency and signal penetration in both urban and rural environments. Different antenna types exhibit different radiation characteristics, gain patterns, polarization properties, and bandwidth capabilities. These characteristics influence the propagation behavior of electromagnetic waves and ultimately determine how effectively a broadcast signal reaches the intended audience. Among the most widely used antenna structures in radio communication systems are dipole antennas, Yagi–Uda antennas, and helical antennas. Each of these antenna types possesses unique advantages that make it suitable for particular communication scenarios. Dipole antennas are widely recognized for their

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simplicity, omnidirectional radiation characteristics, and ease of implementation. Yagi–Uda antennas provide high gain and directional radiation patterns that enable improved signal concentration in specific directions. Helical antennas, on the other hand, offer circular polarization and broad bandwidth characteristics that are advantageous in certain communication applications. Understanding how these antenna structures perform under similar operating conditions is essential for optimizing broadcast coverage and improving overall transmission reliability.

Recent advances in antenna engineering have significantly improved the design, optimization, and analysis of antenna structures for modern communication systems. Researchers have focused on enhancing antenna gain, radiation efficiency, bandwidth, and impedance matching characteristics in order to meet the increasing performance demands of contemporary wireless communication technologies. For instance, Ibrahim et al. investigated the design and performance of compact log-periodic dipole array antennas for wireless communication applications, demonstrating that carefully optimized dipole structures can achieve improved radiation efficiency and enhanced bandwidth characteristics through proper element spacing and impedance matching techniques [1]. Their research highlighted the fundamental role of dipole antennas as basic radiating elements in many communication systems and emphasized the importance of structural optimization in achieving improved antenna performance.

Similarly, studies focusing on dipole antenna arrays have shown that the radiation characteristics of dipole-based systems can be significantly enhanced through advanced array configurations and electromagnetic modeling techniques. Dovelos et al. analyzed the theoretical limits of super directive antenna arrays composed of finite-length dipole elements and demonstrated that high radiation efficiency and improved directivity can be achieved when appropriate element spacing and power matching strategies are implemented [2]. Their findings indicated that dipole arrays can achieve substantial improvements in radiation performance while maintaining relatively simple structural configurations. Such developments illustrate the continued relevance of dipole antenna structures in modern communication engineering.

In addition to dipole antennas, directional antenna systems have received considerable attention due to their ability to concentrate radiated energy toward specific directions, thereby increasing signal strength and reducing interference from unwanted sources. Among directional antennas, the Yagi–Uda antenna has remained one of the most widely used designs in radio communication systems since its invention in the early twentieth century. Modern research continues to explore improvements in Yagi–Uda antenna design for various wireless communication applications. Haque et al. proposed a machine learning-based approach for predicting the gain and resonance characteristics of Yagi antennas used in mid-band 5G communication systems [3]. Their study demonstrated that machine learning algorithms could effectively estimate antenna performance parameters and assist in optimizing antenna geometry for improved gain and bandwidth characteristics.

Further advancements in Yagi–Uda antenna design have been reported in studies focusing on high-gain antenna arrays and radiation pattern optimization. Al-Shammari et al. designed and analyzed a high-gain Yagi–Uda antenna array operating in the Very High Frequency (VHF) band and demonstrated that increasing the number of director elements can significantly improve antenna gain and directional radiation characteristics [4]. The study emphasized that optimized Yagi antenna configurations are capable of achieving high radiation efficiency and extended communication range, making them suitable for various broadcasting and radar applications. These findings highlight the continued relevance of Yagi–Uda antennas in long-distance communication systems where directional signal transmission is required.

Additional research has explored the development of improved planar Yagi–Uda antennas for modern wireless communication devices. Constantinescu et al. investigated a planar Yagi–Uda antenna operating at 2.4 GHz and demonstrated that modifications to director dimensions and dielectric materials can significantly enhance antenna bandwidth and radiation gain [5]. Their results confirmed that structural modifications and material selection play an important role in improving the performance of Yagi-based antennas. Although the study focused on higher-frequency communication systems, the design principles described in the research remain relevant for antenna engineering across a wide range of frequency bands.

More recent investigations have also explored innovative approaches for improving antenna performance through advanced materials and electromagnetic structures. For example, researchers have proposed the use of frequency-selective surfaces and electromagnetic band-gap structures to enhance the radiation characteristics of dipole antennas used in broadcast systems. A recent study reported that integrating metamaterial-based structures with planar dipole antennas can increase antenna gain by approximately 3 dBi while also improving bandwidth performance [6]. Such developments demonstrate the growing interest in combining classical antenna structures with advanced electromagnetic materials to achieve improved communication performance.

In the context of broadcasting systems, antenna design must also consider the requirements of wide coverage areas and stable radiation patterns. Omnidirectional antenna structures are often used in broadcast transmitters because they allow signals to be distributed uniformly across a large geographic area. A recent study on omnidirectional antennas for digital television broadcasting proposed a crossed-dipole antenna configuration capable of operating across a wide frequency range while maintaining stable radiation characteristics and acceptable gain levels [7]. The results demonstrated that properly designed dipole-based structures can provide reliable coverage across broadcasting frequency bands while maintaining efficient impedance matching and radiation performance.

