International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

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Design, Development and Evaluation of Directional Yagi-Uda Antenna Transmitter for an Amateur FM Radio Station at Cavite State University – Main Campus

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International Journal of Science and Research Archive, 2026, 18(01), 315-324

Publication history: Received on 04 November 2025; revised on 6 January 2026; accepted on 8 January 2026

Article DOI: https://doi.org/10.30574/ijsra.2026.18.1.0053

Abstract

This study describes the design, development and evaluation of a directional Yagi-Uda antenna transmitter for an amateur FM radio station at the main campus of Cavite State University. The antenna was made of an aluminum rail with a 9.525 mm diameter that includes two directors, a reflector, and a driving element. The Directional Yagi-Uda Antenna Design is the focus of the research goals for the Amateur Radio Station at Cavite State University's Main Campus, which include increasing signal strength, maximizing antenna gain, and reducing interference from unwanted signals and noise sources. These goals are intended to increase signal transmission range by at least 30%. The antenna has an operational frequency range of 88.7 MHz. A measured gain of 7.88 dBi was obtained after simulation using the YagiMAX ver. 3.11 program to assess the design attributes. Following testing at the Department of Computer and Electronics Engineering building, the prototype antenna successfully transmitted signals from the rooftop. Audible sound reception was accomplished throughout the university, with open sections experiencing particularly good reception. This study showcases the effective use of the directional Yagi-Uda transmission antenna and its enhanced signal reception capabilities for the amateur FM radio station at Cavite State University's Main Campus.

Keywords: Yagi Uda Antenna; Transmitter; Directivity; Frequency Modulation; Amateur FM Station

1. Introduction

A shared understanding and the mechanism for information transfer between two people are the two main components of communication. Electronic communication has established itself as a reliable and quick method of communication. This method of communication uses data, which can include speech, text, graphics, or any other form of shareable information. The most well-known application of radio waves, a form of electromagnetic radiation, is in conventional communication systems [1]. Electromagnetic energies are transmitted via antennas as radio waves [2]. An antenna is a device that converts a radio frequency signal into an electromagnetic wave in free space traveling along a conductor. It is seen as being a necessary component of communication systems [3]. An antenna is a device that emits directed signals to radiate waves in empty space and the other way around (in either the transmitting or receiving mode of operation) [4]. Reciprocity is a trait of antennas that allows them to maintain the same attributes whether they are used for transmitting or receiving. There are several particular parameters that are frequently seen and are taken into consideration when conducting analyses. These consist of radiation pattern, gain, and directivity. The antenna's directivity refers to its ability to focus energy in a specific direction [5]. The design of the antenna affects its gain. Relative field strength at a fixed distance in various directions from the antenna is determined by the radiation pattern. The radiation pattern serves as both an indication of the antenna's receiving characteristics and a pattern of reception [3].

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Heinrich Hertz's early work in the 1880s, which sought to prove the presence and propagation of free space electromagnetic waves, can be linked to the invention of radio wave wireless power transfer [6]. The wavelength, frequency, and speed of these waves are specifically described [7]. The speed formula, where the rate is the product of the distance traveled and the time required by one wave, describes the relationship between the three. $\lambda=c/f$, Where c denotes the speed of light in a vacuum, which is represented by the celeritas letter in Latin and is regarded as a constant in all reference frames [8]. Equation 1 is helpful in determining the lengths of the Yagi antenna parts [9]. The range of electromagnetic waves known as radio waves that are generated by transmitters and absorbed by antennas make up the radio frequency spectrum. For communication, it uses frequencies between 3 Hz to 300 GHz [10].

The goal of antenna transmitter design is to achieve the ideal radiation distribution by manipulating currents, sometimes referred to as its pattern [11]. Elementary dipoles and monopoles are the smallest and most non-directional antennas. In the HF (3-30MHz), VHF (30-300MHz), and UHF (300-3000MHz) frequency bands, Yagi antennas are employed [12]. It is a highly directional antenna made up of a series of dipoles, a group of parasitic elements located behind the driving element, several directors, and a reflector, when properly aligned, enhances the antenna's radiating qualities [13]. One of the highest established gain antennas is a simple Yagi. A Yagi's performance is influenced by numerous things. These include the amount of elements used, their size, and the distance between elements [14]. In 1926, in Sendai, Japan, Assistant Professor Shintaro Uda and his instructor Professor Yagi jointly developed the Yagi-Uda antenna [15]. Reflectors and directors are believed to be the parasitic components of the Yagi-Uda antenna, which is considered to be a directional antenna [16].

