Extending the Mission Duration of Agriculture UAVs through Wireless Power Transfer

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Abstract

In service of advancing sustainable technologies, we have implemented a conformal, strongly-coupled magnetic resonance (CSCMR) system that enables wireless power transfer over a distance up to **0.145m with an efficiency over 72%.** CSCMR offers high-efficiency power transfer, even over high distances of separation and coil misalignment, while **eliminating reliance on interfaces such as wires and connectors**. Moreover, SCMR permits wireless charging with benefits including **reduced physical degradation/exposure of components**. The isolated SCMR system eliminates the necessity for direct exposure to live high voltage lines and can also wirelessly transmit data through modulated backscatter. Our proposed SCMR wireless power and data transfer system has the potential to revolutionize the use of UAVs in the agricultural industry. By providing high-efficiency power transfer over longer distances, even with coil misalignment, our system can **significantly improve the reliability of agricultural UAVs.** This can help overcome the challenges currently faced by UAVs in agriculture, such as limited flight times, communication distance, and battery efficiency. Furthermore, our system reduces the need for materials like connectors and wires, making it a sustainable solution.

Figure 1: A high-level concept of our CSCMR WPT System

BACKGROUND

- Unmanned Aerial Vehicles (UAVs) have been a reliable tool for enabling remote interaction with our surroundings.
- A customized UAV system that cater to the agricultural industry can perform various tasks such as conducting land and crop surveys, spraying, planting, growth assessment, and artificial pollination.[1][3]
- Moreover, using UAVs can significantly reduce the need for workers to handle hazardous materials, thereby minimizing their exposure to hazardous materials.
- The use of UAVs in agriculture still confronts several technical challenges, such as low flight times, communication distance, and battery efficiency. [1]
- The inability to efficiently charge a cooperative UAV with tolerance for misalignment while providing robust charging capabilities reduces the efficiency of agricultural missions.

Objectives

To address some of these limitations, we are currently investigating an **efficient way of wirelessly transmitting power and data** between an aerial vehicle and a base station to prolong its task duration and transfer mission-critical data. A UAV with a module that can harvest wireless energy and communicate with a base station can be used to prolong its task duration. This can be realized with a charging system based on the aforementioned CSCMR system. This design can be used for both power and data transfer while providing a robust method of efficient power delivery.

System Overview

The system is divided into two main systems. The major systems are the base system and the receiving system. The main purpose of the base system is to transfer the high RF power from an RF generator to the base station side CSCMR coils, switch between a low/high power state, and the receive modulated backscatter from the receiving system. The main purpose of the receiving system is to harvest the RF power being transmitted by the base station, convert the RF power into a DC form which can be used by a onboard battery charger, and to provide modulated backscatter - informing the base station of its charge state.

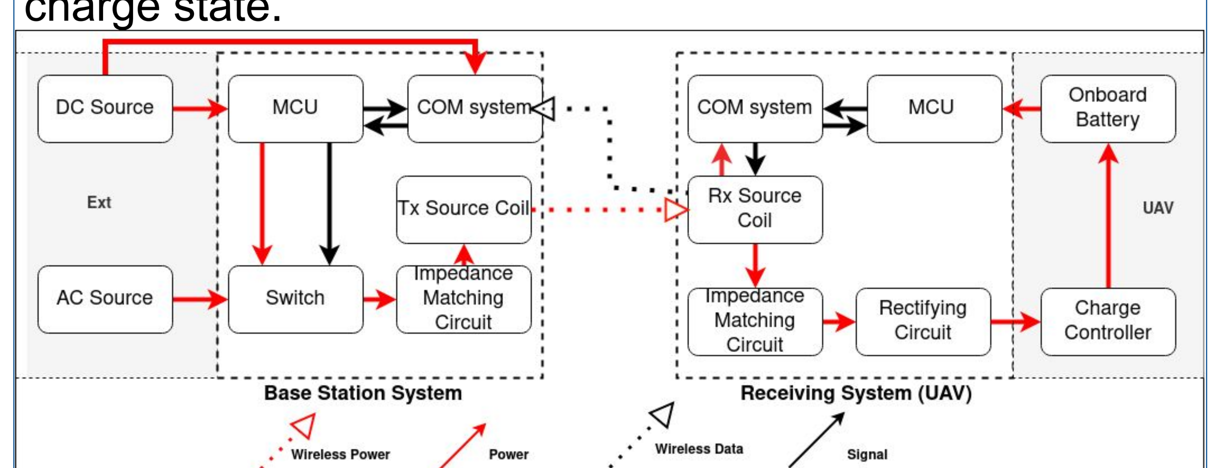

Figure 2: A high-level system diagram of our CSCMR WPT System

CSCMR Power Transfer

- The wireless power transfer system is based on a Conformal SCMR (CSCMR) configuration.
- CSCMR provides high power transfer efficiency even with separation distance and lateral displacement.
- SCMR allows for the use of backscatter as a communication medium - requiring no extra antenna