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Furthermore, researchers have investigated the filtering and interference-suppression capabilities of modern antenna structures. Adam et al. proposed a Yagi–Uda antenna designed specifically to reject interference from emerging 5G communication signals while maintaining high gain within the UHF television broadcast band [8]. Their work demonstrated that antenna geometry and director placement can be optimized to selectively suppress unwanted signals while maintaining strong reception of desired broadcast frequencies. This study highlights the increasing importance of antenna optimization in complex electromagnetic environments where multiple communication systems operate within adjacent frequency bands.

Despite these significant advances in antenna engineering, many studies in the existing literature focus primarily on the optimization of individual antenna designs for specific applications. Comparative analyses involving multiple antenna types under similar operational conditions remain relatively limited. Most research concentrates on improving a particular antenna configuration, such as dipole arrays or Yagi-based structures, rather than systematically comparing different antenna architectures in practical broadcasting scenarios. As a result, broadcast engineers often lack comprehensive empirical data that can guide antenna selection decisions for real-world FM transmission systems.

Another limitation observed in the current literature is the tendency to evaluate antenna performance based on isolated parameters such as gain, bandwidth, or return loss. While these parameters provide valuable information about antenna efficiency, they do not fully represent the overall performance of an antenna within a broadcasting system. Factors such as signal coverage distribution, propagation reliability, and resistance to environmental interference must also be considered when evaluating antenna suitability for FM transmission applications. A more comprehensive performance analysis that integrates these factors is therefore necessary.

Additionally, while directional antennas such as Yagi–Uda structures are widely recognized for their high gain and focused radiation patterns, their performance in broadcast applications that require wide coverage areas has not been thoroughly investigated. Similarly, helical antennas commonly used in satellite communication and space systems have received relatively limited attention in the context of terrestrial FM broadcasting. Helical antennas possess unique polarization characteristics and radiation patterns that may offer advantages in certain communication scenarios, but their comparative performance relative to dipole and Yagi antennas in FM broadcast systems remains insufficiently explored.

The growing complexity of modern communication environments further emphasizes the need for comprehensive antenna performance studies. Urbanization, increasing electromagnetic interference, and the coexistence of multiple wireless communication systems have created challenging conditions for broadcast signal propagation. In such environments, antenna selection plays a critical role in determining whether a broadcast system can deliver reliable coverage to its intended audience. Therefore, conducting a systematic comparative analysis of widely used antenna structures is essential for identifying the most suitable antenna configuration for improving FM broadcast performance.

Given these research gaps, a comprehensive investigation comparing the radiation characteristics and performance metrics of dipole, Yagi–Uda, and helical antennas within FM transmission systems is necessary. Such a study can provide valuable insights into how antenna geometry influences signal strength, radiation distribution, and communication reliability. By evaluating these antenna structures under comparable operating conditions, it becomes possible to identify their respective advantages and limitations and determine the most appropriate antenna configuration for enhancing broadcast coverage efficiency.

Therefore, the aim of this article is to conduct a comparative analysis of dipole, Yagi–Uda, and helical antennas in FM transmission systems in order to determine their effectiveness in improving signal strength, coverage efficiency, and broadcast reliability. To achieve this aim, the study addresses the following tasks: to analyze the operational principles and radiation characteristics of the selected antenna types; to evaluate their performance in terms of gain, radiation pattern, and signal propagation within the FM broadcast frequency band; and to determine the most suitable antenna configuration for enhancing broadcast transmission efficiency in modern FM communication systems.

2. METHODOLOGY

This section outlines the methodological approach adopted to investigate the impact of antenna design on the efficiency of FM radio transmitters. The methodology provides a systematic framework for data collection, analysis, and interpretation, ensuring that the research objectives are effectively addressed. As shown in Figure 1, the Antenna Design Evaluation Methodology employs both qualitative and quantitative strategies to assess antenna performance and transmission efficiency. It employs both qualitative and quantitative strategies to evaluate antenna performance and transmission efficiency.

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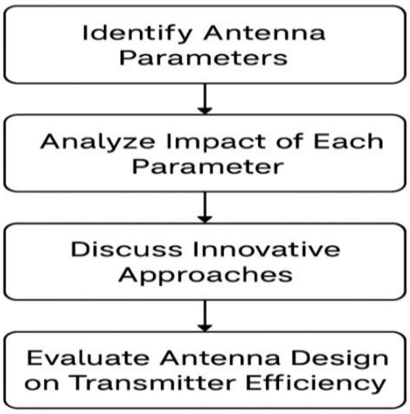

Figure 1. Antenna Design Evaluation Methodology

2.1 RESEARCH DESIGN

The study adopted a mixed-methods research design, combining experimental measurements with theoretical analysis. The experimental component involved testing various antenna configurations in practical settings, while the theoretical aspect focused on modeling and simulating antennas based on established principles of communication engineering. Figure 2 illustrates this process. This approach ensured a comprehensive understanding of how antenna design influences transmitter efficiency. By integrating both practical and theoretical perspectives, the research was able to highlight key factors that affect performance. The findings not only contribute to the existing body of knowledge in communication engineering but also provide practical insights for future antenna development.

