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Investigating the Effects of Temperature on Radio Signal Propagation at Frequency Modulation Band and Exploring Antenna Mitigation Strategies

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Abstract: *Wireless communication systems, particularly in radio broadcasting, are valued for their cost-effectiveness and ease of deployment. However, ensuring high signal quality remains critical, especially given the significant impact of environmental factors such as temperature fluctuations on radio propagation. This study investigates the effects of temperature on the radiation patterns of FM radio antennas using a locally engineered FM transmitter. By systematically comparing three antenna configurations: wire monopole, parabolic reflector, and loop, under identical weather conditions, our experimental results demonstrate that the wire monopole antenna outperforms the parabolic reflector and loop antennas by 4.4% and 11.9%, respectively. These findings highlight the necessity of accounting for temperature variations in FM broadcasting system design and provide a foundation for the development of more robust, weather-resilient antenna solutions.*
Keywords: *Antenna Design, Mitigation Techniques, Solar Radiation, Radio Signal and Frequency Modulation.*

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I. INTRODUCTION

Radio signal propagation, especially in the Frequency Modulation (FM) band, plays a critical role in communication systems, enabling effective broadcasting with minimal interferences over wide areas [1]. However, signal quality and strength are susceptible to various environmental factors, one of the most significant being solar radiation. Solar radiation, primarily from the sun's intense electromagnetic emissions, directly affects the ionosphere, a key atmospheric layer responsible for radio wave reflection and refraction. Solar activities such as sunspots, solar flares, and geomagnetic storms can alter the ionospheric conditions, leading to signal fading, interferences, and loss of transmission clarity, commonly referred to as ionospheric scintillation. [2].

In regions or seasons with a high solar radiation, FM radio signals often experience anomalies such as phase shifts, doppler shifts, and increased noise levels, which can degrade the quality of signal transmission [3]. This interference presents challenges to both broadcasters and listeners, particularly during periods of high solar activity. Consequently, there is a need to develop strategies and models to mitigate the impact of solar radiation on FM radio transmissions [4]. This study focuses on exploring different antenna techniques and impact on the quality of FM radio signals, to enhance communication stability and reliability under varying weather conditions. Solar radiation, known to cause signal degradation through phenomena such as increased noise and signal attenuation, poses a significant challenge to FM radio signal transmission [5]. As weather patterns become increasingly unpredictable, the need for robust solutions to maintain consistent signal quality is paramount. To address this issue, this research involves the design, construction and evaluation of three different antenna types: the wire monopole, parabolic reflector, and loop antennas. Each antenna type was designed with varying dimensions to assess how design parameters influence signal performance under the influence of solar radiation. The selection of these antenna designs is strategic, as each offers distinct advantages. The wire monopole is known for its simplicity and broad frequency coverage, the parabolic reflector for its high gain and directional capabilities, and the loop antenna for its sensitivity and compact design [6].

The experimental approach included systematic measurements of FM radio signal strength, quality, and stability while correlating these parameters with recorded solar radiation data, by analyzing signal behavior in response to fluctuations in solar radiation, the study aims to identify optimal antenna configurations and designs that can minimize signal loss and enhance reception clarity. [7]. The research also examines the interplay between antenna dimensions such as length, curvature, and surface area and their effectiveness in mitigating the adverse effects of solar radiation. This study is expected to contribute to the development of adaptive antenna systems capable of dynamically adjusting to environmental changes, thereby ensuring uninterrupted FM radio communication. The practical implications extend to broadcast industries, emergency communication systems, and rural areas where reliable FM signals are crucial. Furthermore, the insights gained could influence antenna design principles in broader communication technologies, promoting resilience against weather-induced signal disruptions. [8].

Ultimately, this research aims to bridge the gap between antenna design and environmental adaptability, offering a pathway to more resilient and high-performance communication systems in the face of changing solar radiation patterns. The paper is structured as follows: introduction in (Section 1), literature review in (Section 2), methodology in (Section 3), results and discussions in (Section 4), and conclusion and future directions in (Section 5).