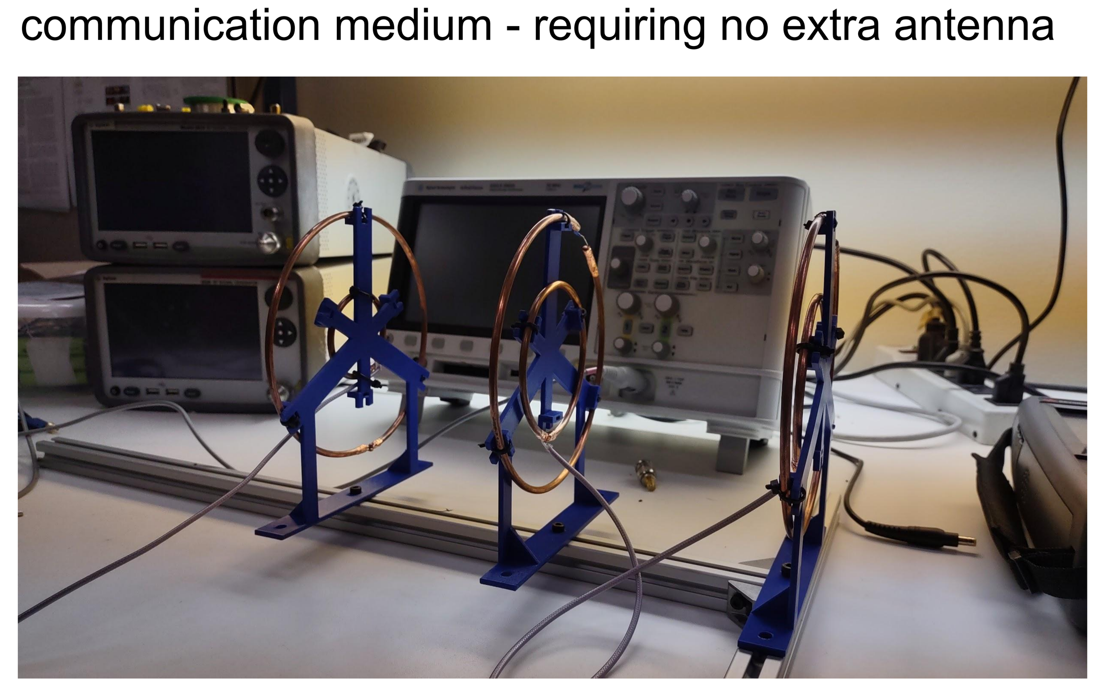

Figure 3: A working prototype of our CSCMR WPT System

Base System Receiver

- Backscattered signals from receiving system get picked up by bistatic collocated antenna in base system.
- Signal-to-Noise Ratio is sufficient for non-coherent detection of modulated line code allowing for a simple receiver design

$$Signal\ to\ Noise\ Ratio:$$
$$SNR = 10log_{10}\left(\frac{Signal\ Power}{Noise\ Power}\right)dB$$

- Demodulated line code is fed into the ADC of a microcontroller for decision making.

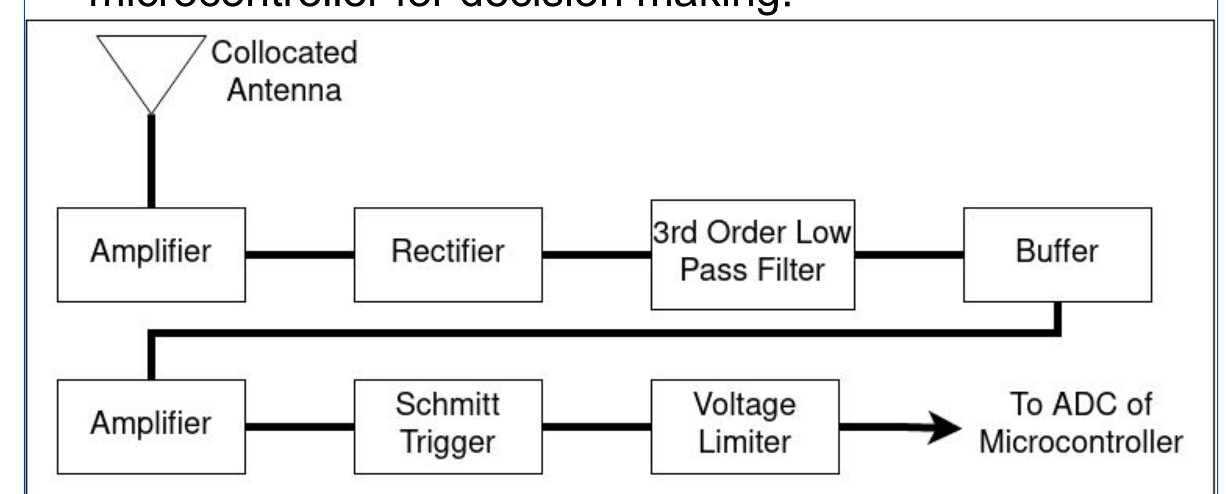

Figure 4: A system diagram of the Base System Receiver for our CSCMR WPT System

Backscatter Communication Link

- A BJT transistor across the input of the receiving system to provide a modulated backscattered signal
- MCU onboard the UAV sends line code to the base of the BJT turning it on and off
- The on and off state introduce two different load impedance state
- This means that the scattered signal will be proportional to the line code being sent to the BJT

$$Reflection\ Coefficient:\ \Gamma = \frac{Z_L - Z_o}{Z_L + Z_o}$$
$$Reflected\ Wave \sim \Gamma\, V_o^+$$