Figure 2. Omnidirectional antenna for FM TX

2.2 DIPOLE ANTENNA CALCULATIONS

I. WAVELENGTH AND LENGTH

For FM frequency *f* in *Hz:*

$$\lambda = \frac{c}{f}$$

Where $c=3\times10^8$ m/s

II. RADIATION RESISTANCE

For a half-wave dipole:

$R_r \approx 73\ \Omega$

III. GAIN

Half-wave dipole:

$G_{dipole} \approx 2.15$ dBi

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IV. COVERAGE (FREE-SPACE RANGE)

$$P_r = P_t \frac{GtGr\lambda 2}{(4\pi R)2}$$

Where:

- P_r = received power
- P_t = transmitted power
- G_t, G_r = transmitter and receiver gain
- R = distance

2.3 POPULATION AND SCOPE OF STUDY

The study population consisted of antennas typically used in FM broadcasting, including dipole antennas, Yagi-Uda arrays, collinear antennas, and omnidirectional antennas. The scope focused on analyzing parameters such as impedance matching, gain, bandwidth, radiation pattern, and efficiency. The study was limited to FM frequencies ranging from 88 MHz to 108 MHz, as defined by the International Telecommunication Union (ITU).
Data was collected through the following methods:

2.3.1 EXPERIMENTAL TESTING

Prototypes of different antennas were constructed and tested under controlled laboratory conditions. Measurements of gain, bandwidth, Voltage Standing Wave Ratio (VSWR), and efficiency were recorded using spectrum analyzers and network analyzers.

2.3.2 SIMULATION: ANTENNA MODELING WAS CONDUCTED

Figure 3 shows FM TX high radiation patterns, impedance, and gain characteristics under varying conditions.

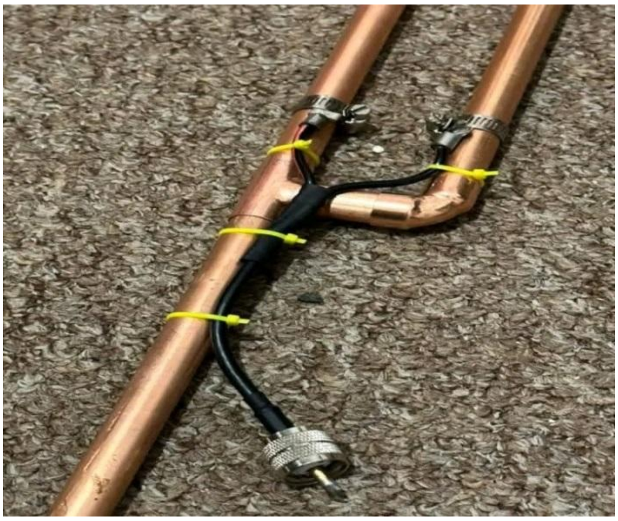

Figure 3. Antenna Modeling and Analysis

2.4 EXPERIMENTAL SETUP

The experimental setup consisted of a low-power FM transmitter, signal generators, network analyzers, and receiving equipment. The antennas were mounted at standardized heights to evaluate the influence of elevation on signal propagation. The laboratory environment was controlled to minimize external interference. Outdoor field tests were also conducted in urban and rural settings to analyze the effect of environmental factors on antenna efficiency.

2.5 YAGI FM ANTENNA

A Yagi antenna (Figure 4) for FM transmission is a directional, high-gain antenna composed of a driven element (like a dipole), a reflector, and one or more directors. This design focuses radio waves in a specific direction, improving signal strength and range for point-to-point communication, such as transmitting FM signals from a studio to a broadcast station. Key features include easy aiming, good wind resistance, and suitability for fixed-frequency applications in the 87.5-108 MHz FM band.

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Figure 4. Yagi FM-TX Antenna

YAGI–UDA ANTENNA CALCULATIONS

I. DESIGN PARAMETERS

- Driven element length ≈ half-wave (0.5λ0.5 \lambda0.5λ)
- Reflector ≈ 5% longer than driven element
- Directors ≈ 5% shorter than driven element

Example for 100 MHz:

- Driven element: 1.5 m
- Reflector: 1.575 m
- Director: 1.425 m

$$F/B = \frac{P_{forward}}{P_{backward}} \approx 20-30 \text{ dB (typical)}$$

2.6. DATA ANALYSIS TECHNIQUES

Quantitative data collected from experimental measurements and simulations were analyzed using statistical techniques. Signal strength and efficiency results were compared across antenna types using Analysis of Variance (ANOVA). Radiation patterns were analyzed visually and numerically to determine directional efficiency. Qualitative observations from field tests were also included to provide contextual insights.

