

A 1-watt Rectenna Prototype for Wireless Power Charging of Lunar Robots

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Abstract—Ensuring reliable power supply is a critical challenge for robotic systems operating in lunar environments, particularly in regions devoid of sunlight, where conventional power solutions like solar panels and batteries are ineffective. This research explores the feasibility of microwave-based wireless power charging of lunar robots over larger distances. The paper presents the design and development of a rectenna prototype for 2.45 GHz resonant frequency, comprising a hexagonal patch antenna array and a rectifying circuit. Experimental validation displayed a high gain of 7.8 dB for the patch antenna and rectifying circuit with a measured efficiency of 81.7% at 1-Watt input power.

Keywords—Microwave Wireless Power Transfer(MWPT), Rectenna, RF-DC conversion efficiency

I. INTRODUCTION

Planetary and lunar exploration, driven by scientific curiosity and the goal of expanding humanity's presence beyond Earth, has advanced significantly since missions like Apollo [1]. Current initiatives, such as Japan's Moonshot R&D Program [2], aim to develop intelligent, modular robots for autonomous tasks like lunar outpost construction and in-situ resource utilization.

A key challenge in these missions is ensuring a reliable long-term power supply. Conventional systems like solar panels, batteries, and radioisotope power systems (RPS) face significant limitations where sunlight is scarce and temperatures are extreme. Power cables are impractical over rugged terrain, and RPS units pose cost and safety concerns.

Microwave-based Wireless Power Transmission (MWPT) offers a promising alternative for delivering power across long distances. Experiments conducted on Earth have demonstrated the potential of MWPT to power unmanned aerial vehicles (UAVs), microaerial vehicles (MAVs), Mars observation airplane and moving rovers [4] [5] [6]. This paper presents the design, development and experimental validation of a rectenna prototype, capable of receiving high RF power and converting into usable DC power, as a step toward validating MWPT for lunar robotic applications, as illustrated in Fig. 1.

II. RECTENNA DESIGN

The proposed hexagonal patch antenna was considered for its compact size, precise frequency tuning, dual polarization capability and ease of integration with rectifying circuits.

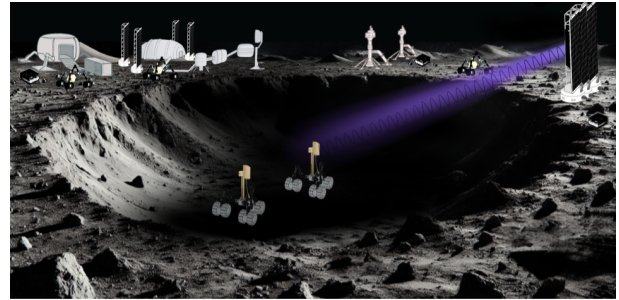


Fig. 1. Conceptual illustration depicting microwave-based wireless power transmission to power modular, heterogeneous lunar robots operating in permanently shadowed regions of the Moon.

These antennas were designed using the NPC-H220A substrate ($\epsilon_r = 2.17$, $\tan\delta = 0.0005$, $t=18 \mu\text{m}$, $H=1.6 \text{ mm}$) manufactured by Nippon Pillar Packing Co., Ltd. The antenna dimensions were determined using standard microstrip antenna design equations outlined in [?] and simulations were performed in CST Microwave Studio for an operating frequency of 2.45 GHz.

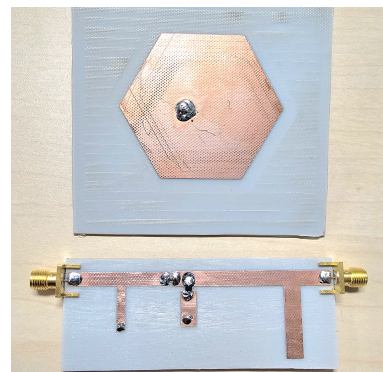


Fig. 2. Fabricated antenna and rectifying circuit

The corresponding element of rectenna, a rectifier circuit converts the incoming RF signal into DC power. The proposed rectifier circuit employs Broadcom HSMS-270C Schottky diodes with a breakdown voltage of 15 V. Impedance matching is achieved using a short-circuited microstrip stub and a 4 pF series capacitor, which also serves as a DC block. The output filter combines a $\lambda/4$ transmis-

sion line with an open-circuited stub to suppress higher-order harmonics and smooth the DC output. Simulations were performed in Keysight ADS at 30 dBm input power, using harmonic balance analysis across various load resistances to determine the optimal load for maximum power conversion efficiency. The fabricated patch antenna and rectifier circuit are as shown in Fig. 2