II. REVIEW ON SIGNAL PROPAGATION

The Earth's atmosphere, comprising five main layers distinguished by temperature, composition, and altitude (see Table 1), allows radio signals in the frequency modulation (FM) band to propagate for widespread audio broadcasting.

Table 1: Atmosphere divide and its Composition

Divide	Layers	Temperature	Weather Composition
Troposphere	Lowest (0 – 7.5 miles)	Decrease with Altitude	Cloud, Precipitation
Stratosphere	Above Troposphere (7.5 31 miles)	Increase or remain constant with Altitude	Ozone Layer
Mesosphere	Above Stratosphere (31 – 53 miles)	Decrease with Altitude	Atmospheric Pressure Decreases
Thermosphere	Above mesosphere (53 – 373 miles)	Increases with Altitude	Aurora borealis and australis
Exosphere	Outermost layer (373 - 6,200 miles)	Interacts with solar wind and interstellar space	Atmospheric particles escape into space

Source: http://www.nasa.gov./planetarydefense, accessed on 28th September, 2024 by 12pm.

The Earth's atmospheric layers and composition as depicted in Table 1 significantly impact FM signal propagation. FM signals are absorbed by water vapor and oxygen in the troposphere, leading to attenuation, and scattered by rain, fog, and clouds, causing signal loss. Temperature gradients in the troposphere also bend FM signals, affecting their direction [3]. Additionally, the ozone layer in the stratosphere absorbs FM signals, particularly at higher frequencies, while the stable temperature minimizes signal refraction. In the mesosphere, atmospheric particles scatter FM signals, and increasing atmospheric density absorbs them [9]. Furthermore, ionized particles in the thermosphere and exosphere refract FM signals, affecting propagation, and high-energy particles absorb them. Lower FM frequencies propagate better than higher frequencies through the atmosphere. terrain, obstacles, and atmospheric conditions, such as hills, buildings, and vegetation, also impact FM signal strength [1]. Moreover, time of day and season affect FM signal propagation due to changing solar radiation and atmospheric conditions.

Overall, radio telecommunication researchers have made diverse attempt in understanding the effect of the weather compositions on radio signal degradation, of such work is the tremendous study on the growing of wireless communication by (Jayalakshmi *et. al.,* 2014). The study laid emphases on wireless communication system as replacement to long wired communication system along with the provision of a real – time weather monitoring system at FM band channel. Finally, the research concluded that knowing the effect of the weather components on wireless communication system will provide room for the development of a compact, robust and resilient wireless communication networks at different weather conditions.

Roshidah *et. al.,* (2016), investigated weather (temperature) effect on radio propagation at 9GHz band. The research employed the used of patch antenna and a continuous wave envelope fading waveforms were recorded over a period of one hour. Overall, the study presented that there was a relationship between radio signal with changes in temperature.

The reviewed study by Felix *et al.,* 2024) evaluated the influence of atmospheric temperature, relative humidity, and atmospheric pressure on FM radio signal strength across different seasons. The research found that radio signal strength was lowest during the rainy season, while improved signal quality was observed in the dry season. This seasonal variation highlights the impact of weather conditions on FM signal propagation, where increased moisture and atmospheric disturbances during the rainy season can lead to greater signal attenuation and interference. Additionally, the review considers the influence of antenna design and placement on signal performance under varying weather conditions. Vertical antennas are noted for their effectiveness in urban environments, where they are less affected by obstructions like buildings, while horizontal antennas may provide better performance in open areas but are more susceptible to multipath effects. Directional antennas, such as Yagi or parabolic types, offer the advantage of focusing signals in specific directions, thereby minimizing interference and maintaining stronger signal quality during adverse weather conditions (Balanis, 1992).