Antennas are continually being innovated and enhanced to support modern communication systems by improving bandwidth, size, adaptability, and performance [17]. Antennas must be carefully designed to be efficient, small, safe, and high-performing, and that new, innovative antenna designs are needed to meet the growing demands of modern communication systems [18]. Antenna technology must continuously evolve to meet the growing demand for efficient wireless communication [19]. Different types of antennas have unique advantages and limitations, and their suitability depends on trade offs between size, cost, and performance for specific wireless communication applications [20].

The researchers provided a list of probable limitations of the study which are the following: Environmental Factors: The performance of the antenna may have been impacted by factors in the environment, such as the weather, temperature variations, and topography. Signal degradation or misalignment of the antenna elements may have occurred as a result of specific weather conditions, such as intense rain or powerful winds.

2. Materials and Methods

2.1. Materials

An overview of the components utilized to build the proposed Yagi-Uda antenna is provided in the table below.

Table 1 Materials

Materials	Specifications
Transmitter	Transmitting Power = 1W
RG58 Coaxial Cable	1 meter
Aluminum Square Beam Pipe	5.9ft
Aluminum Tube Pipe	20.17ft

2.2. Methods

A reflector, driven element, and two directors make up the unidirectional antenna that is being suggested. The frequency at which this antenna will function is 88.7 MHz. This antenna uses RG-58 coaxial cable, which has a 50ohm impedance. YagiMax 2.21 was employed in the design of the suggested antenna.

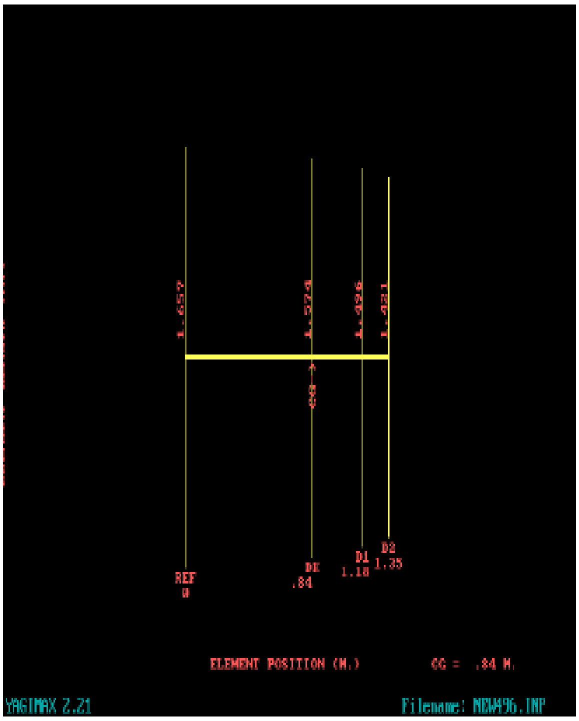


Figure 1 The projected Yagi-Uda antenna's YagiMax 2.2 design

2.3. Design Consideration

The length of the reflector is typically 5% longer than the driven element and varies on the sizes and diameters of each individual element. About 0.1-0.25λ is the spacing between the reflectors. The input impedance and gain of the antenna are both impacted by the reflector [6].

The center of the dipole element is the feed point where the greatest power transfer takes place. The driving element often takes a linear form, though it is also foldable [4].

The director is the element with the shortest length, which is less than 5% of the length of the dipole. Depending on the antenna's framework, its spacing ranges from 0.1 to 0.5 λ. The number of directors has an impact on the directive gain as well. The directed radiation pattern and its directive gain are both enhanced by increasing the number of directors.

The equation $\lambda = c/f$ provided the mathematical computation for the elements' length and spacing. The dimensions were determined using this formula.

