A Drone-Based Wireless Power Transfer and Communications Platform

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***Abstract*—This paper explores the possibility of using cost effective drone based communication systems for both wireless power transfer and communications simultaneously. A working prototype of a drone based basestation for communicating with sensors is successfully constructed, measured and characterized featuring the capability of communicating 1 Mbits/sec at a distance of almost 3m using a fully battery-less system design. The operation of the system was confirmed through static and dynamic flight test using the drone and could provide an effective solution for deployment of ad-hoc networks in emergency situations and remote locations.**

***Index Terms*—Wireless Power Transfer (WPT), Backscattering Communication,Drone Basestation**

I. Introduction

The idea of wireless power transfer has been around since Hertz and Tesla. However, ambient power density, particularly at high frequencies is too low to power any practical systems. Recently with the advent of internet of things (IoT) devices and other low power electronics, wireless power transfer is particularly attractive. It can completely remove conventional power sources such as batteries which requires periodic replacement, thus driving up the cost of maintenance and time making it unsustainable for multiple sensor networks. Particularly for remote areas such as national parks or large farms, where the distance to the nearest basestation is large, it can be extremely cost effective to utilize drones to deliver power to wireless sensor nodes, and collect data simultaneously.

Prior research has shown the concept of the idea. In [1] a similar idea was presented where the drone would collect the data from wireless sensor networks and act as the data collection platform, but the problem is that there is no power delivery system in place. In [2] another similar idea was introduced with wireless power transfer. However, the utilization of that system was too large and heavy, too expensive, and required extreme accurate precision to align due to the nature of both the transmit and receive high directivity antennas. Due to these factors, the drone only has 8 minutes of flying time using that setup, which is not a practical solution. In [3] the UAV used inductive coupling to deliver over 5 watts. However due to the nature of inductive coupling, power delivery is only at 15cm height and the coil is subject to deformities which can drastically hinder the operation. In addition, a function generator needed to be connected via a wire to the drone, and the paper did not demonstrate communication capabilities.

In this work, a lightweight, far-field, fully custom transmitter and receiver and relatively high altitude WPT system using a 1MHz backscattering tag was developed and experimentally tested. As opposed to resonator coils, far-field radiating antennas gives farther operation distance, less deformities, and better beamwidth than resonator coils. A custom made patch antenna array was utilized to reduce weight and size. The frequency of operation is 2.3GHz, which was chosen due to the fact that it is relatively easy to obtain off the shelf components at this frequency range, and that the path-loss is not too large. This gives the drone larger operation distance, and better balance as patch antennas are planar in addition to being thin and relatively light. In addition the patch antenna ground plane eliminates the effects of mettalic structures in the drone. The drone utilized in the experiments is the DJI Phantom 4 which is a commercially available drone which as opposed to [2] which uses a 2 stroke gasoline engine, uses a Li-Po battery, and unlike [3], the DJI drone is larger and can fly much greater distances and heights, acting as a true mobile basestation platform. The complete system is shown in Figure 1. Which is composed of the transmitter, energy harvester, ultra-low power oscillator, and the DJI drone.

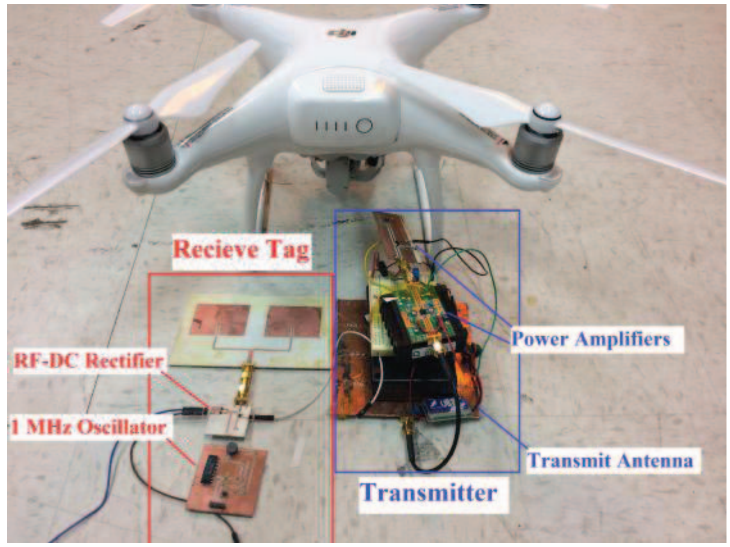

Fig. 1. Completed drone platform with all components displayed, with the 2.3 GHz transmitter antenna facing downwards.