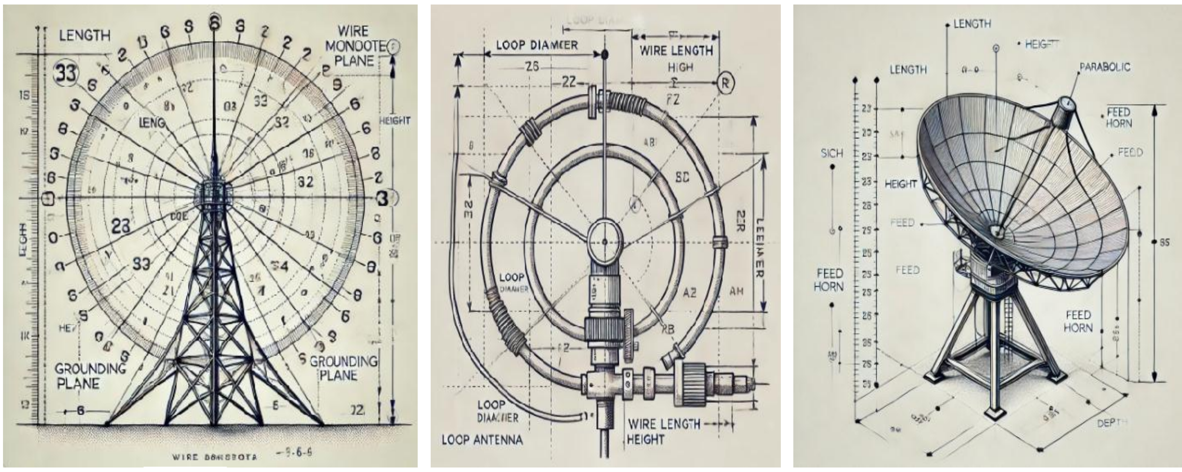
Material choice is also crucial in antenna design, using corrosion-resistant materials like stainless steel or aluminum can help maintain performance over time, particularly in harsh weather environments. The strategic placement of antennas at higher elevations can reduce the impact of ground-level obstructions, such as trees and buildings, which are more problematic during windy or rainy conditions. Moreover, antenna designs that prevent water pooling can mitigate signal degradation caused by water absorption (Cho and Byun, 2019).

While it is impossible to eliminate the effects of weather on radio signals, the integration of optimal antenna shapes, materials, placement strategies, and advanced technology can significantly enhance signal resilience. These strategies contribute to more reliable FM radio communication across diverse environmental conditions. This study aims to contribute academically by bridging the gap between antenna design and environmental adaptability. It will provide insights into how specific design considerations can mitigate weather-induced signal degradation. The findings are expected to enrich the existing knowledge and offer practical guidelines for designing robust antenna systems capable of maintaining stable FM radio signal quality in challenging weather conditions.

III. METHODOLOGY OF THE STUDY

I. Research designs and calculations

This study adopts an experimental design and construction techniques as depicted in Figure 1 for the development of each of the antenna types and the study of temperature's effect on the signal propagation patterns of FM radio antennas. Field measurements were conducted to assess variations in antennas' performances under the same weather conditions.



(a) (b) (c)

Fig.1: Design dimensions for the (a) wire monopole, (b) loop and (c) parabolic reflector antennas using Inkscape open-source tools

a. Wire monopole antenna

A wire monopole antenna is typically a quarter – wavelength antenna. The design formula is as expressed in (1) by [10]

$$L = \frac{c}{4f} \quad (1)$$

where L is the length of the antenna, c is the speed of light, and f is the frequency of operation.

b. Loop antenna

A single-turn small loop antenna, the formula for the circumference is

$$C = \frac{3*10^8}{100*10^6*\pi} = 0.95m \quad (2)$$

The diameter of the loop

$$D = \frac{C}{\pi} = \frac{0.95}{\pi} = 0.30 \quad (3)$$

c. Parabolic reflector

The gain of a parabolic reflector antenna is as expressed in (4) by [11]

$$G = \frac{4\pi A}{\lambda^2}\eta \quad (4)$$

where A is the aperture area, η is the efficiency (typically 0.55 to 0.70) and λ is the wavelength. An FM transmitter converts audio signals into radio waves for broadcast. The Printed circuit design depicted key stages: the audio input feeds into a modulator, where the audio signal modulates the frequency of a carrier wave. The modulated signal then passes through an oscillator, a frequency multiplier, and a power amplifier to boost signal strength. Finally, the antenna transmits the amplified FM signal. The circuit diagram details components like transistors, capacitors, and inductors, showcasing the electronic design that enables efficient modulation, amplification, and transmission of FM signals for clear and stable radio broadcasts.