Reflector's Length, RL = 0.49λ;

Dipole's Length, DiL = < 5% of RL;

1st Director's Length, D1L = < 5% of DiL;

2nd Director's Length, D2L = < 5% of D1L;

Spacing from the Reflector to the Dipole, SR-D = 0.25λ;

Spacing from the reflector to the 1st Director, SR-D1 = 0.348λ;

Spacing from the reflector to the 2nd Director, SR-D2 = 0.40λ;

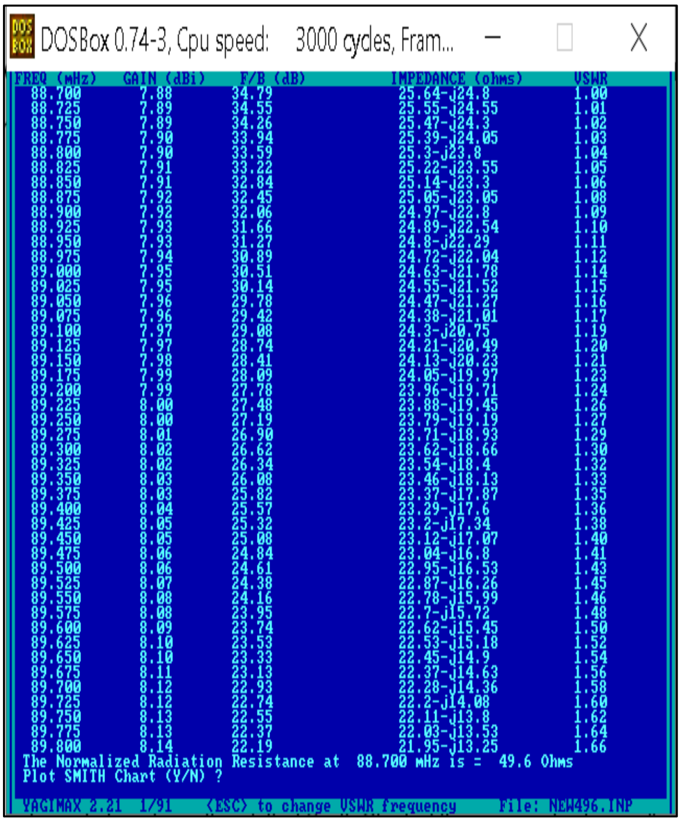
Employing the offered tools, a Yagi-Uda antenna can be designed in phases employing a number of important steps. Using a Yagi-Uda antenna design calculator, first figure out the operating frequency and then compute the lengths of the driving element, reflector, and directors. To the predicted lengths, cut the aluminum square beam pipe for the driving element and the aluminum tube pipe for the reflector and directors. Use the RG58 coaxial wire to connect the components, making sure to solder and ground everything properly. Test the antenna, check the SWR, and make any necessary adjustments to fine-tune it. The antenna should then be safely mounted in a suitable location, and its functioning should be thoroughly tested. By following these steps, a working Yagi-Uda antenna design utilizing the given tools will be produced. It costs 350 pesos to purchase the antenna. The price of the aluminum square beam pipe is exactly the same as the price of the aluminum tube pipe: $165. Based on their effectiveness and dependability, the materials utilized to create the antenna were evaluated. The length, spacing, and positions of each element are summarized in the table below.

Table 2 Dimensions of the Elements

	Length (m)	Spacing (m)	Position (m)
Reflector	1.6574	0	0
Driven	1.5745	0.8455	0.8455
Director 1	1.4958	0.3315	1.1770
Director 2	1.4210	0.1759	1.3529

3. Results

Utilizing YagiMAX version 2.2, the proposed antenna was created. This program is executed using the DOSBox DOS emulator as shown in Figure 2.



