Design and Testing of VHF Eggbeater Antenna

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***Abstract*— In the field of satellite communication, the design and performance of VHF eggbeater antennas play a pivotal role in establishing reliable links with low Earth orbit (LEO) satellites. This paper presents a detailed study on the design, testing, and verification of a VHF eggbeater antenna optimized for 145.8 MHz, a frequency commonly used for satellite communication. The design methodology involves precise calculations of antenna dimensions, simulation for performance optimization, and practical implementation using a NanoVNA for characterization. Experimental results, including an SWR of 1.168, impedance of 43.7 + j3.654 Ω, and a Logmag value of -22.20 dB, confirm the antenna's efficient signal transfer with a low reflection coefficient. These findings, along with SWR curves, impedance measurements, and radiation pattern analysis, validate the antenna's efficacy in achieving circular polarization and omnidirectional coverage suitable for LEO satellite communication. Verification tests demonstrate robust signal transmission capabilities over varying distances and environmental conditions, highlighting the antenna's reliability and efficiency. This study contributes valuable insights into enhancing antenna performance for satellite communication applications, paving the way for further advancements in antenna technology.**

Keywords— ***VHF eggbeater antenna, LEO satellites, circular polarization, NanoVNA, SWR, impedance.***

I. INTRODUCTION

The VHF eggbeater antennas are essential in satellite communication for establishing robust links with low Earth orbit (LEO) satellites operating at 145.8 MHz. They provide omnidirectional coverage and circular polarization, crucial for stable communication without mechanical tracking, making them ideal for mobile and flexible satellite operations, particularly in amateur radio. This paper details the design, testing, and verification of a specialized VHF eggbeater antenna optimized for the 145.8 MHz band. Using tools like the NanoVNA, key metrics such as SWR, impedance, and radiation patterns are thoroughly examined. The findings aim to enhance the reliability and efficiency of satellite communication systems, benefiting scientific research, educational initiatives, and amateur radio enthusiasts.

Eggbeater antennas have been extensively studied for their applications in satellite communication. Research [1] highlighted the effectiveness of eggbeater antennas in providing consistent signal quality in LEO satellite communications due to their circular polarization properties. Research [2] demonstrated that the unique design of eggbeater antennas significantly improves signal reception and transmission capabilities, even in challenging environmental conditions. Research [3] confirmed the advantages of eggbeater antennas, particularly in achieving a balanced radiation pattern and minimizing signal losses during satellite communication. These studies emphasize the eggbeater antenna's vital role in reliable LEO satellite communication.

Eggbeater antennas are extensively utilized in the amateur radio community due to their ability to establish reliable communication links without the necessity for complex and expensive mechanical tracking systems. The omnidirectional and circular polarization characteristics of eggbeater antennas make them particularly suitable for amateur satellite operations, where maintaining stable links with moving satellites is crucial. Research on eggbeater antennas for satellite communications has indicated that these antennas significantly enhance the ability of amateur radio operators to communicate with satellites, ensuring robust and clear signal transmission. The design and optimization of eggbeater antennas have been explored to improve their performance in challenging environments, providing consistent signal quality for LEO satellites [6]. Furthermore, the simplicity and effectiveness of eggbeater antennas have made them a popular choice for educational and experimental satellite missions. Educational institutions have adopted these antennas for student-led satellite projects, thereby contributing to practical learning and advancements in satellite communication technology [7].

Despite extensive research on eggbeater antennas, there is a need for continued exploration to optimize their design and performance for specific frequencies used in satellite communication. This study aims to design, test, and verify a VHF eggbeater antenna optimized for 145.8 MHz, focusing on achieving minimal SWR, optimal impedance matching, and a consistent radiation pattern. The goal is to enhance the antenna's efficiency in satellite communication applications, contributing to the development of more reliable and effective communication systems.