Frequency of Oscillator for a tuned LC circuit, the frequency is as expressed in (5) by (ref)

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

where L and C are the inductor and capacitor in henry and farad respectively.

II. Study variables

- Independent Variable: Temperature (measured in Degree Celsius)
- Dependent Variable: Radiation pattern characteristics such as signal strength.

Control Variables: Antennas (parabolic reflector, loop antenna and wire monopole), frequency of operation (89.9MHz) and transmitter power (1Watts).

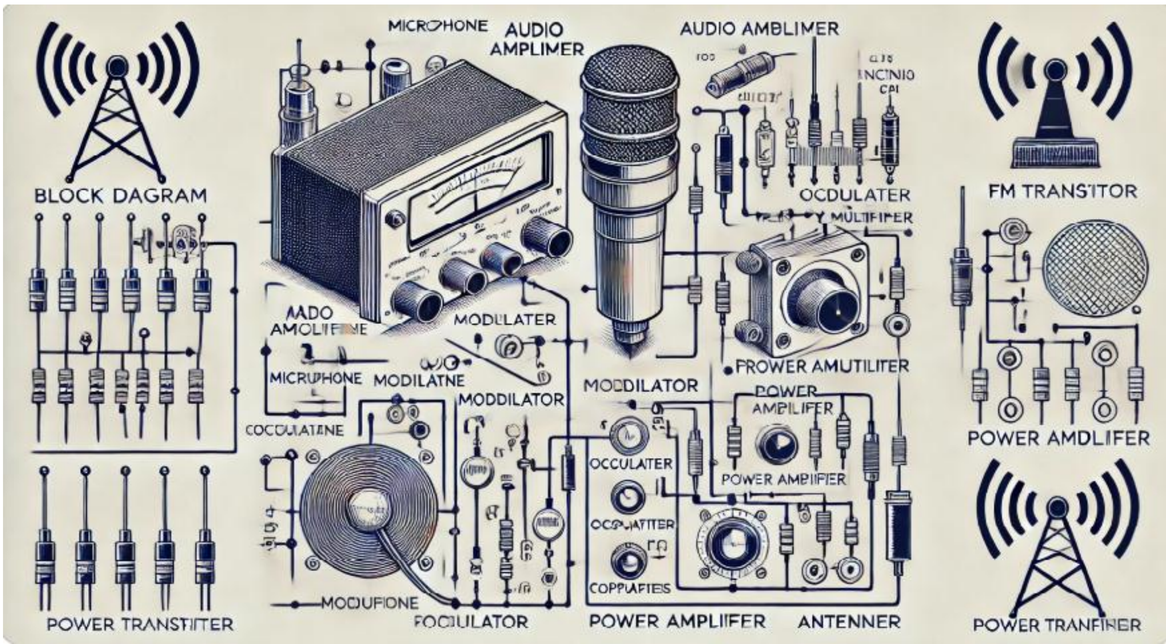


Fig. 2: The Printed Circuit Design using Inkscape open-source tool.

III. Experimental Setup

FM radio antennas were connected to the locally made transmitter in a laboratory as depicted in Figure 3, to create a mini studio. The setup includes:

- A temperature-measuring device.
- A spectrum analyzer to measure radiation patterns in form of signal strength.

Fig. 3: The Mini Experimental Setup

IV. Data Collection

- Laboratory Work: Each of the FM antennas was connected to the transmitter one after the other.
- Field Work: The values of temperature and the signal strength were taken using temperature-measuring device and signal analyzer respectively.

