

Design and Implementation of Ground Station for LEO Satellite

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Abstract—This paper presents the design, fabrication, and evaluation of a Very High Frequency (VHF) Eggbeater antenna operating at 145 MHz for Low Earth Orbit (LEO) satellite communication. The antenna consists of two perpendicular loop elements fed with a 90° phase shift to achieve right-hand circular polarization (RHCP) and near-omnidirectional radiation, eliminating the need for mechanical tracking. The antenna was designed analytically and optimized using computer simulation technology (CST) Studio Suite to improve impedance matching and radiation performance. A prototype was fabricated and tested, achieving a VSWR of 1.517 at the operating frequency 145 MHz with good impedance matching. Radiation pattern measurements showed stable horizontal coverage and the experimental results agreed well with theoretical free-space path loss calculations. The proposed antenna provides a simple, low-cost, and effective solution for Automatic Packet Reporting System (APRS) reception and educational LEO satellite ground stations.

Keywords— *Eggbeater antenna, LEO satellite, Simulation, circular polarization, ground station.*

I. INTRODUCTION

Satellite communication has become an essential technology for Earth observation, scientific research, disaster management, and amateur radio applications. Among the various satellite systems, Low Earth Orbit (LEO) satellites are widely utilized because of their low propagation delay, reduced free-space path loss, and frequent accessibility from ground stations [4]. Many LEO satellites, including the International Space Station (ISS), operate in the Very High Frequency (VHF) band around 145 MHz. However, their high orbital velocity results in continuously changing signal direction and polarization,

making it challenging to maintain a reliable communication link throughout a satellite pass. Consequently, ground-station antennas require wide coverage, stable circular polarization, and consistent radiation for reliable satellite communication [1]–[4].

Several antenna configurations have been investigated for VHF LEO satellite communication. Yagi–Uda antennas provide higher gain (approximately 9–12 dBi) but are directional and generally require tracking, increasing system complexity and cost [5]. Dipole and folded-dipole antennas offer simpler implementation but provide lower gain (approximately 2.15 dBi) and linear polarization [6], [7]. Crossed-dipole and miniaturized antennas have also been proposed to provide circular polarization and compact solutions for satellite applications [8], [9]. Recent studies have demonstrated the suitability of Eggbeater antennas for 145-MHz LEO communication through improved impedance matching, circular polarization, and radiation characteristics [10], [11]. In this work, the proposed Eggbeater achieves a simulated realized gain of 5.08 dBi with low structural complexity and no mechanical tracking. Thus, it provides a practical balance between gain, coverage, implementation complexity for LEO satellite ground-station applications.

This paper presents the design, optimization, fabrication, and testing of a 145 MHz VHF Eggbeater antenna for LEO satellite communication. Using Antenna Magus and CST Studio Suite, the antenna was optimized for impedance matching, gain, and radiation characteristics. VNA and radiation pattern measurements confirmed its low-cost, circularly polarized, and near-omnidirectional performance.

II. SYSTEM DESIGN AND METHODOLOGY

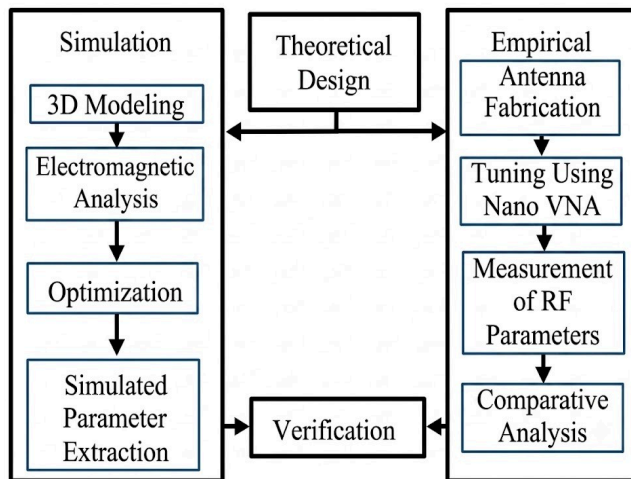


Fig. 1. Block diagram for Comparative analysis of physical and simulated Antenna

This work follows a four-phase methodology to design and validate a ground-station antenna for LEO satellite communication: theoretical calculation, simulation, empirical fabrication, and verification, as shown in Fig.1 adapted from [11].

A. Theoretical Design

The theoretical design of the antenna's baseline dimensions using standard electromagnetic resonance and wavelength equations at the desired operating frequency. The antenna element dimensions, illustrated in Fig. 2, are calculated using the design equations presented in [10].