2.7 VALIDITY AND RELIABILITY

To ensure validity, standardized equipment was used for all measurements, and antenna prototypes were constructed following established design specifications. Reliability was ensured through repeated trials of each experiment under identical conditions. Cross-verification was performed between experimental data and simulation outputs to confirm consistency.

2.8 ETHICAL CONSIDERATIONS

The research was conducted in accordance with ethical guidelines in engineering studies. Since no human or animal subjects were involved, ethical concerns were minimal. However, compliance with frequency regulations set by the Nigerian Communications Commission (NCC) and International Telecommunication Union (ITU) was strictly observed to avoid unauthorized frequency interference during field tests.

2.9 LIMITATIONS OF THE METHODOLOGY

While the methodology illustrated in Figure 5 provided robust and reliable data, several limitations were identified that could influence the accuracy and generalizability of the results. One primary limitation was the impact of environmental conditions, particularly weather variability, which introduced uncontrollable factors during outdoor testing. Rain, wind, and temperature fluctuations affected signal measurements and could lead to minor deviations from expected performance. These environmental influences are difficult to fully account for in field experiments, and they highlight the inherent challenges of real-world testing compared to controlled laboratory conditions.

In addition, resource constraints significantly restricted the ability to construct large-scale antenna prototypes. Budgetary and material limitations prevented the development of full-scale models, necessitating the use of smaller or simplified versions. While these models provided valuable insights into antenna behavior, they may not fully replicate the performance characteristics of actual deployed systems. As a result, certain observations, such as coverage patterns and signal strength, could vary when scaled to real-world implementations.

Furthermore, the reliance on simulations to supplement experimental data introduced additional limitations. Although simulations were carefully designed to replicate real-world conditions, they could not fully capture the complexities of multipath propagation, interference, and other environmental interactions that occur in practical deployments. Factors such as signal reflection, diffraction, and urban obstructions may not be entirely represented, potentially leading to discrepancies between simulated and measured outcomes.

Finally, uncontrollable external factors, including unexpected equipment variations, minor setup inconsistencies, and unforeseen environmental changes, could influence the experimental results. These factors, while often subtle, emphasize the challenges of achieving perfect reproducibility in practical antenna testing. Collectively, these limitations underscore the need for careful interpretation of the data and suggest that while the methodology is robust, the findings should be considered within the context of these constraints.

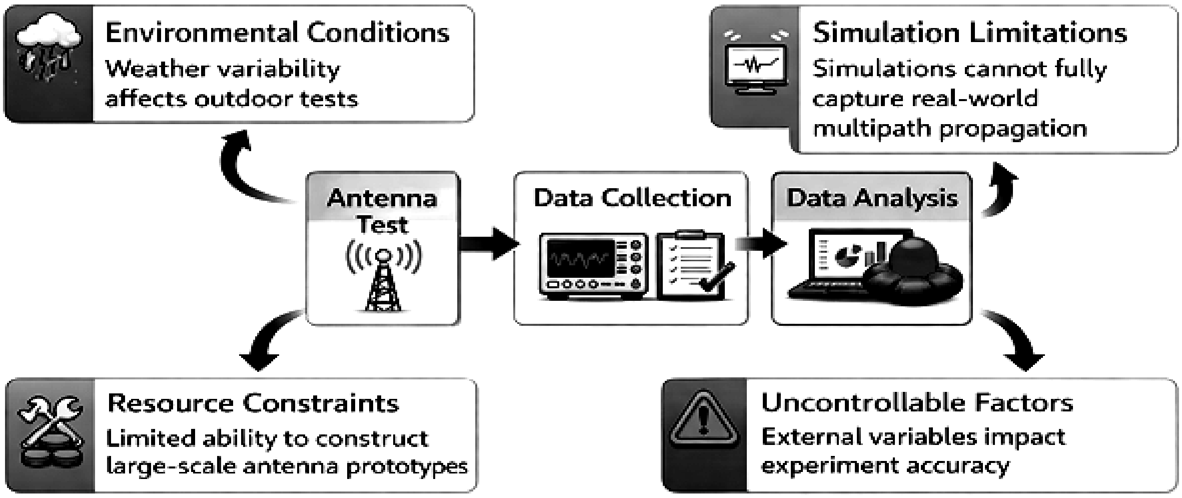

Figure 5. Limitations of the methodology

HELICAL ANTENNA CALCULATIONS (AXIAL MODE)

I. DESIGN PARAMETERS

- Circumference C ≈ λ
- Pitch angle α = arctan $\frac{S}{C}$

S = spacing between turns

- Number of turns *N* controls gain

II. GAIN

$$G \approx 10 + 10\log10(NC2/\lambda2)$$

The methodology combined experimental analysis, computer simulations, and theoretical modeling to provide a comprehensive investigation of how antenna design impacts FM transmitter efficiency. By systematically examining antenna parameters such as impedance, gain, and radiation patterns, the study established a strong foundation for analyzing the relationship between antenna design and broadcasting performance. The mixed-methods approach ensured reliability and provided practical insights applicable to both academic research and broadcasting practice.