V. Data Analysis

- A Statistical tool i.e regression analysis was used to determine the correlation between temperature changes and variations in radiation patterns / signal strength.
- Temperature and signal strength graphs were plotted to identify the antenna with better performance.

VI. Mathematical Concepts

Regression Analysis

The general form of a linear regression model is presented in equation 7 by (ref)

$$Y = a_o + bx \tag{6}$$

where y is the dependent variable, e.g. signal strength, x is the independent variable, e.g. temperature, a_o is the intercept of the regression line / the regression coefficients, b is the slope of the regression line a_o was estimated to be 5436.6, and b was 0.2.

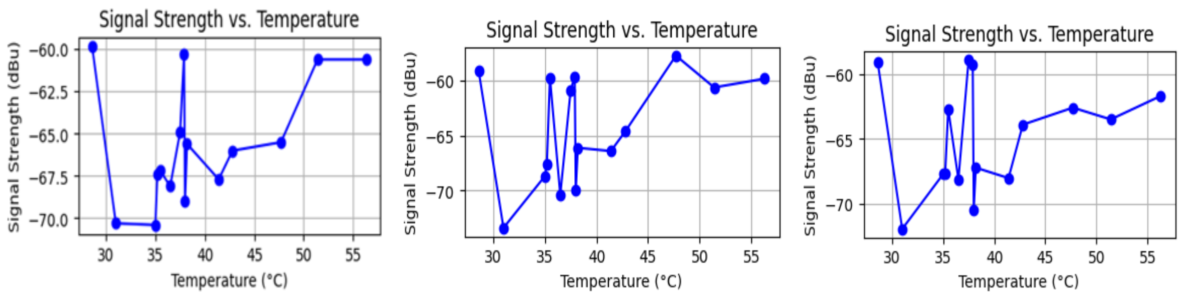
$$y = 5436.6 + 0.2x \tag{7}$$

Equation 8 shows that for each one unit increase in the value of temperature, the signal strength increases by 0.2.

IV. Results and Discussions

The results of the field work carried out on the locally made transmitter with 1Watt power and operating frequency of 88.9 MHz were presented in Figure 4. The graphs of temperature and signal strength of the FM radio signal on the application the three different types of antennas are separately shown in Figures 1-3, while Figure 4 depicts and compares the results of all the radiators. It can be deduced from the results that increased temperature has a slight effect on the signal strength of the FM radio signal.

Due to the ionization effect of the solar radiation on the layer of the atmosphere that serves as reflector to the FM radio signal, some portions of the signals are scattered and the resultant signal that reaches the required destination is reduced in strength. This practically indicates that the increased temperature slightly reduces the strength of the FM radio signal. However, from the results of the experiment carried out, the adverse effect of the increased temperature is minimum with the application of wire monopole antenna.



(a) (b) (c)

Fig. 4: Signal Strength variation with Temperature for (a) wire monopole antenna, (b) parabolic reflector and (c) loop antenna