II. SYSTEM MODEL

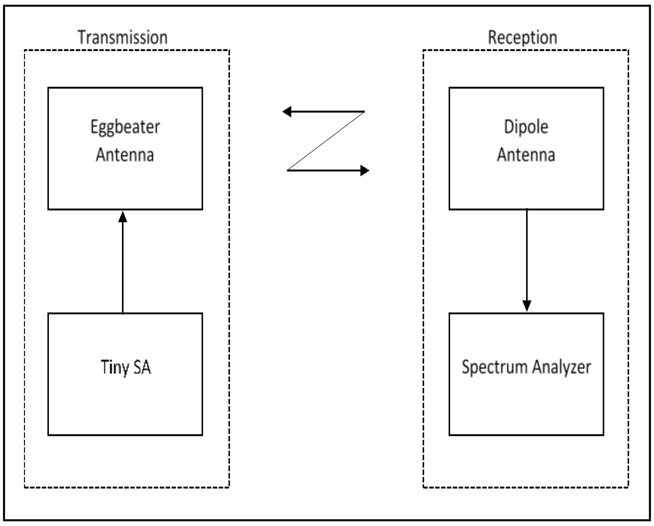

Figure. 1. Block diagram of system model

The block diagram of a system model designed to verify the transmission and reception capabilities of an eggbeater antenna is shown in Fig. 1. The verification process involves the use of a Tiny SA (spectrum analyzer) and a spectrum analyzer, along with two types of antennas: the eggbeater antenna and a dipole antenna that was previously designed. In the transmission setup, the eggbeater antenna is connected to the Tiny SA, which generates the signal. On the reception side, a dipole antenna is connected to a spectrum analyzer to receive the transmitted signal. This setup ensures that the eggbeater antenna can successfully transmit a signal and the corresponding reception can be verified using the spectrum analyzer. This model effectively demonstrates the signal transmission capabilities of the eggbeater antenna and the reception capabilities of the dipole antenna.

A. Amateur Band

The amateur radio band, or ham radio band, is allocated for non-commercial use by licensed operators for message exchange, experimentation, self-training, recreation, and emergency communication. Worldwide, amateur radio frequencies range from HF bands (1.8 MHz to 30 MHz) to VHF and UHF bands extending into several GHz, with 145.8 MHz being a common VHF frequency for satellite communications [5]. In Nepal, the NTA allocates the 144 MHz to 146 MHz VHF band for amateur radio use, aligning with international standards. Operating on these frequencies requires a license from the NTA, which involves passing an exam on radio theory, regulations, and practices. We use the 145.8 MHz frequency under proper licensing. This band is chosen due to its favorable propagation characteristics for satellite communication with low power, the eggbeater antenna's suitability for providing necessary omnidirectional coverage, widespread use in amateur satellite operations ensuring compatibility with other systems, and support from regulatory bodies fostering an active community of users and innovation.

B. Eggbeater antenna

The eggbeater antenna is an omnidirectional antenna known for its circular polarization, crucial for maintaining consistent signal quality with low Earth orbit (LEO) satellites. Its design features two orthogonal dipoles phased 90 degrees apart, providing a radiation pattern that covers all directions without requiring mechanical tracking. This characteristic makes it highly suitable for mobile and flexible satellite operations. We use the eggbeater antenna in this research due to its ability to provide stable communication links with LEO satellites operating at 145.8 MHz. Its ease of construction and deployment, along with its proven performance in amateur radio satellite communications, makes it an optimal choice [1]. The antenna's circular polarization helps minimize signal fading caused by the rotation of satellites, ensuring reliable data transmission and reception. Various antennas are used for LEO satellite communication, including Yagi, helical, and patch antennas. However, the eggbeater antenna's unique combination of omnidirectional coverage and circular polarization sets it apart [5]. Unlike the Yagi-Uda antenna, which offers high gain but requires precise directional alignment, the eggbeater provides consistent performance in all directions without mechanical tracking. In comparison to the helical antenna, which also supports circular polarization but involves complex and costly construction, the eggbeater's simpler design and cost-effectiveness make it a more practical choice for satellite communication. It simplifies the ground station setup by eliminating the need for mechanical tracking systems, making it ideal for applications requiring mobility and flexibility. This research focuses on leveraging these advantages to enhance the reliability and efficiency of satellite communication systems.