- L : Loop length
- N : Number of radials
- L_p : Phasing line length
- D_{re} : Wire radii of reflectors
- L_{re} : Reflector length
- D_w : Wire radii of loops
- S_{re} : Loop-to-reflector spacing

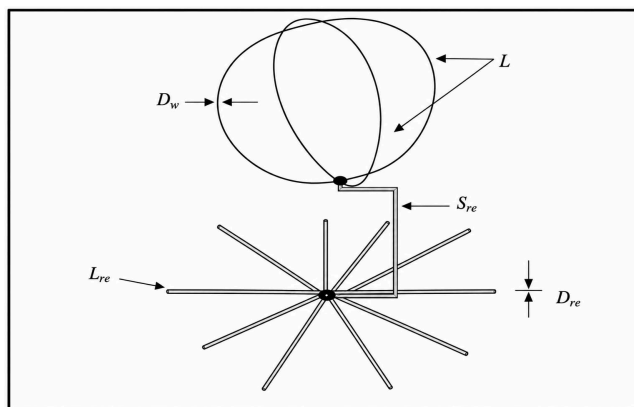


Fig.2. Eggbeater Antenna

At the operating frequency of 145 MHz, the wavelength was first calculated as $\lambda = c/f_0 = 206.8$ cm. The calculated loop length, including a 4% construction margin, is approximately 220 cm. The reflector length ($\lambda/2$) and spacing (0.2λ) are 103.4 cm and 41.4 cm, respectively, while the RG-58 phasing line (velocity factor = 0.66) is 34.1 cm. The parameters L_1 and L_2 were determined analytically, whereas L_{re} , S_{re} , N , D_w , and D_{re} were optimized through CST simulations due to the absence of closed-form solutions.

B. Simulation

The antenna design was simulated using Antenna Magus and CST Studio Suite. Antenna Magus was used first to obtain an initial reference model at the target frequency of 145 MHz with the required polarization, which was then imported into CST Studio Suite for detailed electromagnetic analysis. In CST, the loop length and phasing line length were fixed at their theoretical values of 219.675 cm and 34.1 cm, respectively, while the reflector length, reflector spacing, number of reflector elements, and wire diameters were varied one at a time through a series of parametric sweeps to observe their effect on S11, VSWR, gain, and radiation pattern. The optimization resulted in a reflector length of $\lambda/5$ (41.36 cm), spacing of $\lambda/14$ (14.77 cm), 10 reflector elements, and 4 mm wire diameter, achieving a realized gain of 5.08 dBi and return loss of 17.9 dB. These optimized parameters were used for fabrication [11].