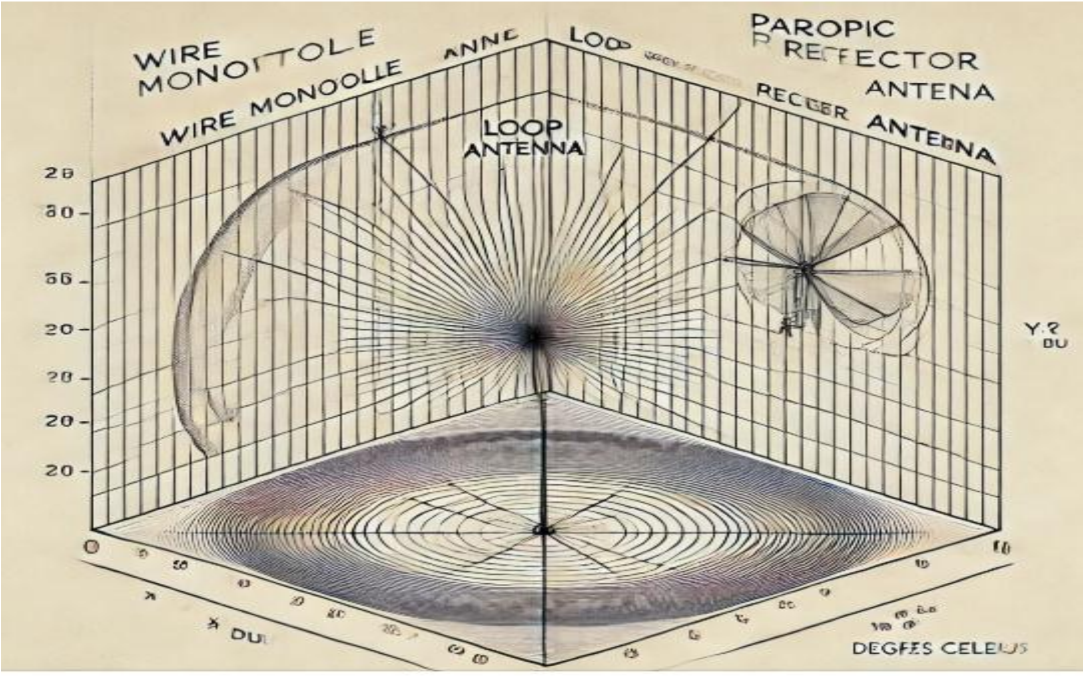


Fig. 5: One-Dimension (1D) Radiation patterns of the wire-monopole, parabolic reflector and loop antenna

The graph of Figure 5 displaying the radiation patterns of the wire monopole, loop antenna, and parabolic reflector antenna offers valuable insights into their directional characteristics and performance. Wire Monopole Antenna typically exhibits an omnidirectional radiation pattern in the horizontal plane, resembling a doughnut shape in 3D but appearing as a uniform line in the 1D graph. The 1D graph should show relatively consistent signal strength around the antenna, highlighting its ability to receive and transmit signals equally well in all horizontal directions. This makes the wire monopole ideal for broadcasting and situations where signal direction is not fixed.

Loop antenna generally shows a bidirectional radiation pattern with nulls (weak points) at specific angles. In the 1D representation, this would manifest as peaks of signal strength along two opposite directions with reduced strength (or dips) at 90 degrees to those directions. The loop antenna's pattern makes it useful in applications requiring specific directionality or noise rejection, as it can minimize interference from unwanted directions. The parabolic reflector antenna demonstrates a highly directional radiation pattern, characterized by a sharp, narrow peak in the 1D graph. This indicates its focused beam and strong signal strength in a particular direction, with rapid signal drop-off outside this beam. This design is advantageous for point-to-point communication and applications requiring precise targeting, such as satellite dishes and long-distance communication links.

V. Conclusions and Recommendation

FM radio transmission is a popular process of transmitting radio signal using frequency modulation. It is widely used for broadcasting high-fidelity sound over the radio particularly in the 88 – 108 MHz frequency range. Therefore, it is very essential to carry out research on the FM radio system, to ensure its effectiveness by giving a technical guide to its users to satisfy the need of the audiences. As a result, this research is one of its kind that proffers solution to the problem encountered along the transmission path of FM radio signal. The research serves as a benchmark for the use of antenna to optimize the signal quality of FM system.

The three antenna types selected for the research are: wire monopole, parabolic reflector and loop antenna. The wire monopole antenna was observed to be the suitable antenna for use during the hot climatic condition when the ambient temperature is always at peak. This research is a clue for radio system engineers who are into antenna design for the FM radio broadcasting stations to solve the problem of antenna selection and effective radio transmission.

For future research, it is advisable to apply a novel method of optimization such as Machine Learning to the FM radio systems, and even a forecast can be made on the radiation patterns of the antennas as well as the channel characteristics.