FREQ (mHz)	GAIN (dBi)	F/B (dB)	IMPEDANCE (ohms)	VSWR
88.700	7.88	34.79	25.64-j24.8	1.00
88.725	7.89	34.55	25.55-j24.55	1.01
88.750	7.89	34.26	25.47-j24.3	1.02
88.775	7.90	33.94	25.39-j24.05	1.03
88.800	7.90	33.59	25.3-j23.8	1.04
88.825	7.91	33.22	25.22-j23.55	1.05
88.850	7.91	32.84	25.14-j23.3	1.06
88.875	7.92	32.45	25.05-j23.05	1.08
88.900	7.92	32.06	24.97-j22.8	1.09
88.925	7.93	31.66	24.89-j22.54	1.10
88.950	7.93	31.27	24.8-j22.29	1.11
88.975	7.94	30.89	24.72-j22.04	1.12
89.000	7.95	30.51	24.63-j21.78	1.14
89.025	7.95	30.14	24.55-j21.52	1.15
89.050	7.96	29.78	24.47-j21.27	1.16
89.075	7.96	29.42	24.38-j21.01	1.17
89.100	7.97	29.08	24.3-j20.75	1.19
89.125	7.97	28.74	24.21-j20.49	1.20
89.150	7.98	28.41	24.13-j20.23	1.21
89.175	7.99	28.09	24.05-j19.97	1.23
89.200	7.99	27.78	23.96-j19.71	1.24
89.225	8.00	27.48	23.88-j19.45	1.26
89.250	8.00	27.19	23.79-j19.19	1.27
89.275	8.01	26.90	23.71-j18.93	1.29
89.300	8.02	26.62	23.62-j18.66	1.30
89.325	8.02	26.34	23.54-j18.4	1.32
89.350	8.03	26.08	23.46-j18.13	1.33
89.375	8.03	25.82	23.37-j17.87	1.35
89.400	8.04	25.57	23.29-j17.6	1.36
89.425	8.05	25.32	23.2-j17.34	1.38
89.450	8.05	25.08	23.12-j17.07	1.40
89.475	8.06	24.84	23.04-j16.8	1.41
89.500	8.06	24.61	22.95-j16.53	1.43
89.525	8.07	24.38	22.87-j16.26	1.45
89.550	8.08	24.16	22.78-j15.99	1.46
89.575	8.08	23.95	22.7-j15.72	1.48
89.600	8.09	23.74	22.62-j15.45	1.50
89.625	8.10	23.53	22.53-j15.18	1.52
89.650	8.10	23.33	22.45-j14.9	1.54
89.675	8.11	23.13	22.37-j14.63	1.56
89.700	8.12	22.93	22.28-j14.36	1.58
89.725	8.12	22.74	22.2-j14.08	1.60
89.750	8.13	22.55	22.11-j13.8	1.62
89.775	8.13	22.37	22.03-j13.53	1.64
89.800	8.14	22.19	21.95-j13.25	1.66

The Normalized Radiation Resistance at 88.700 mHz is = 49.6 Ohms
Plot SMITH Chart (Y/N) ?

YAGIMAX 2.21 1/91 <ESC> to change VSWR frequency File: NEW496.INP

Figure 2 The 88.7 MHz proposed antenna's Forward Gain, F/B, Impedance, and VSWR were generated by the YagiMax program

A polar and linear plot were provided. The SWR (Standing Wave Ratio) is 1:1 with 50 ohms of coaxial cable connected directly to the dipole element, while the impedance at the center frequency (88.7MHz) is 49.6 ohms as shown in Figure 3. This ratio indicates how closely the impedances of the source and load are matched. The front-to-back ratio only describes the radiation intensity coming from the directional antenna's back.The antenna has an F/B of 34.79 dB and an overall gain of 7.88 dBi. This gain identifies the antenna's ability to steer radiation in a particular plane.