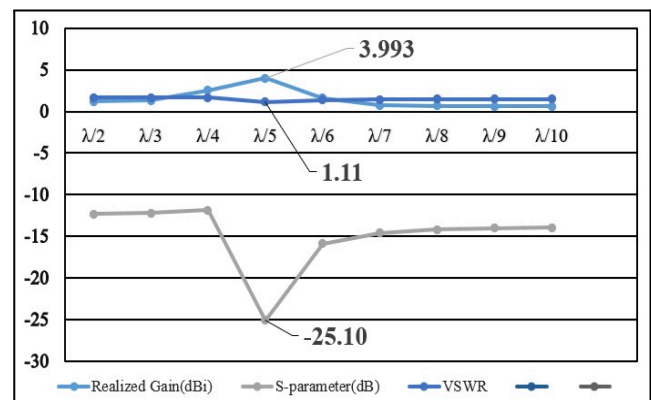


Fig.3. Plot of L_{re} vs Antenna performance parameters

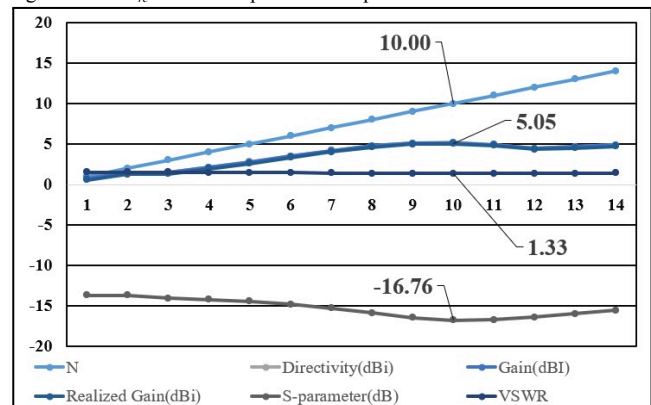


Fig. 4. Plot of N vs Antenna Performance Parameters

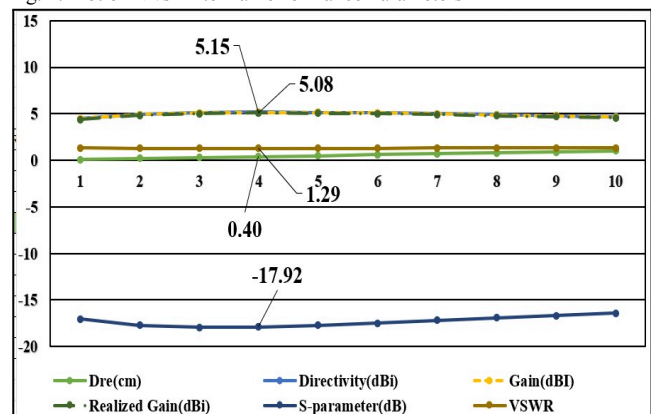
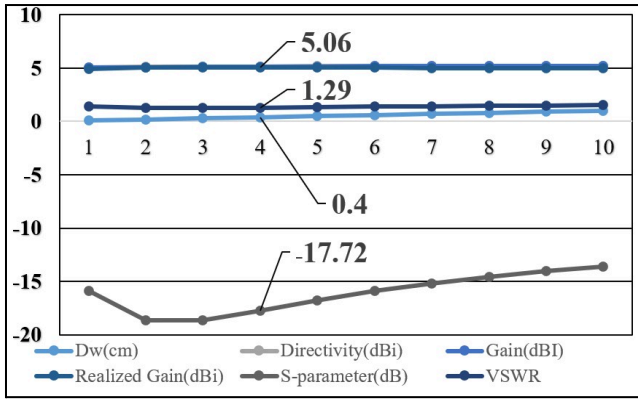
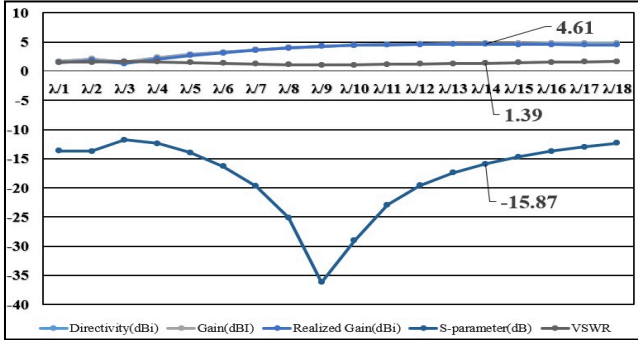


Fig. 5. Plot of D_{re} vs Antenna Performance Parameters


Fig. 6. Plot of D_w vs Antenna Performance Parameters

Fig. 7. Plot of S_{re} vs Antenna Performance Parameters

The radial reflector parameters were optimized through parametric simulations in CST Studio Suite by varying one parameter at a time while maintaining all other parameters constant. The optimum values and the corresponding antenna performance metrics are presented in Table I [10].

TABLE I. SIMULATED VALUE FOR RADIAL REFLECTOR

	Optimized value	Directivity (dBi)	Gain (dBi)	Realized gain (dBi)	S-Parameter (dBi)	VSWR
L_{re}	$\lambda/5$ cm	3.993	3.993	3.978	-25.10	1.11
S_{re}	$\lambda/14$ cm	4.750	4.738	4.615	-15.87	1.38
N	10	5.053	5.053	4.995	-16.76	1.33
D_w	0.4 cm	5.062	5.062	5.005	-17.72	1.29
D_{re}	0.4 cm	5.078	5.078	5.020	-17.91	1.29

C. Empirical

The fabricated Eggbeater antenna achieved a VSWR of 1.517 and input impedance of $76.9 + j22.5 \Omega$ at 145 MHz, confirming good matching. A slight variation in VSWR (approximately 1.5–1.7) was observed between the NanoVNA VSWR trace and Smith Chart due to differences in numerical conversion and display resolution. Radiation pattern testing showed 2.6–5 dB variation over 360° , demonstrating near-omnidirectional coverage. Measured path loss agreed closely with theoretical FSPL at shorter ranges, with greater deviations at longer distances due to cable, connector, and polarization losses, supporting its suitability for LEO satellite reception.