References

[1]. N. M. Rodrigues, F. M. Janeiro, and P. M. Ramos, "Influence of Weather Conditions in Power Quality Events," in *2020 IEEE 14th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, Setubal, Portugal: IEEE, Jul. 2020, pp. 219–223. doi: 10.1109/CPE-POWERENG48600.2020.9161676.

[2]. P. E. Afolabi, S. Oluwole Ikubanni, B. O. Adebesin, S. John Adebiyi, and E. F. Adeleke, "Effects of Weather Parameters on Signal Attenuation: A Brief Review," in *2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG)*, Omu-Aran, Nigeria: IEEE, Apr. 2024, pp. 1–5. doi: 10.1109/SEB4SDG60871.2024.10629947.

[3]. Roslan Umar, Shahirah Syafa, Atiq Wahidah Azlan, and Zainol Abidin Ibrahim, "Radio Frequency Interference: The Study of Rain Effect on Radio Signal Attenuation," *Malays. J. Anal. Sci.*, vol. 9, no. 2, pp. 1093–1098, 2015.

[4]. O. Laptiev, I. Polovinkin, S. Vitalii, O. Stefurak, O. Barabash, and O. Zelikovska, "The Method of Improving the Signal Detection Quality by Accounting for Interference," in *2020 IEEE 2nd International Conference on Advanced Trends in Information Theory (ATIT)*, Kyiv, Ukraine: IEEE, Nov. 2020, pp. 172–175. doi: 10.1109/ATIT50783.2020.9349259.

[5]. H. Chiroma *et al.*, "Large scale survey for radio propagation in developing machine learning model for path losses in communication systems," *Sci. Afr.*, vol. 19, p. e01550, Mar. 2023, doi: 10.1016/j.sciaf.2023.e01550.

[6]. M. Ayadi, A. Ben Zineb, and S. Tabbane, "A UHF Path Loss Model Using Learning Machine for Heterogeneous Networks," *IEEE Trans. Antennas Propag.*, vol. 65, no. 7, pp. 3675–3683, Jul. 2017, doi: 10.1109/TAP.2017.2705112.

[7]. R. Gray and M. DiBenedetto, "RF Coupling Simulation Model Development for Optimal Placement of Antennas Supporting Wireless Communications Systems," in *2009 Joint Rail Conference*, Pueblo, Colorado, USA: ASMEDC, Jan. 2009, pp. 297–302. doi: 10.1115/JRC2009-63036.

[8]. C. Nguyen and A. A. Cheema, "A Deep Neural Network-Based Multi-Frequency Path Loss Prediction Model from 0.8 GHz to 70 GHz," *Sensors*, vol. 21, no. 15, p. 5100, Jul. 2021, doi: 10.3390/s21155100.

[9]. L. E. Pineda and P. Willems, "Rainfall extremes, weather and climate drivers in complex terrain: A data-driven approach based on signal enhancement methods and EV modeling," *J. Hydrol.*, vol. 563, pp. 283–302, Aug. 2018, doi: 10.1016/j.jhydrol.2018.05.062.

[10]. Y. H. Cho and W. J. Byun, "Generalized Friis Transmission Equation for Orbital Angular Momentum Radios," *IEEE Trans. Antennas Propag.*, vol. 67, no. 4, pp. 2423–2429, Apr. 2019, doi: 10.1109/TAP.2019.2891438.

[11]. M. Cheffena and M. Mohamed, "Empirical Path Loss Models for Wireless Sensor Network Deployment in Snowy Environments," *IEEE Antennas Wirel. Propag. Lett.*, pp. 1–1, 2017, doi: 10.1109/LAWP.2017.2751079.

[12]. Roshidah M., Marhamah M. S., Sabir A., Roslau U., Yew-Been S. and Nor-Hazmin S. (2016). Temperature effect on the Tropospheric Radio Signal Strength for UHF Band at Terengganu, Malaysia. *Information Journal on Advances Science Engineering Information Technology*, 6(5), ISSN: 2088-5334.