II. System Designs

A. Transmit Antenna

The antenna design primarily consists of designing a small antenna, with high gain, and relatively large beamwidth. A patch antenna was chosen due to its planar structure and by

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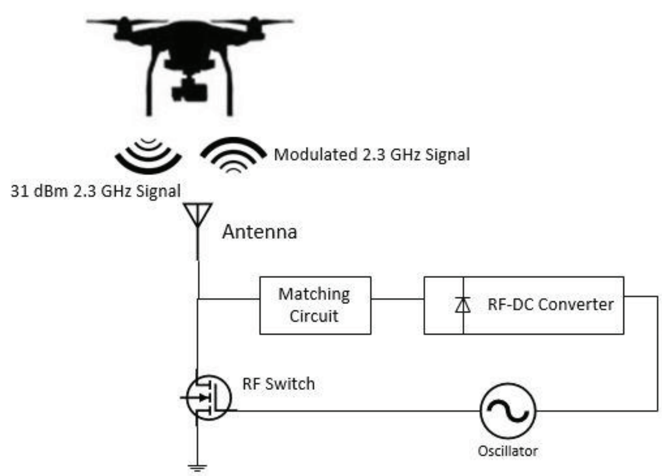

Fig. 2. Block diagram of the proposed system architecture with the DJI drone acting as both the power source and communication platform.

the fact that it is grounded which isolates the antenna operation and performance from the effects of the drone.

A 2x2 patch antenna array for 2.3 GHz was designed in CST Microwave Studio and fabricated on Rogers Duroid 6010 1.91mm thick substrate to decrease the size and get good bandwidth respectively. The total size of the antenna measured 11cm x 11cm, and provided a realized gain of 9.3 dB and a beamwidth of 58^o.

1) 2.3GHz Transmitter: To provide a continuous wave signal to the receiver, an oscillator and power amplifier is required. The oscillator chosen for this design was the Maxim Integrated MAX 2750 voltage controlled oscillator (VCO) which generates -3dbm of RF power. The signal is buffered by a RF power amplifier (PA), the Analog Devices ADL5545, with a gain of 20dB. The output PA is the Triquint Qorvo TQP9111 2Watt P1dB power amplifier with a gain of 28dB. The measured output power is 31dBm due to driving the PA in saturation in order to get the maximum output power from the PA and due to output matching conditions. Both PAs utilize 5V supply voltage. Therefore, the expected maximum output power of the transmitter is 31dBm which is 1.25W. Both PAs operate at 5V at a total of 550mA, which is 2.75W which can easily be supplied by the onboard 5300mAh 15V battery. It was difficult to find the power source for the drone, without cutting open the drone itself, so another 12V battery was used as the power source. This increases the weight, which decreases flight time, but utilizing the onboard battery can drastically reduce the weight and increase the flight time.

B. Receiving Rectenna and Ultra-Low Power Oscillator

For the receiver, another patch antenna was designed in CST Microwave Studio. This 2x1 patch antenna doesnt have a size constraint per se but it cannot be too small so that it has small gain, and cannot be too large so that it is impractical to be used as a part of an autonomous sensor. It was fabricated on Rogers 4003C, with a dielectric constant of 3.38, 1.52mm thick substrate, which gives a gain of 8 dB. For RF to DC rectification, a voltage doubler was utilized, using HSMS-282x schottky diodes. According to [4], the HSMS rectifier diodes at 0dBm of input power can achieve 72 % power conversion efficiency. However, the addition of another diode will reduce the power conversion efficiency, even though the voltage was increased using the voltage doubler. Using the voltage doubler, the measured open circuit voltage is 3.2V at 0dBm. With an equivalent resistance of 5k Ω, the output voltage drops down to 0.9V.