The driven loop length (L_1) and L_p were obtained from theoretical calculations, while the L_{re} and S_{re} were optimized through simulation. The eggbeater antenna was then fabricated and assembled according to these optimized dimensions for performance evaluation.

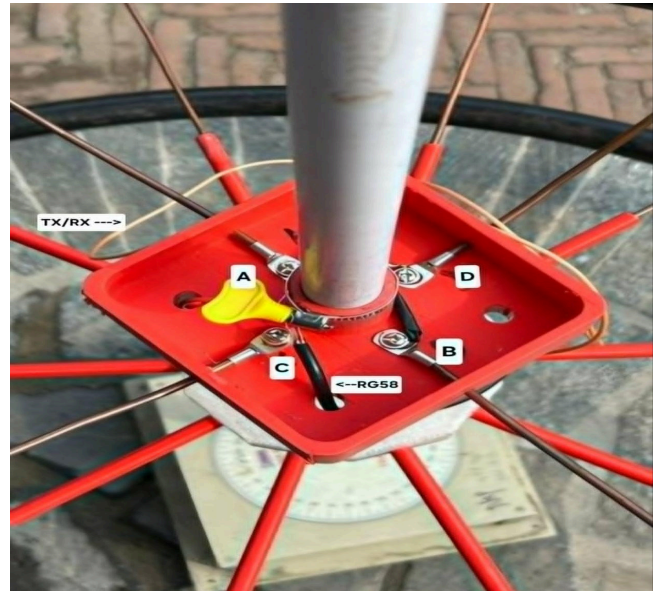


Fig. 8. Eggbeater Antenna Feeder Circuit

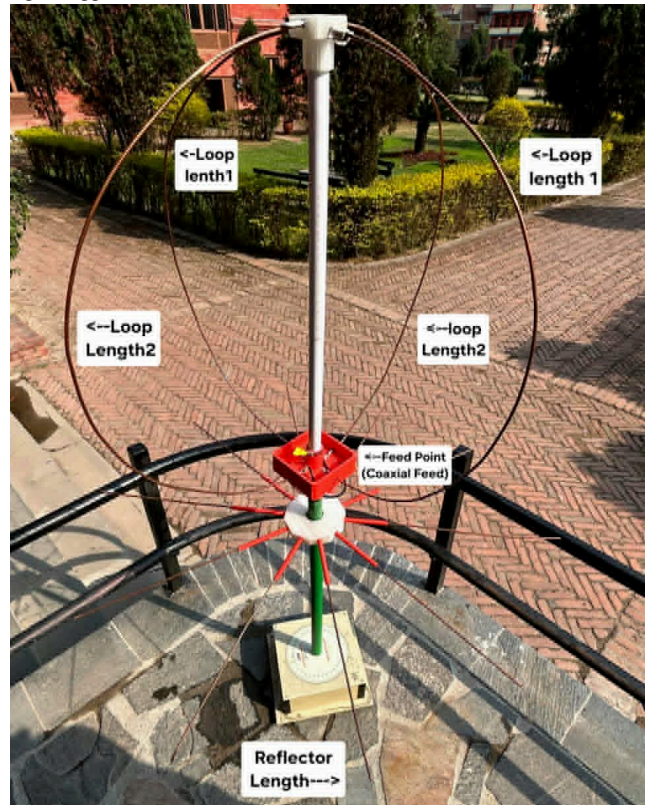


Fig. 9. Assembled Eggbeater Antenna



Fig. 10. VSWR of Assembled Eggbeater Antenna

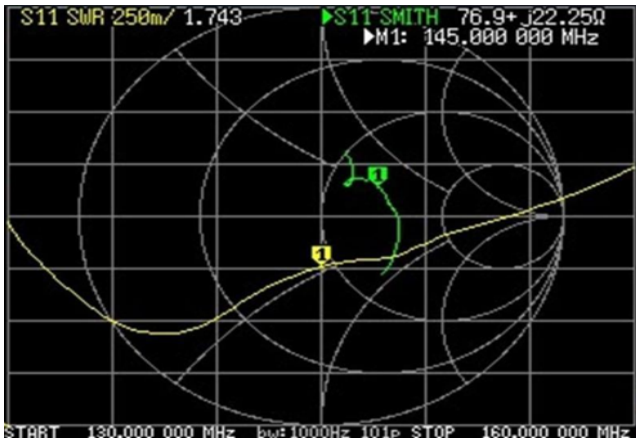


Fig. 11. Smith Chart of Assembled Eggbeater Antenna

D. Verification

The three design stages show that the fabricated antenna performed largely as expected. The measured VSWR (1.517) and impedance ($76.9 + j22.25 \Omega$) closely matched the simulation, while the near-omnidirectional pattern (2.6–5 dB variation) confirmed stable radiation. Although loop and phasing lengths matched theoretical values, reflector dimensions differed significantly, highlighting the importance of simulation-based optimization.