III. EXPERIMENTAL VALIDATION

The designed antenna was fine-tuned and fabricated with a side length of 25.6 mm and a feed point located 5.88 mm from the center. Measurements were conducted using a network analyzer inside an anechoic chamber, thus measuring $|S_{11}|$ of -24 dB and a gain of 7.8 dB at resonance frequency of 2.45 GHz. The antenna impedance was measured to be $57.05 - j2.05 \Omega$. Fig.3 presents a comparison between the simulated and measured results, validating the design approach.

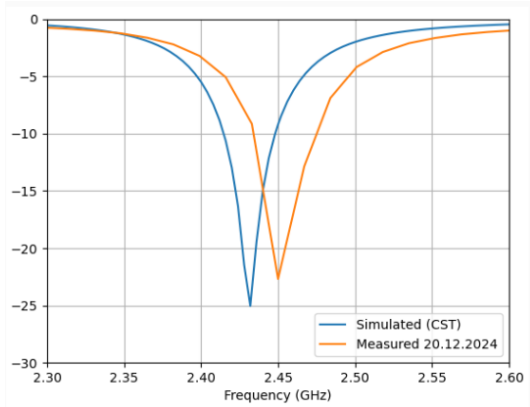


Fig. 3. Simulation and fabrication results of Hexagonal patch of side 25.6 mm at 2.45 GHz

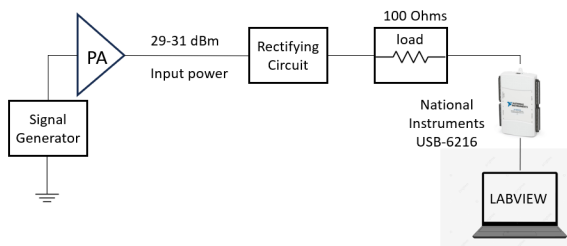


Fig. 4. Rectifier circuit measurement setup block diagram

The fabricated rectifying circuit was tested separately using NI USB-6216 DAQ and LabVIEW, as displayed in Fig. 4. The rectification efficiency η , was calculated using the following expression:

$$\eta = \frac{\frac{V_{out}^2}{R}}{10^{\left(\frac{P_{in} [dBm] - 30}{10}\right)}} \times 100 \quad (1)$$

Fig. 5 presents the measured output voltages for input power between 29 dBm to 30 dBm. A peak output voltage of

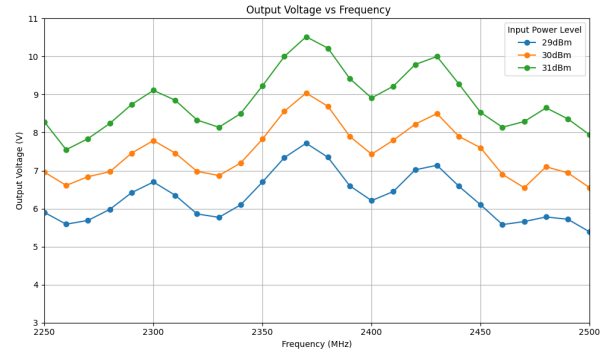


Fig. 5. Measured output voltages of the rectifier between 29-31 dBm for a frequency range of 2.25 GHz to 2.5 GHz

9.04 V with a load of 100Ω , at 2.37 GHz and 30 dBm input power was recorded. The rectifier achieved a peak efficiency of 81.7% at 2.37 GHz with 30 dBm input power, slightly below the antenna's 2.45 GHz resonant frequency. At 2.45 GHz, efficiency dropped to 57.8%. This frequency offset is likely due to parasitic effects and component tolerances, highlighting potential areas for further optimization.

IV. CONCLUSION

A rectenna prototype for receiving high power has been proposed and experimentally evaluated. It is found that the rectifier circuit requires fine-tuning to match to the antenna's resonant frequency. Post fine-tuning, the rectenna unit will be tested for wireless power charging of smaller capacity battery and overall RF-Dc conversion efficiency will be evaluated. Metrics such as charging time and energy storage efficiency will be analyzed to assess system performance and scale to larger power requirements.

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