For backscattering, an oscillator needs to be designed for modulation, which needs a high oscillation frequency for high data transfer, and also low voltage and power draw. The oscillator's function is to switch between different loads. The ATF54143 JFETs were used as the RF switches, which switched from matched, to power the oscillator, to short circuit ground, or total reflection with 180^o phase shift. The switching threshold voltage (Vth) for the transistor is 0.4V. For the oscillator, using FETs, such as JFETs and depletion mode MOSFETs are the optimal choice due to their 0V threshold voltage, which reduces the supply voltage and power requirement. The MOSFETs used are the ADL110800 from Advanced Linear Devices and was configured in the Colpitts oscillator topology using a LC tank resonator tuned to resonate at 1MHz as shown in Fig 3[5]. The Colpitts oscillator was modified to include a varactor for variable frequency shifting. The LC tank can be replaced with a 1MHz crystal to decrease phase noise, but the supply voltage requirement is higher which decreases the read range. Using SPICE model according to the datasheet, this oscillator topology can oscillate with a 0.2V supply voltage, but will not provide an adequate voltage swing to switch the transistor. At least a 0.5V supply voltage is required to increase the voltage swing which limits the maximum read distance. At this supply voltage, 6 μA is drawn, equating to a 3 μW power consumption. The oscillation frequency can be also adjusted using a varactor as shown in Fig. 3, for FSK modulation, which could allow for different modulation schemes.

III. Experimental Results

A. Static Tests

Initially, static tests were conducted by measuring each individual component on the lab bench, without mounting them on the drone.

Figure 4 shows the fabricated transmit patch antenna array with the simulated radiation pattern and input matching measurements. The measured output power is 31dBm using the spectrum analyzer. The total weight of the system is 467 grams.

Figure 5 demonstrates the transmission and 1MHz at a distance of 3m. At further distances, the oscillator works intermittently due to the low power density and due to the matching of the diodes and the voltage swing drops below 0.4V, which is not enough swing to switch between loads for backscattering.

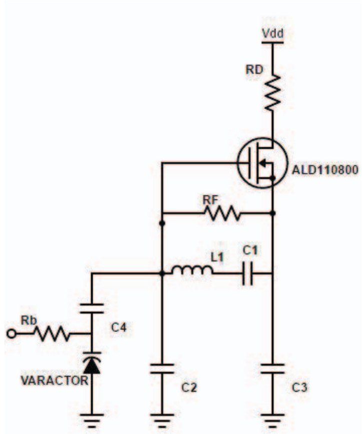

Fig. 3. Colpitts oscillator topology with the ALD110800 MOSFET as the active device. 0.5V VDD is required to operate properly. C1 and L1 act as the LC tank, tuned to 1MHz.

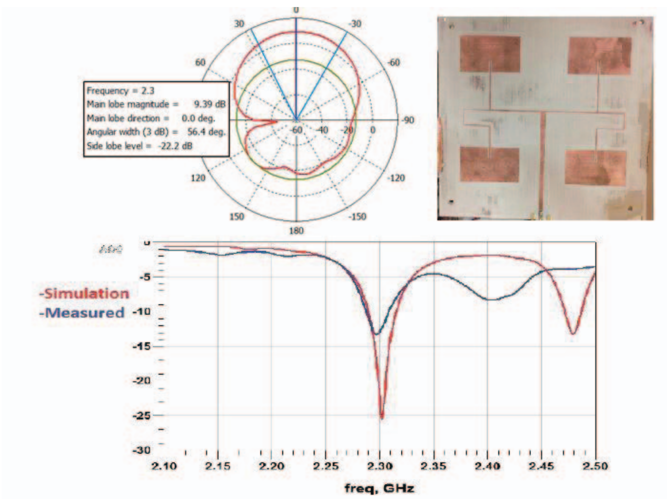

Fig. 4. Clockwise from top left, antenna radiation pattern, manufactured antenna prototype, input matching. The other resonance at around 2.41GHz could be due to the coupling between the feedlines.

IV. In-Air Tests

Figure 6, shows the flight test of the drone integrated transmitter system with the 1 MHz oscillation displayed on screen. As long as the oscillator is on, modulation and thus communication can occur. It was found that the movement and wobble of the drone would cause some noise with the battery supply, which would change the oscillation frequency of VCO on the transmitter. The supply voltage noise can perturb the VCO frequency by around 8MHz, making it hard to read off of the spectrum analyzer. Thus, to view the mixing of the carrier frequency and backscattering, the transmitter was held stationary at 3m. The mixing frequencies are shown in Figure 7 which clearly shows the 1MHz mixed signal with the carrier frequency.