III. RADIATION PATTERN OUTCOMES

A. Horizontal Setup - Eggbeater as Transmitter (TX)

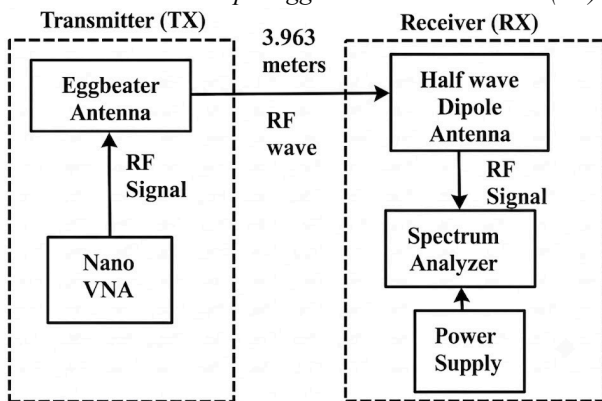


Fig. 12. Block Diagram of Horizontal Setup - Eggbeater as TX

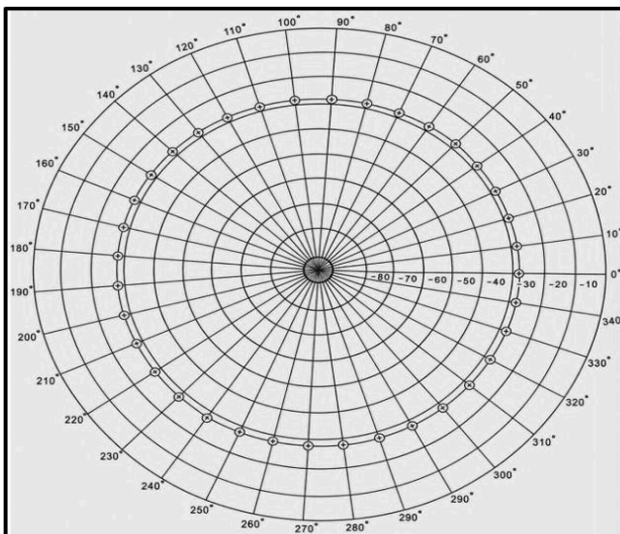


Fig. 13. Radiation Pattern of Horizontal Setup-Eggbeater as TX

The horizontal radiation pattern was measured by configuring the fabricated eggbeater antenna as the transmitter (TX) and a half-wave dipole antenna as the receiver (RX). A continuous 145 MHz RF signal was transmitted, and the received power was recorded using a spectrum analyzer while the eggbeater antenna was rotated from 0° to 360° at 10° intervals

TABLE II. HORIZONTAL SETUP DATA-EGGBEATER AS TX

Angle (Degrees)	Power(dBm)	Angle (Degrees)	Power (dBm)
0	-32.30	180	-32.30
10	-32.30	190	-32.30
20	-33.30	200	-32.30
30	-32.30	210	-31.30
40	-30.80	220	-31.30
50	-32.30	230	-33.30
60	-32.30	240	-32.00
70	-33.50	250	-33.80
80	-33.30	260	-33.80
90	-33.30	270	-32.30
100	-33.50	280	-32.30
110	-33.30	290	-32.30
120	-33.30	300	-32.30
130	-33.30	310	-32.30
140	-34.30	320	-33.80
150	-34.30	330	-33.80
160	-35.00	340	-33.80
170	-35.00	350	-33.30

The measured pattern exhibits near-omnidirectional radiation with approximately 3 dB power variation, demonstrating uniform horizontal coverage.