Receiving System Power Harvesting

- Received power rectified with medium power Schottky diodes.
- Low-Pass-Filter and regulator converts Alternating Current (AC) signal to smooth and stabilized Direct Current (DC).
- Micro Lipo Charge Module in series with INA219 sensor delivers regulated power to load (1S Lithium Polymer Battery) while monitoring key parameters.

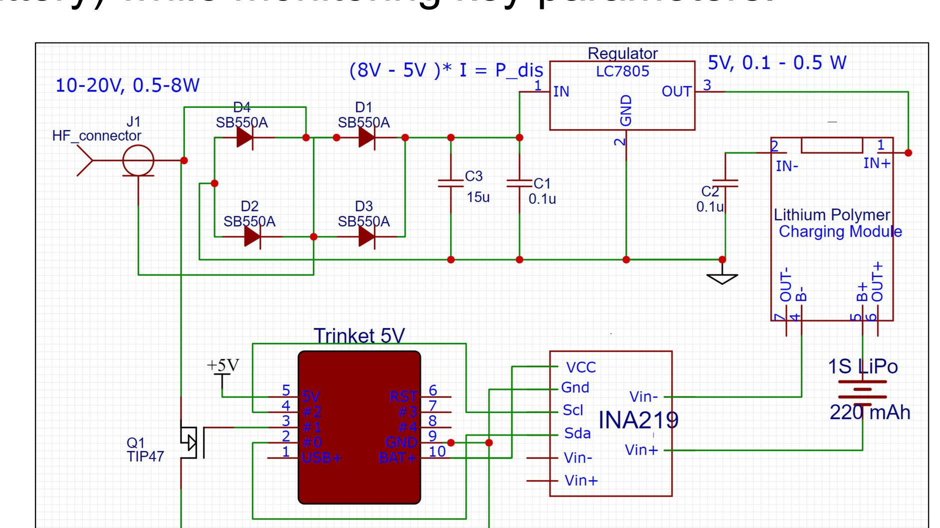

Figure 5: A hardware diagram of the Receiving Power Harvesting System for our CSCMR WPT System

Conclusion

- Power transfer of **38.9dBm [7.76W]** was observed with a efficiency of **72%**, **exceeding the 70% benchmark at 26.4 dBm [0.437W].**

$$Measurement\ Results:\ S_{21} = -0.699dB$$
$$Efficiency\ Calculation:$$
$$Power\ Transfer\ Efficiency\ Calculation:$$
$$|S_{21}(ratio)|^2 = \left|\frac{V_2^-}{V_1^+}\right|^2 = |0.851|^2 = 0.725$$
$$Power\ Transfer\ Efficiency = 72.5\%$$

- Low power test results were consistent with the efficiency reported by prior researchers who were working with less power [3].
- Test results confirm that the system can accurately **monitor current with a +/- 5 mA resolution**.
- With up to 500 mW of charge reaching the load under optimal conditions against our minimum of 200 mW, performance criteria was met.
- The ability to attain a high-efficiency power transfer using SCMR allows for high sustainability in UAV missions. Long distances and battery efficiency significantly improve the reliability of agricultural UAVs.

Future Work

- Evaluation of reliability to determine expected lifecycle or other information related to conservation.
- The CSCMR system was unable to achieve the desired charge efficiency as the efficiency during the high power stage was below 70%.
- Researchers have shown that a broadband CSCMR system can offer 85% efficiency[3]. So one of the future considerations would involve a transition from CSCMR to broadband CSCMR.
- The broadband configuration would involve adding an additional resonant coil in the CSCMR system
- Advanced receiving system design could incorporate additional power-handling features including load-sharing.

References

[1] L. Gipson, "A Civil Future for Unmanned Aircraft Systems," *NASA*, May 09, 2016. https://www.nasa.gov/aeroresearch/programs/iasp/uas/civil-future-for-uas

[2] J. Kim, S. Kim, C. Ju, and H. I. Son, "Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications," *IEEE Access*, vol. 7, pp. 105100–105115, 2019, doi: https://doi.org/10.1109/ACCESS.2019.2932119.

[3] D. Liu, "Novel Strongly Coupled Magnetic Resonant Systems" (2018). Florida International University Electronic Theses and Dissertations. 3717. https://digitalcommons.fiu.edu

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