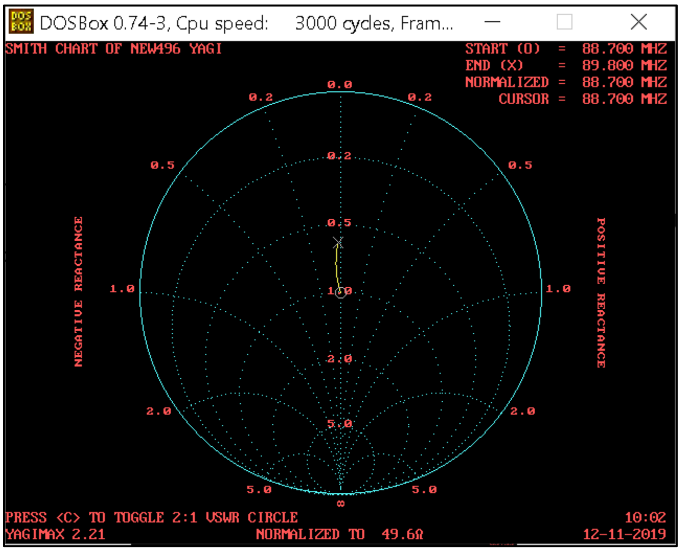


Figure 3 Smith Chart data plotted at the proposed antenna's normalized impedance

A classic visual representation of an antenna's directional features is its radiation pattern. The E-plane has the greatest amount of electric field vector along the vertical direction as shown in Figure 4 and 6, while the H-plane has the greatest amount of magnetic field vector as shown in Figure 5and 7. At the major lobe, there lies the greatest amount of radiation. The antenna's directivity is revealed by its direction. Where the excess radiation is wasted is indicated by the minor lobes, which are positioned behind the major lobes.

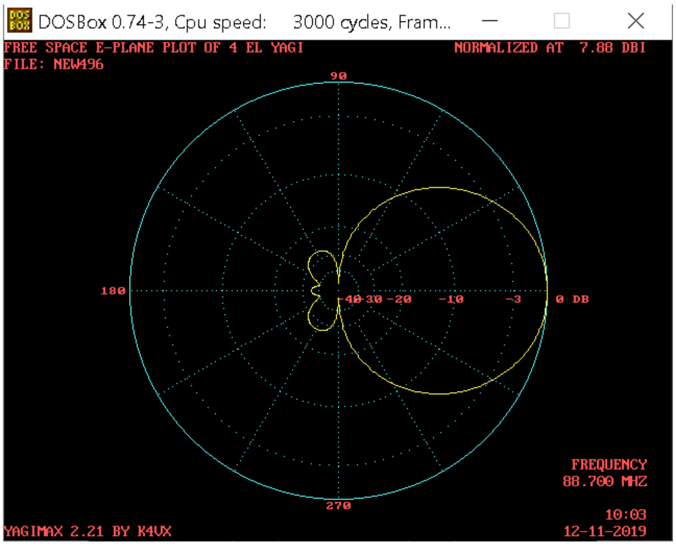


Figure 4 Polar Plot of the Azimuthal "E-Plane"

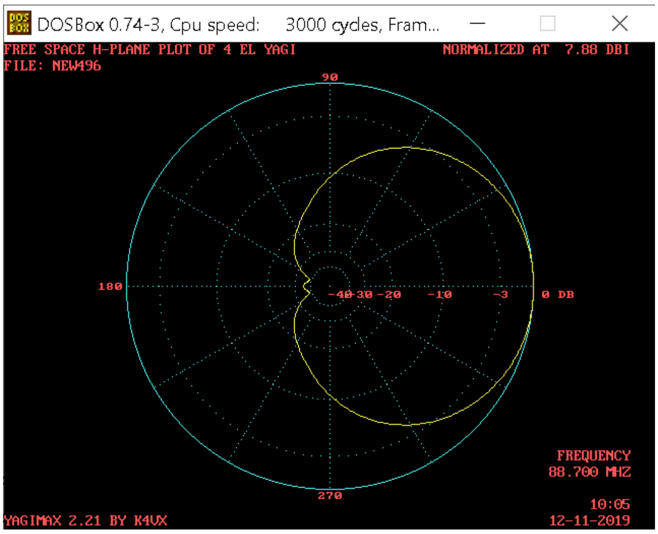


Figure 5 The Polar Plot of the Elevation "H-plane"

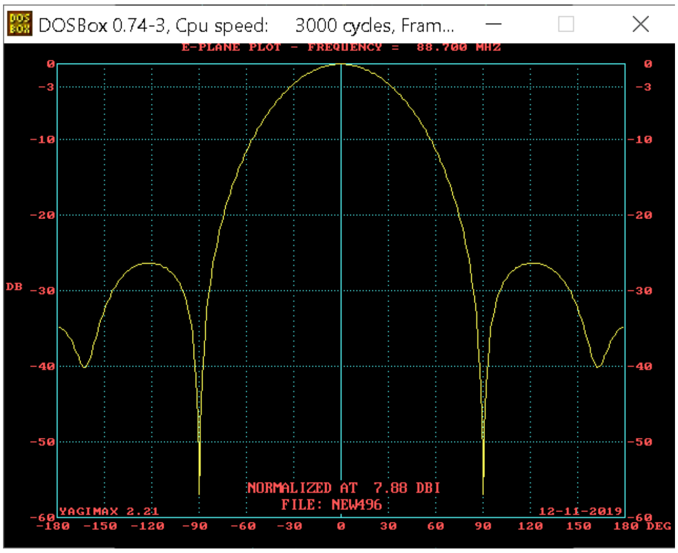


Figure 6 The Linear Plot of the Azimuthal "E-Plane"