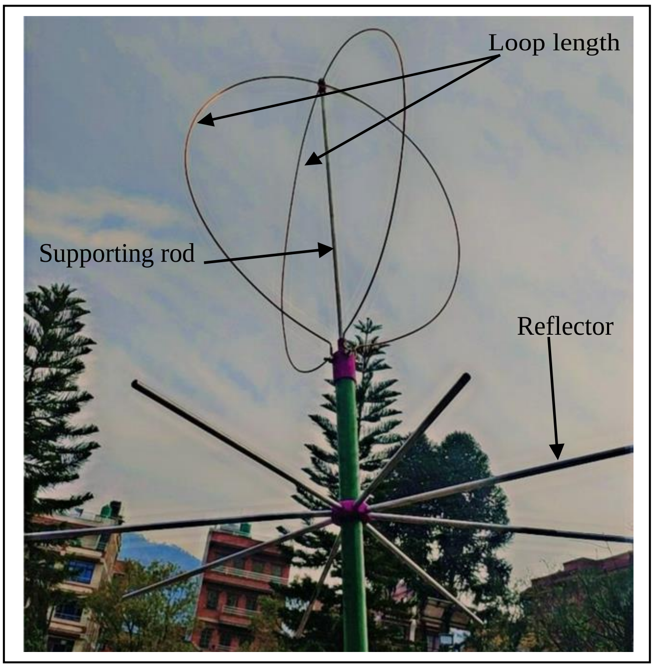

Figure. 2. Standard Eggbeater Antenna

C. Testing of Antenna

The NanoVNA (Vector Network Analyzer) is used for testing the eggbeater antenna. Calibration of the NanoVNA is performed using open, short, and load standards to ensure measurement accuracy. Following calibration, the NanoVNA is connected to the designed antenna via a coaxial cable. This setup facilitates testing of key parameters such as SWR and impedance around the 145.8 MHz frequency range, determining the optimal performance of the antenna for satellite communication.

III. ANTENNA DESIGN

The VHF eggbeater antenna design involves precise calculations for the loop lengths, phasing line, reflector dimensions, and reflector-to-loop distance, critical for optimal performance in satellite communication applications [4].

Loop Length Calculation: The loop length (L_l) determines the circumference of each loop in the antenna. Using a copper rod of 9 gauge, the calculation for a desired frequency (F) of 145.8 MHz is:

$$L_l = \frac{1005}{F}\text{ ft} \tag{1}$$

$$L_l = \frac{1005}{145.8}\text{ ft}$$

$$L_l = 6.89\text{ ft}$$

For safety and bandwidth considerations, the loop length is rounded up to 7 feet, with fine-tuning during testing.

Phasing Line Length Calculation: The phasing line (L_p), crucial for achieving the necessary phase difference between antenna loops, uses RG62 A/U coaxial cable (Impedance: 93 Ω, Velocity Factor: 0.86):

$$L_p = \frac{246 \times VF}{F}\text{ ft} \tag{2}$$

$$L_p = \frac{246 \times 0.86}{145.8}\text{ ft}$$

$$L_p = 1.45\text{ ft}$$

Reflector Length Calculation: The reflector length (L_r) enhances antenna performance, calculated as half the wavelength (λ) of the operating frequency:

$$L_r = \frac{\lambda}{2} \tag{3}$$

$$L_r = \frac{C}{2F}$$

$$L_r = \frac{3*10^8}{2*145.8*10^6}$$

$$L_r = 1.02\text{m} \approx 1\text{m}$$

Reflector-to-Loop Distance Calculation: The reflector-to-loop distance (L_{rl}) is typically 0.2λ:

$$L_{rl} = 0.2*\lambda \tag{4}$$

$$L_{rl} = 0.2*\frac{C}{F}$$

$$L_{rl} = 0.2*\frac{3*10^8}{145.8*10^6}$$

$$L_{rl} = 0.41\text{m}$$

By following these calculations, the VHF eggbeater antenna is optimized for reliable satellite communication at 145.8 MHz.