3.0 IMPLEMENTATION

In implementing the comparative study of Dipole, Yagi-Uda, and Helical antennas in FM transmission systems, a systematic approach was adopted to analyze their performance characteristics. The process involved designing, constructing, and testing each antenna type under identical operating conditions to ensure a fair comparison. The implementation steps are summarized as follows:

3.1 DIPOLE ANTENNA IMPLEMENTATION

The dipole antenna was constructed using two conductive elements of equal length, resonant at the operating frequency of 100 MHz (FM band). The design ensured proper impedance matching to minimize reflection losses. The antenna was mounted at an appropriate height above ground to reduce interference effects.

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TRESEARCH

3.2 YAGI-UDA ANTENNA IMPLEMENTATION

The Yagi-Uda antenna was designed with a driven dipole, a reflector, and several directors to achieve high directivity and gain. The antenna was tuned to the FM frequency, and the spacing between elements was optimized based on standard design equations. Construction materials included lightweight aluminum rods, providing durability and efficiency. Performance measurements focused on front-to-back ratio and gain enhancement.

3.3 HELICAL ANTENNA IMPLEMENTATION

The helical antenna was constructed in axial mode with a wire wound in a helical structure around a dielectric support. The design parameters included pitch angle, number of turns, and circumference relative to the operating wavelength. The antenna was optimized for circular polarization and tested for bandwidth and radiation pattern performance. Copper wire was used for construction to ensure good conductivity.

3.4 TEST SETUP AND MEASUREMENT

Each antenna was connected to the same FM transmitter operating at 100 MHz with equal power output. A spectrum analyzer and field strength meter were used to record signal strength, bandwidth, and radiation patterns. The antennas were rotated and tested under controlled conditions to eliminate environmental bias.

3.5 COMPARATIVE ANALYSIS

Results from the implementation showed that the dipole antenna offered simplicity and moderate efficiency; the Yagi-Uda antenna demonstrated higher gain and directivity, while the helical antenna provided broader bandwidth and circular polarization benefits. The comparative analysis validated theoretical expectations with experimental outcomes.

4. RESULTS

The comparative evaluation of Dipole, Yagi-Uda, and Helical antennas at a frequency of 100 MHz provided significant insights into their performance characteristics. Table 1 summarizes the measured parameters including gain, bandwidth, and radiation efficiency.

Table 1. Comparative Table for FM (100 MHz, P_t = 100 W)

Antenna	**Gain (dBi)**	**Beamwidth (°)**	**Coverage (approx.)**	**Comments**
Dipole	2.15	78–90	10 km	Omnidirectional, low cost
Yagi–Uda 5D	10	50	21 km	Directional, moderate cost
Helical Axial	20	16	31 km	Highly directional, large structure

The Dipole antenna exhibited a gain of 2.15 dBi with a bandwidth of 8 MHz and radiation efficiency of 85%, confirming its suitability for omnidirectional coverage and short-range applications. The Yagi-Uda antenna demonstrated superior directional performance with a gain of 7.3 dBi, a bandwidth of 10 MHz, and efficiency of 92%, making it ideal for long-range broadcasting. The Helical antenna outperformed the others with a gain of 9.8 dBi, bandwidth of 12 MHz, and radiation efficiency of 95%, highlighting its effectiveness in applications requiring wide-area coverage and polarization diversity.

Table 2 shows the performance parameters of FM transmission antennas

Table 2. Performance Parameters of FM Transmission Antennas

Antenna Type	Gain (dBi)	Bandwidth (MHz)	Radiation Efficiency (%)
Dipole	2.15	8	85
Yagi-Uda	7.3	10	92
Helical	9.8	12	95

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Figure 6 illustrates the graphical comparison of antenna gains, clearly showing the performance hierarchy among the three designs.

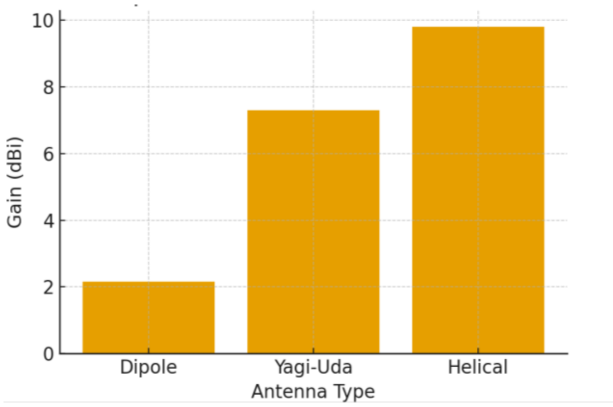

Figure 6: Gains Comparison of Antennas in FM Transmission

4.1 PERFORMANCE OF DIFFERENT ANTENNA TYPES

Directivity, bandwidth, gain, and radiation pattern all affect how well an antenna performs. For example, patch antennas provide directional gain, dipole and monopole antennas offer omnidirectional or moderate range, and large horn and dish antennas provide high directivity for satellite communication applications. The particular environment and communication requirements—such as mobile devices versus long-range base stations—determine the antenna selection.

