P&O EAGLE – Wireless power transfer via resonant inductive coupling

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1 Introduction

Unmanned Aerial Vehicles (UAVs) or drones capture the imagination of the general public and companies alike. Not only are drones a fun hobby, offering e.g. the opportunity to take pictures and videos from impossible angles, but they become a useful tool in multiple civil/commercial applications [2, 1], e.g. a drone can help charging wireless sensor networks.

Wireless sensor networks are widely used, from border security to monitoring waterway pollution. Supplying energy for long term deployment is a crucial challenge in wireless sensor networks, as batteries are the primary energy source. Current wireless sensor networks deployed for long periods require either additional infrastructure (e.g. solar panels) or periodic maintenance. The use of small drones equipped with resonant wireless power transfer for charging the sensor nodes and prolonging the sensor network lifetime is an attractive alternative [3]. See e.g. Fig. 1 that represents a drone charging wireless sensor nodes, which monitor the structural health status of highway bridges [3].

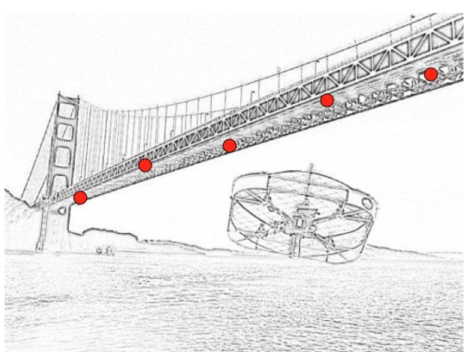

Figure 1: A drone helps charging bridge sensor nodes used for monitoring structural health.

2 Operation principle of inductive wireless power transfer

Ampere's law and Faraday's law govern the physics behind the principle of operation of inductive wireless power transfer (IWPT) systems. See Fig. 2 as illustration. An alternating current circulates through a coil, referred to as the primary or transmitting coil, and generates an alternating magnetic field. If a second coil, referred to as the secondary or receiving coil, is placed in the vicinity of the transmitter, then the alternating magnetic field induces an electromotive force (e.m.f.) in the receiver coil and a current will flow through a load connected to the coil. Therefore, power is transferred from the transmitter coil to the receiver coil [4].

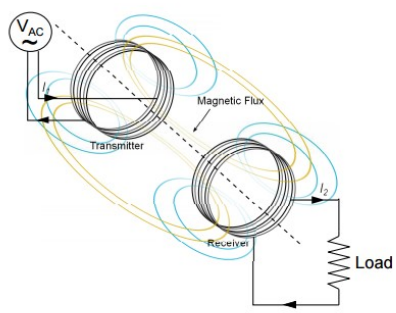

Figure 2: Principle of operation of inductive wireless power transfer.

Intuitively, two resonant coils of the same resonant frequency tend to exchange energy very efficiently, while dissipating relatively little energy around. In systems of coupled resonances, there is often a strong coupling regime. If one can operate in that regime, the efficiency improves dramatically.

If resonant coupling is used, each coil is capacitively loaded so as to form a tuned LC-circuit. If the primary and secondary coils resonate at a given frequency, the power transmitted between them over a range of a few times the primary coil diameter increases significantly with a reasonable efficiency [4, 5, 6].

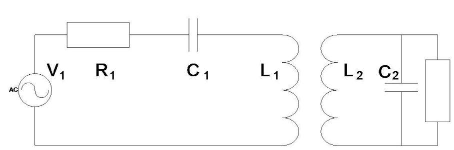

Figure 3: Basic circuit of resonant coupled inductors.

3 Building a resonant IWPT system for a drone

The resonant IWPT system comprises: 1) a driving coil (mounted on the drone) that generates an alternating magnetic field which drives a neighboring resonant coil by inductive coupling (see upper part in Fig. 4); 2) a receiver coil placed in the vicinity of another resonant coil and coupled inductively with the load coil, which is in turn connected to a receiver board (see lower part in Fig. 4).

System requirements:

- Power transfer coils working at the same frequency, with a high enough quality factor. The selected operating frequency affects the size and weight of the system as well as the efficiency. Some data, suitable for a drone, is available in [7].
- A board for driving the resonant circuit at the transmitter coil, with a signal generator at the suitable frequency.
- A controller that maximizes the received power at the receiver coil and rectifies the received signal for feeding a load.
- Efficiency in the power transfer rapidly decreases with increasing distance and the misalignment. The longer the transfer distance between the coils, the bigger the coils we need to use. Particular attention must be paid to the misalignment.