B. Horizontal Setup - Eggbeater as Receiver (RX)

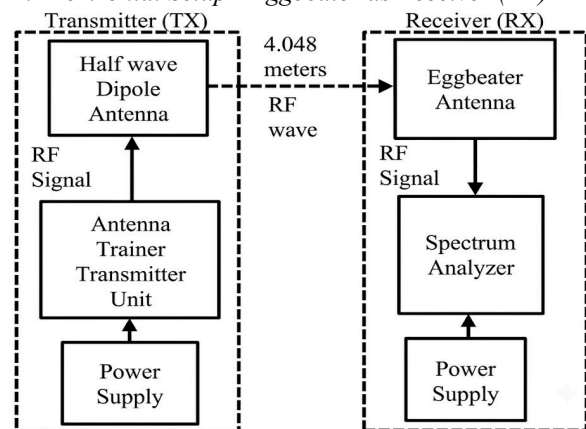


Fig. 14. Block Diagram of Horizontal Setup- Eggbeater as RX

For receiving performance evaluation, the setup was reversed, with a half-wave dipole transmitting a continuous 145 MHz signal and the fabricated Eggbeater antenna acting as the receiver. The Eggbeater antenna was rotated through 360° in 10° steps, and the received power at each position was measured using a spectrum analyzer.

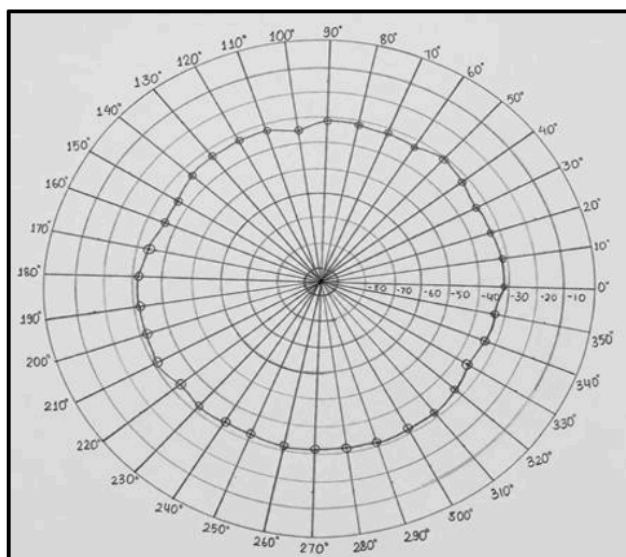


Fig. 15. Radiation Pattern of Horizontal Setup-ggbeater as RX

The measured receiving pattern was near-omnidirectional, with only 2.8 dB power variation, confirming stable reception in all horizontal directions. Slight fluctuations were observed as the measurement distance increased, while the antenna remained suitable for reliable LEO satellite communication.

TABLE III. HORIZONTAL SETUP DATA-EGGBEATER AS RX

Angle (Degrees)	Power(dBm)	Angle (Degrees)	Power (dBm)
0	-28.0	180	-28.20
10	-28.2	190	28.50
20	-29.2	200	-28.70
30	-29.5	210	-29.70
40	-28.70	220	-28.50
50	-29.50	230	-28.70
60	-29.35	240	-27.20
70	-29.20	250	-28.00
80	-29.20	260	-28.70
90	-29.70	270	-28.0
100	-28.70	280	-28.50
110	-29.20	290	-28.20
120	-28.80	300	-28.00
130	-28.70	310	-28.20
140	-28.50	320	-28.20
150	-28.5	330	-28.20
160	-28.5	340	-28.50
170	-28.0	350	-28.70

The measured horizontal radiation patterns in Figs. 13 and 14 confirm the near-omnidirectional performance of the fabricated Eggbeater antenna. Over 360°, the received power varied by only 3.7 dB and 2.6 dB at 4.048 m and 3.963 m, respectively. The measured losses (32.3 dB and 28.5 dB) were close to the theoretical FSPL values (27.82 dB and 27.63 dB), with small differences attributed to cable, connector, mismatch, and polarization losses.

IV. CONCLUSION

This work presented the complete design, simulation, fabrication, and experimental validation of a VHF Eggbeater antenna optimized at 145 MHz for LEO satellite communication, particularly ISS (Zarya) communication. The optimized design used a loop length of approximately 220 cm, a phasing line length of 34.1 cm, reflector spacing of about $\lambda/14$, 10 reflector elements, and conductor diameters of 4 mm. A reflector length near $\lambda/5$ was obtained from simulation, and 50 cm was selected for fabrication as a practical length expected to provide effective reflection while maintaining mechanical robustness. NanoVNA measurements confirmed acceptable impedance matching near the design frequency, while free-space radiation tests demonstrated near-omnidirectional coverage with 0–5 dB power variation across the azimuth. These results validate the Eggbeater as a low-cost and mechanically simple solution for fixed LEO ground stations. Future work will focus on optimizing the feed, reflector placement, cabling, and connectors to reduce signal loss, along with automated satellite tracking and axial-ratio and vertical-plane radiation analysis to further validate circular polarization.

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