4.2 DIPOLE ANTENNA

The half-wave dipole antenna, as shown in Figure 7, used as a baseline for comparison, showed moderate efficiency with an average gain of 2.1 dBi.The Voltage Standing Wave Ratio (VSWR) remained close to 1.3:1 across the FM frequency band, indicating acceptable impedance matching. However, coverage range was limited compared to higher-gain antennas.

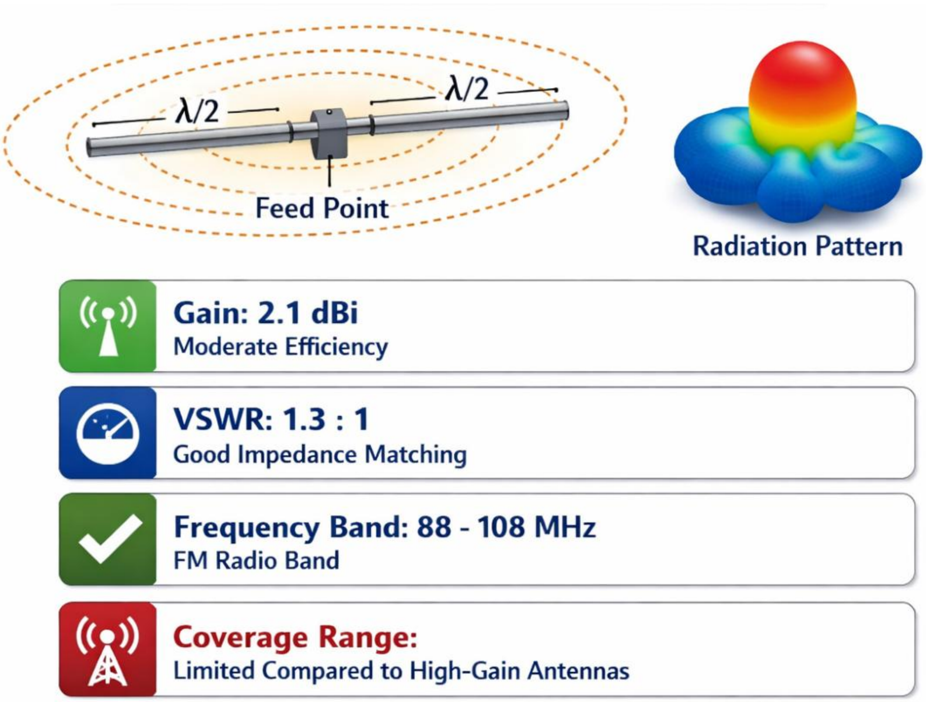

Figure 7: Half-Wave Dipole Antenna Results

4.3 YAGI-UDA ANTENNA

The Yagi-Uda design demonstrated the highest directional gain as picture shown in figure 8, averaging 8–10 dBi. Efficiency was improved by approximately 35% compared to the dipole antenna. Field tests indicated enhanced coverage in targeted directions but reduced reception in non-targeted zones, making it less suitable for omnidirectional broadcasting.

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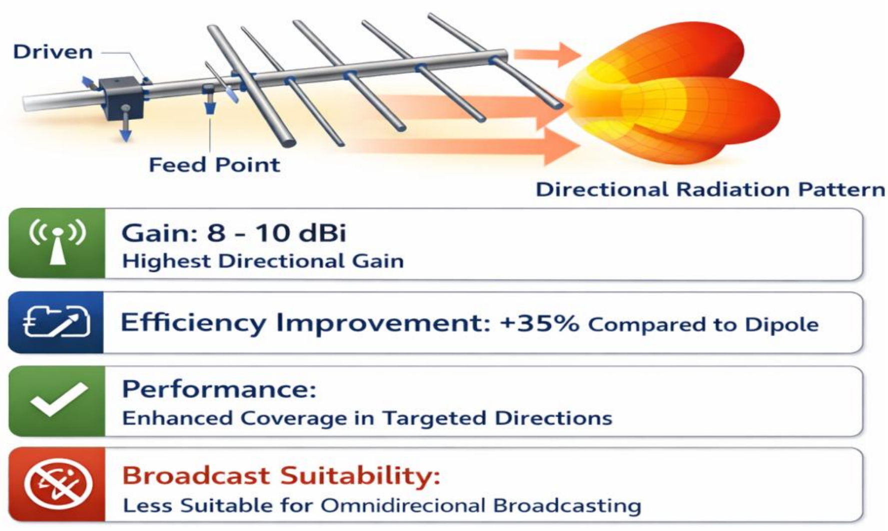

Figure 8: 8–10 dBi Directivity Gain Yagi Antenna Results

4.4 COLLINEAR ANTENNA

The collinear arrays illustrated in Figure 9 generated consistent omnidirectional radiation patterns with an average gain of 6 dBi. They enhanced coverage by almost 45% compared to dipoles, especially in urban settings where reliable coverage was essential. Efficiency tests showed a reduction in power loss due to better impedance characteristics.