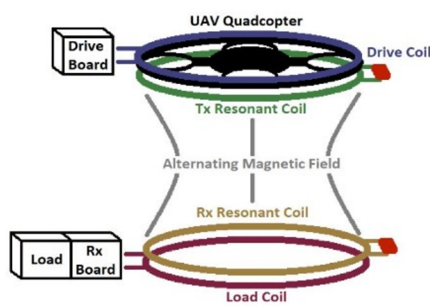

Figure 4: UAV with wireless power transfer. Illustration taken from [7].

4 Material/data provided to the student

The efficient design of resonant circuits for wireless power transfer is far from trivial. Therefore a general block diagram is depicted in Fig. 5.

- The main power source of the drone is its 12V DC battery. Of course, another (better) design may be chosen (with e.g. a higher efficiency).

- The load will be provided. The transmitter circuit should be designed to ensure a maximum voltage of 10 V and a maximum current of 1 A.
- Datasheets of the components will be also provided. More precisely, datasheets concerning:
  - copper wire for the transmitter and receiver coils (`CopperEnamelledWire_pro-power.pdf`);
  - dual full bridge driver datasheet (`L6206_DMOS_dual_full_bridge_driver_datasheet.pdf`);
  - ultra fast diodes (`ultrafast diode.pdf`);
  - N-channel MOSFETs (`CSD18531Q5A_60_V_Mosfet.pdf`, `CSD19501KCS_80V_Mosfet.pdf`);
  - External bootstrap diode (`External Bootstrap Diode.pdf`).

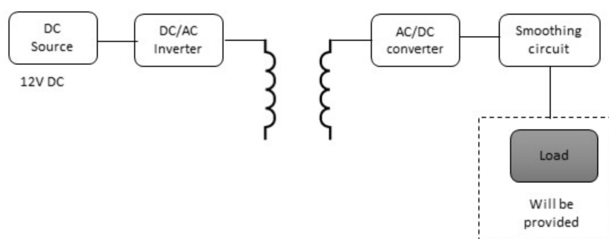

Figure 5: Block diagram of the resonant wireless power transfer system

The interface with the drone is detailed in Fig. 6. The transmitter circuit is fed by the 12V DC battery of the drone via a DC/AC converter. Further, a 5V signal must also be taken from the FPGA in order to enable the transmitter circuit. The pulse width modulated (PWM) control signal is obtained from the FPGA as well (a 3.3V peak-to-peak signal with frequency in the range 10-90 kHz)

5 Tasks to perform

All tasks are to be performed by 2 students.

- Literature review and familiarization with wireless power transfer concept. Consider and study existing commercial solutions. Keywords: concept, different technologies (RFID, microwave, resonant transfer), non-resonant coupled inductors,resonant coupling, design, receiver coils and circuitry, transmitter coils and circuitry, quality factor. Consider and study existing commercial solutions.

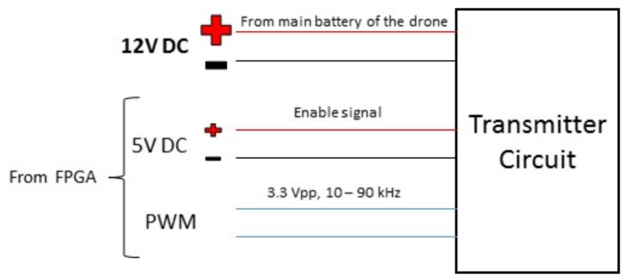

Figure 6: Transmitter circuit of the IWPT integrated with the drone. Detail of the supply and signals needed.

- Design the transmitter and the receiver circuits based on what is explained in section 3. Both circuits are first to be built and validated in a simulation environment (MATLAB/Simulink).
- Improve the circuit design (topology) with goal a higher efficiency of the power transfer. Particular attention to be paid to the coupling of the inductors and the possible misalignment.
- Construct a prototype on a breadboard. Construction of the coils. Verify experimentally that the design actually works. Transfer the final design to a PCB to be integrated with the drone.

6 Milestones

1. Demo of the resonant coupled circuits, simulation and experiment on breadboard. **T2**
2. PCB design finished. **T3**
3. Demo with PCB assembly working, standalone and load provided. **T4**
4. IWPT system integrated on the drone and working. Final test. **T6**

References

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