IV. ANTENNA DESIGN VERIFICATION

A. Antenna Parameters Testing

The designed Eggbeater antenna, designed for VHF band operation at 145.8 MHz, was rigorously tested using the NanoVNA. This testing focused on critical parameters such as SWR, impedance, and Logmag values. The calibration process was meticulously performed to ensure accurate measurements. The results for the designed Eggbeater antenna, made from 9-gauge copper wire, demonstrated excellent performance. The SWR was measured at 1.168, impedance at 43.7 + j3.654 Ω, and Logmag value at -22.20 dB. These parameters indicate efficient signal transfer with a low reflection coefficient, validating the antenna's suitability for satellite communication applications.

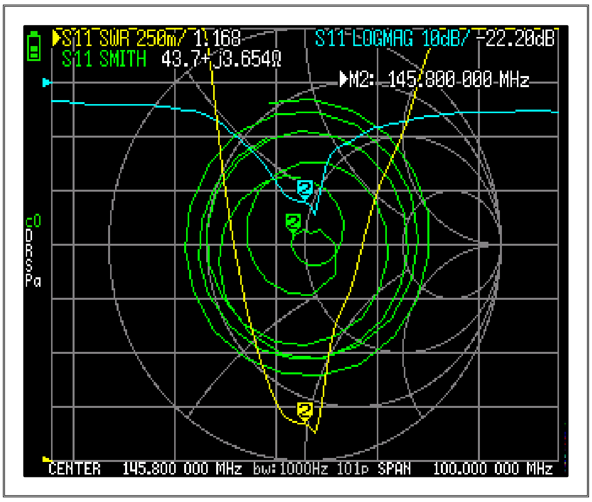

Figure. 3. NANO VNA test result of eggbeater antenna

B. Radiation Pattern of Designed Eggbeater Antenna

The radiation pattern of the designed Eggbeater antenna was meticulously analyzed to assess its directional characteristics and signal propagation efficiency. Conducted within the antenna laboratory at Khwopa Engineering College, the experiment involved systematic rotation of the antenna in 10-degree intervals from 0 to 360 degrees while measuring signal strength at each angle. The results, plotted on a polar graph, illustrated a consistent omnidirectional pattern with peak signal strengths maintained across various azimuth angles. This uniformity in radiation pattern underscores the antenna's suitability for maintaining robust communication links with LEO satellites, minimizing signal loss and ensuring reliable reception over a wide range of orientations and elevations.