The DJI drone advertises a 28min flight time. With the transmitter attached, the flight time reduces to around 20mins which is only a small decrease in flight time as compared

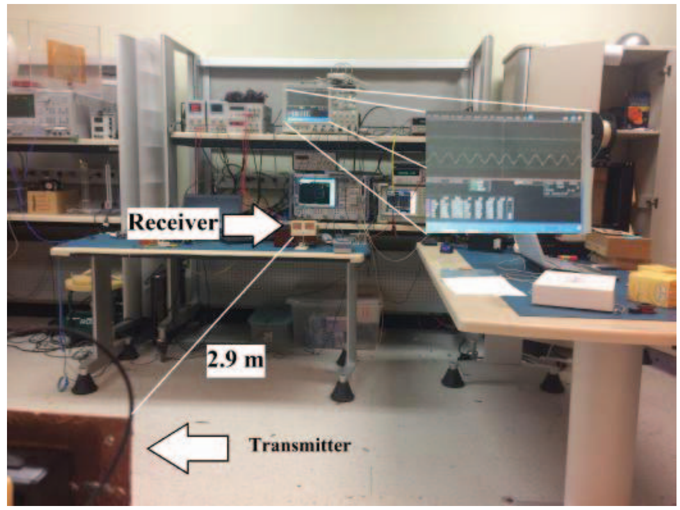

Fig. 5. Static on ground tests, which shows the oscillator working at a distance of 2.9m with a 0.4V peak voltage.

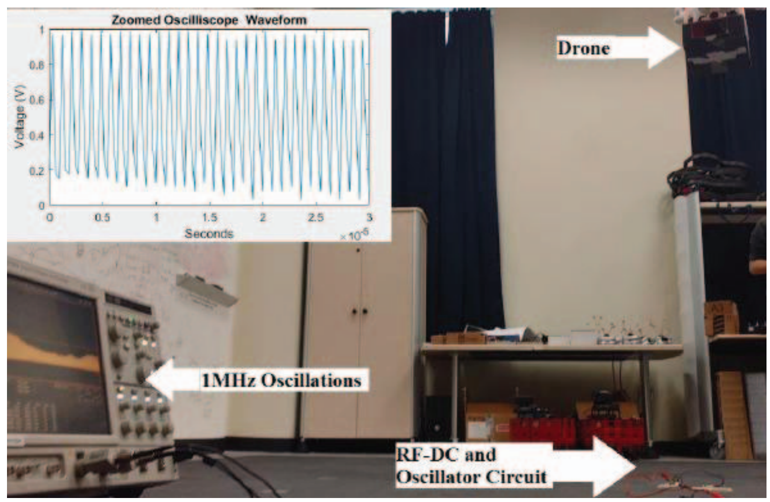

Fig. 6. Flight demonstration of the entire system with the drone flying approximately at 1.8m - 2m flight height. A zoomed in waveform is shown, showing 1MHz oscillations. The peak-to-peak voltage variations are due to the drone movement as it flys.

to other works. This still allows the drone to be utilized in practical situations.

V. Conclusion

The system introduced in this paper successfully demonstrates the ability to construct a low weight, easy to implement, commercially available drone basestation for collecting data from remote sensor networks. As the drone can fly for more than 20 mins, data from areas with limited signal coverage or hazardous areas can be accessed. By adding additional transducers, sensors or low power MCUs, complex data streams can be transmitted at 1 Mbit/sec without the use of batteries or solar power. Future improvements include improving weight by utilizing the onboard batteries, increasing read range, and decreasing the voltage supply noise. Additionally, another ultra

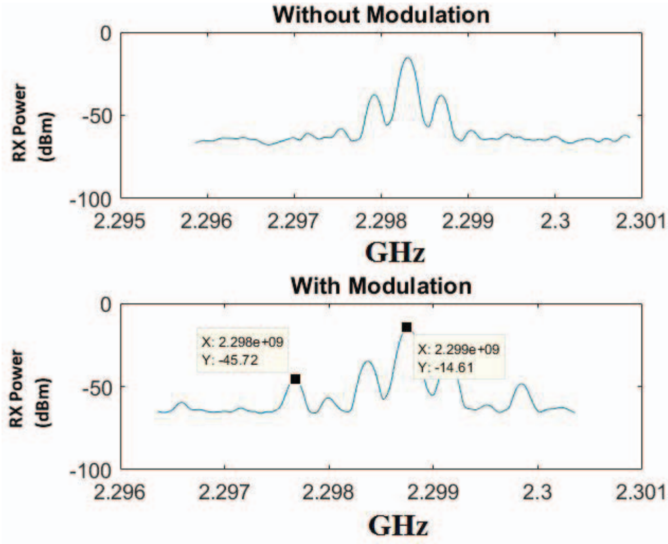

Fig. 7. Frequency mixing of the backscattered 2.3 GHz carrier and the 1 MHz modulation at a range of 3 meters.

low power oscillator and a digital phase shifter can be added to support IQ modulation techniques for high data transfer rates.

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