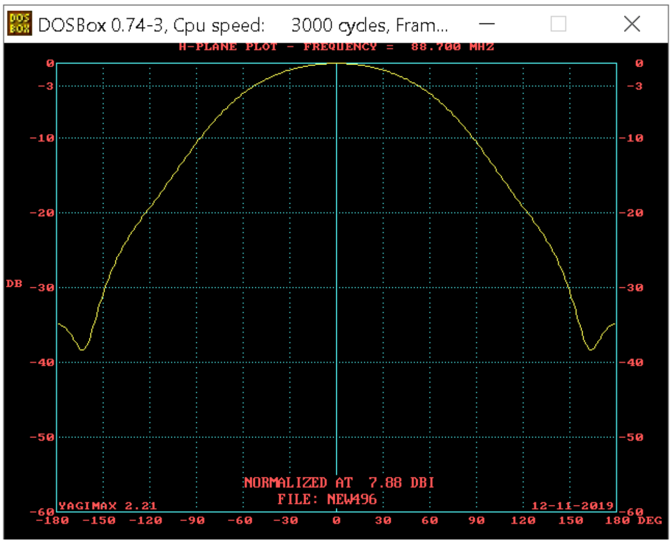


Figure 7 The Linear Plot of the Elevation "H-plane"

3.1. Evaluation of the Developed antenna

Figure 8 The picture of the actual developed antenna

Figure 9 The directivity of the antenna around CvSU-Main Campus Map

The developed transmitter antenna was shown in Figure 8. The main campus of Cavite State University served as the location for the antenna's testing and evaluation. Since the amateur FM radio station was located at the Department of Computer and Electronics Engineering (DCEE) Building, its rooftop served as the location of testing for the antenna's radiation. The main objective was to direct the radiation inside the CvSU premises and avoid radiation outside the university premises. Upon testing the antenna's range of broadcast includes the areas between the University Gates 1 and 3, the International Building and the Administration Building, SAKA and the College of Arts, and the College of Veterinary Medicine and the DCEE Building. Most of the time while evaluating the antenna, the clean broadcast was obtained. There was a small amount of transmission distortion in one occasion. It was discovered that open spaces facilitate clear transmission more so than enclosed spaces.

Directive gain, impedance, and the antenna's radiation pattern are all greatly influenced by the length and spacing of the elements. It was found that as the number of directors increased, so did the antenna's gain. In order to obtain optimal impedance matching and optimum power transfer from the antenna, the right coaxial cable must be utilized. It was discovered that a signal would be distorted by inappropriate impedance matching. For an antenna to be of high quality, it must also have a decent radiation pattern.

4. Conclusion

The selection of an appropriate antenna type is crucial for the performance and functionality of an amateur radio transmitter station. The researchers conducted a comparative analysis of four commonly used antenna types: Yagi-Uda, Dipole, Patch, and Parabolic Dish antennas. By examining their respective strengths and limitations, we can determine the most suitable antenna type for the amateur radio transmitter station at Cavite State University - Main Campus. Each antenna type possesses distinct advantages and limitations. The Yagi-Uda antenna stands out with its high gain, good directivity, and interference rejection, making it suitable for long-range communication. The dipole antenna provides omnidirectional coverage but with lower gain and directivity. Patch antennas offer versatility and compactness but have lower gain and directivity. Parabolic dish antennas excel in high-gain directional communication but have limited coverage and require precise alignment. To determine the most suitable antenna type for the amateur radio transmitter station at Cavite State University - Main Campus, considerations was given to the specific requirements and constraints of the station. All areas of the Cavite State University-Main Campus are covered by the projected Yagi-Uda antenna's transmission. The antenna has a frequency of 88.7 MHz, an adequate impedance of 49.6 ohms, and a gain of 7.88 dBi for clear transmission. A good transmission requires consideration of the antenna's gain, impedance, and radiation pattern. Being a directional antenna by design, the antenna mostly transmitted in all directions. A thorough performance analysis using the Directional Yagi-Uda Antenna Design of the Amateur FM Radio Station at Cavite State University's Main Campus reveals several significant performance indicators. The antenna's measured gain, 7.88 dBi, indicates that it can boost signal power compared to an isotropic radiator. The antenna's radiation pattern is very focused, limiting radiation in the back and side lobes while concentrating energy in the desired direction. Overall performance is optimized via impedance matching, which provides effective power transfer between the antenna and the transmission line. The antenna's capacity to block signals from the back and minimize interference is also indicated by the front-to-back ratio. Taking into account these performance indicators enables a thorough assessment of the antenna's performance in terms of signal amplification, directionality, effective power transmission, and interference reduction for the Amateur FM Radio Station. In terms of cost-effectiveness and good transmission, the proposed antenna is generally satisfactory.