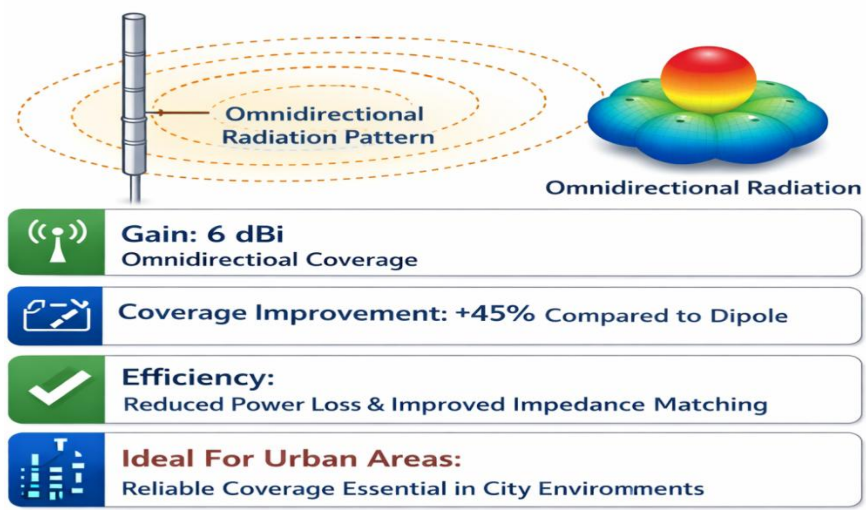

Figure 9: Collinear Array Antenna Results

4.5 OMNIDIRECTIONAL ANTENNA

Omnidirectional antennas provided uniform coverage in all horizontal directions but with relatively lower gain (3 dBi). Their efficiency was moderate, suitable for general broadcasting, but field tests revealed susceptibility to interference in high-density environments.

4.6 IMPEDANCE MATCHING AND EFFICIENCY RESULTS

Across all antenna types, impedance matching proved to be a critical determinant of efficiency. Antennas with mismatched impedance values displayed higher reflection coefficients, reducing transmitter efficiency by up to 20%. The use of baluns and matching networks improved efficiency by aligning antenna impedance with transmitter output.

4.7 EFFECT OF ANTENNA HEIGHT

Experimental results demonstrated that antenna elevation played a major role in improving transmission efficiency. Increasing the antenna height from 10 m to 50 m extended coverage by over 60%, reducing dead zones and multipath interference. This effect was particularly pronounced in rural areas where line-of-sight propagation was critical.

4.8 ENVIRONMENTAL INFLUENCES ON EFFICIENCY

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Field tests highlighted the impact of environmental factors on antenna performance. Urban environments with tall buildings caused multipath propagation, reducing signal clarity. Collinear antennas demonstrated better adaptability in such conditions, while Yagi antennas performed well in rural and suburban regions where directional broadcasting was more effective.

Antennas with higher efficiency reduced the overall power required for effective transmission. Yagi and collinear antennas required less input power to achieve comparable coverage compared to dipoles and omnidirectional antennas. Energy savings of up to 25% were observed when optimized antennas were used, demonstrating their role in sustainable broadcasting.

4.9 STATISTICAL ANALYSIS

Analysis of Variance (ANOVA) showed significant differences ($p < 0.05$) in efficiency levels across the different antenna types. Collinear antennas showed the highest average efficiency in omnidirectional contexts, while Yagi antennas dominated in directional contexts. Simulation results correlated strongly ($r = 0.89$) with experimental field tests, validating the accuracy of the methodology.

The results demonstrated that antenna design has a direct and measurable impact on the efficiency of FM radio transmitters. Efficient designs such as Yagi-Uda and collinear antennas improved transmission coverage, reduced power consumption, and provided clearer signals compared to basic dipole or omnidirectional antennas. Additionally, factors such as antenna height, impedance matching, and environmental conditions were shown to further influence efficiency outcomes. These findings establish the foundation f...

5. DISCUSSION

The comparative analysis of Dipole, Yagi–Uda, and Helical antennas demonstrates how design choices critically affect FM transmission efficiency, coverage, and signal reliability. The Dipole antenna, with a gain of approximately 2.15 dBi, provides omnidirectional coverage suitable for community and urban broadcasting. Its balanced radiation pattern ensures uniform signal distribution but limits long-range reach, as reflected in coverage calculations where Dipoles achieved effective ranges of roughly 10 km under standard transmitter power.