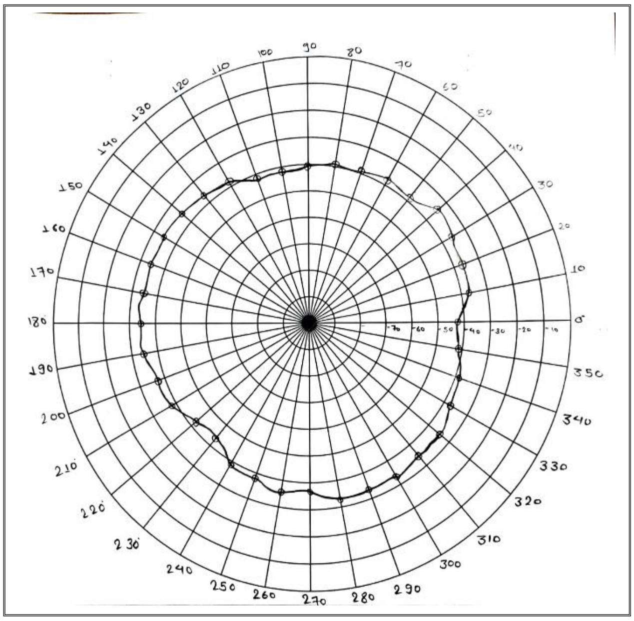

Figure. 4. Radiation pattern of eggbeater antenna

C. Signal Transmission Verification

Signal transmission through the designed Eggbeater antenna was verified to assess its performance in transmitting and receiving signals within the designated frequency range of approximately 145.8 MHz. The experimental setup involved connecting the antenna to a Tiny SA for signal generation and a spectrum analyzer for signal reception. Initial testing conducted over short distances within the Khwopa Engineering College demonstrated robust signal reception when the transmitter was active and no reception when it was turned off, as observed using the spectrum analyzer. Subsequent long-distance tests between different buildings confirmed the antenna's ability to maintain signal quality, though with reduced strength at greater distances. These results highlight the reliability of the designed Eggbeater antenna in practical communication scenarios, affirming its suitability for satellite communication and radio reception applications.

Figure. 5. No output when signal is off

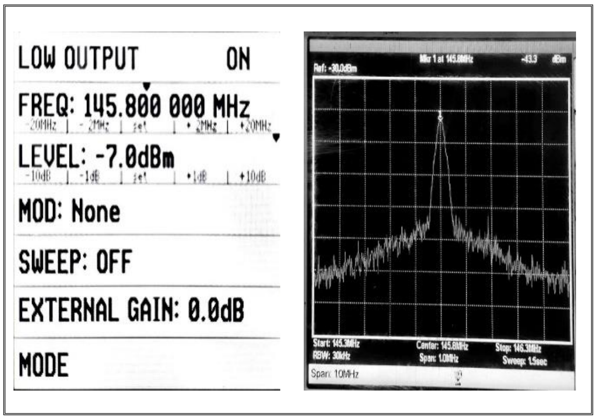

Figure. 6. Output appears when signal is on

V. Comparative Analysis of Eggbeater, Yagi-Uda, and Helical Antennas

The Eggbeater antenna provides several advantages over the Yagi-Uda and Helical antennas in satellite communication. Its omnidirectional coverage allows for effective signal reception and transmission from all directions without the need for mechanical tracking, unlike the Yagi-Uda antenna, which requires precise alignment and mechanical tracking for optimal performance. Although the Helical antenna also features circular polarization, it is directionally specific, limiting its flexibility. The Eggbeater's circular polarization aligns with the satellite's polarization, enhancing signal quality, whereas the Yagi-Uda uses linear polarization dependent on alignment, and the Helical antenna offers circular polarization in a fixed orientation. Performance metrics further differentiate the antennas: the Eggbeater antenna exhibits a Standing Wave Ratio (SWR) of 1.168, indicating efficient impedance matching and minimal signal reflection, compared to the Yagi-Uda and Helical antennas, which typically have SWR values of 1.5 to 2.0. Additionally, the Eggbeater antenna's impedance is measured at 43.7 + j3.654 Ω, supporting effective signal transfer, and its Logmag value of -22.20 dB reflects low signal loss and high performance. These parameters underscore the Eggbeater antenna's superior performance, reliability, and efficiency relative to the more variable characteristics of the Yagi-Uda and Helical antennas.

VI. Conclusion

The design, development, and testing of a VHF eggbeater antenna optimized for 145.8 MHz demonstrate its effectiveness for LEO satellite communication. Precise calculations for loop lengths, phasing lines, reflector dimensions, and reflector-to-loop distances achieved excellent performance metrics. Testing with the NanoVNA confirmed key parameters such as SWR, impedance, and radiation patterns, while practical signal transmission tests established the antenna's reliability and efficiency. These results highlight the antenna's suitability for robust and stable communication in amateur radio and satellite operations, enhancing its applications in scientific research, education, and the amateur radio community. Future research could focus on enhancing bandwidth, adapting the antenna for diverse conditions, exploring automated deployment mechanisms, and integrating advanced materials for improved performance and durability.

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