4.1. Future works

The future works of this paper are in the following:

- Incorporation of Smart Antenna Technologies: Smart antenna technology advancements have a considerable potential to boost the efficiency of amateur radio transmitter stations. Future research should look into how adaptive beamforming, spatial filtering, and other signal processing methods might be combined to reduce interference, enhance signal quality, and expand system capacity. Better communication range, less signal fading, and a higher signal-to-noise ratio can result from these improvements.
- Computer-Aided Design (CAD) Optimization: Make the antenna's design as efficient as possible. Researchers can modify the Yagi-Uda antenna's size, spacing, and other parameters for greater gain, directivity, and radiation pattern features by using simulation and optimization techniques.
- Advanced Materials and Components: Consider the use of advanced materials and components in antenna design. Investigate the possible benefits of adopting high-quality conductive materials, enhanced connectors, and improved feed lines to increase overall antenna performance, including gain, bandwidth, and impedance matching.

- Remote Monitoring and Adjustment: Enabling remote monitoring and adjustment of the antenna system. This would allow operators to remotely monitor the functioning of the antenna, modify its parameters, and maximize its performance without requiring physical intervention. Remote control and monitoring devices can increase antenna efficiency while decreasing maintenance requirements.
- Frequency Band Expansion: The current research may have concentrated on a particular frequency band suitable for Cavite State University's Main Campus needs. Future studies should, however, look into the possibilities of extending the Yagi-Uda antenna's coverage of frequencies. This will increase the amateur radio transmitter station's adaptability and possible applications by enabling it to operate across numerous frequency bands.
- Software-Defined Radio (SDR) Integration: Explore the integration of software-defined radio technology into the amateur radio transmitter station. This would enable greater flexibility and versatility in signal processing, modulation schemes, and communication protocols. Investigate the feasibility of implementing SDR-based systems and evaluate their impact on the overall performance and capabilities of the station.
- Energy Efficiency: Investigate energy-efficient designs and power management techniques for the amateur radio transmitter station. Explore the use of renewable energy sources, such as solar or wind power, to reduce dependency on the electrical grid. Implement energy harvesting and storage systems to optimize power consumption and increase the station's sustainability.
- Long-Distance Communication: Focus on optimizing the Yagi-Uda antenna design for long-distance communication. Investigate ways to improve the antenna's gain, directivity, and signal propagation characteristics to extend the communication range. Consider factors such as ionospheric conditions, atmospheric noise, and signal attenuation over long distances to enhance the station's ability to establish communication with distant locations.
- Ethical Considerations: In the design and implementation of a directional Yagi-Uda antenna for an amateur radio transmitter station at Cavite State University - Main Campus, several ethical considerations were addressed. The project complied with the rules and laws controlling the use of radio frequencies, making sure that the licensing requirements were met and preventing interference with other communication systems. Throughout the antenna's installation and operation, safety procedures were given first priority, reducing any risks to the workforce and the surrounding area. The group also placed a focus on using resources responsibly, taking energy efficiency into account, and reducing environmental effects. Amateur radio operators were urged to interact respectfully and inclusively by using ethical communication techniques. The initiative aims to promote a responsible approach to radio technology deployment, benefiting both the academic community and the larger amateur radio community, by embracing these ethical considerations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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