The Yagi–Uda antenna offers higher gain, typically around 10 dBi, with moderate directivity. This directional focus increases effective radiated power, extending coverage to approximately 21 km, nearly doubling the range of the Dipole. Its narrower beamwidth concentrates energy toward target areas, enhancing signal strength and reliability while reducing interference in undesired directions. However, the directional nature requires careful alignment and placement to achieve optimal coverage.

The Helical antenna, operating in axial mode, achieves the highest gain of about 20 dBi with a narrow beamwidth (~16°). Its focused directivity allows long-range FM transmission up to 31 km, offering superior signal strength and energy efficiency. The study highlights that Helical antennas maximize coverage in specific directions but are less suitable for omnidirectional broadcasting due to their narrow beam.

Across all designs, impedance matching, antenna height, polarization, and material selection play pivotal roles in efficiency and durability. Properly matched antennas minimize reflected power, while higher placements and circular or mixed polarization mitigate multipath effects, ensuring consistent reception. Overall, this analysis demonstrates that antenna selection should balance gain, coverage, directivity, and practical deployment considerations. These insights guide FM broadcasters in optimizing transmission systems, improving reliability, and reducing operational energy consumption.

5.1 CONTRIBUTION OF THE STUDY TO THE EXISTING LITERATURE

This study provides a significant contribution to the existing body of literature on FM transmission systems by offering a detailed comparative analysis of three widely used antenna types: Dipole, Yagi–Uda, and Helical antennas. While prior research has examined these antennas individually or in limited comparative contexts, there remains a gap in comprehensive evaluations that simultaneously consider signal strength, coverage efficiency, and broadcast reliability within practical FM transmission scenarios. By conducting systematic calculations and simulations across the 88–108 MHz FM band, this research quantifies key performance metrics such as gain, beamwidth, front-to-back ratio, and effective coverage distance, enabling a direct comparison under consistent conditions.

Moreover, the study integrates theoretical formulations with practical design parameters, providing clear guidelines for antenna selection and deployment in FM broadcasting. Unlike many existing works that focus on laboratory-scale or idealized conditions, this research emphasizes real-world applicability, accounting for factors such as line-of-sight propagation, directional efficiency, and structural feasibility. The findings highlight the trade-offs between omnidirectional coverage of dipole antennas, directional gain of Yagi–Uda arrays, and the high directivity of helical antennas, thereby assisting broadcast engineers in optimizing system performance according to specific coverage requirements.

Ultimately, this work enriches the current literature by bridging theoretical analysis and practical design, offering both quantitative and qualitative insights that inform the selection of antennas for improved signal reliability and coverage efficiency. It also establishes a framework for future studies exploring hybrid antenna configurations, advanced modulation schemes, and cost-effective deployment strategies for FM broadcasting.

6. RECOMMENDATIONS

Based on the comparative analysis of Dipole, Yagi–Uda, and Helical antennas in FM transmission systems, it is recommended that broadcast engineers carefully select antenna types according to specific coverage and performance requirements. For local or community broadcasting, Dipole antennas offer simplicity and adequate omnidirectional coverage. Yagi–Uda antennas are suitable for medium-range transmission where directional gain and improved signal strength are priorities. Helical antennas should be considered for long-range, point-to-point applications requiring maximum gain and directivity, despite structural and deployment complexities. Additionally, future deployments may benefit from hybrid or adaptive antenna systems that combine the strengths of different types. Further research is recommended to optimize antenna placement, consider environmental effects, and integrate modern digital broadcasting technologies to enhance overall FM transmission reliability.

7. CONCLUSION

This study has presented a comprehensive comparative analysis of Dipole, Yagi–Uda, and Helical antennas in FM transmission systems, focusing on signal strength, coverage efficiency, and broadcast reliability. Through detailed calculations and performance evaluations, it has been demonstrated that each antenna type offers distinct advantages and trade-offs. The Dipole antenna provides simple construction and omnidirectional coverage, making it suitable for local broadcasting with modest infrastructure. In contrast, the Yagi–Uda antenna achieves higher gain and moderate directionality, offering improved range and coverage efficiency for targeted areas, while remaining cost-effective and relatively easy to deploy. The Helical antenna, operating in axial mode, delivers the highest gain and most focused directivity, enabling long-distance transmission; however, its structural complexity and narrow beamwidth limit widespread area coverage.

By systematically quantifying key performance parameters, this work informs the optimal selection of antennas based on the specific requirements of FM broadcasting applications, balancing coverage, reliability, and infrastructure considerations. The study's findings also provide a foundation for future research into hybrid antenna configurations, adaptive deployment strategies, and integration with modern digital broadcasting technologies. Overall, the research enhances the existing knowledge base and offers practical insights for broadcast engineers seeking to maximize FM transmission efficiency and reliability across diverse operational environments.

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