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Effective Techniques for Wireless Charging for Unmanned Aerial Vehicles (UAV)

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Abstract
Unmanned aerial vehicles are devices that can operate in air without any external human interference, thus making them completely autonomous. These devices are crucial for security surveillance and various payload services. The main aim in this paper will be to discuss the scope of wireless charging for such unmanned aerial vehicles (UAV) or simply speaking drones/quad copters and to come up with the ways to efficiently implement the above aim using readily available Wireless Power Transfer (WPT) modules and components. Three methods with their advantages, drawbacks and overall efficiency is considered. Method 1 will focus on implementing wireless power transmission using readily available modules like XKT-801. Method 2 will show the implementation of WPT using a Flyback transmission topology. Method 3 explores the usage of a Full bridge transmission for WPT.

Keywords: Unmanned aerial vehicles (UAV), wireless power transfer (WPT), security surveillance.

1. Introduction

The 21st century has seen a meteoric rise in usage of unmanned vehicles for tasks that are seemed to be dangerous or simply too monotonous for humans. This seems to highly true for Unmanned Aerial Vehicles (UAV) in the field of surveillance or military operations. In addition to military operation it is also used for scientific, hospitals, commercial and public safety purposes [1]. The world has headed researchers, activist, government agencies, public and private R&D department actively participating towards development of unmanned aerial vehicles. Balloons with explosives were used to attack enemy by American Civil War in 1916 that's when the first unmanned aerial vehicles (UAV) came into existence, military showed interest and researchers and developers conducted studies. During World War II Germany developed Buzz bomb which was also an unmanned aerial vehicle (UAV) [2-8]. Payload, Monitoring system and surveillance can be taken care without need of human beings. Fig.1- UAV for surveillance.

Fig.1-UAV for surveillance

For any application UAV needs to be transported from one place to another place easily and uninterrupted signal is required to collect live data [9]. Charging such autonomous devices manually nullifies their purpose completely. Unmanned drones are the best examples of such application. Wireless charging is solution to these problems [10]. Wireless charging stations can be made which will be able to charge an unmanned drone without any external help. Fig.2- Wireless system.

Fig.2-Wireless system

A wireless power transfer (WPT) Module (consisting of both a transmitter and a receiver) needs to be fitted in the station and drone respectively. An unmanned aerial vehicle (UAV) with low battery level can track a nearby charging station and with the help of GPS and its PID sensors it will be able to locate and position itself in the required way in order to begin the charging process. Fig.3- XKT-801 WPT module.

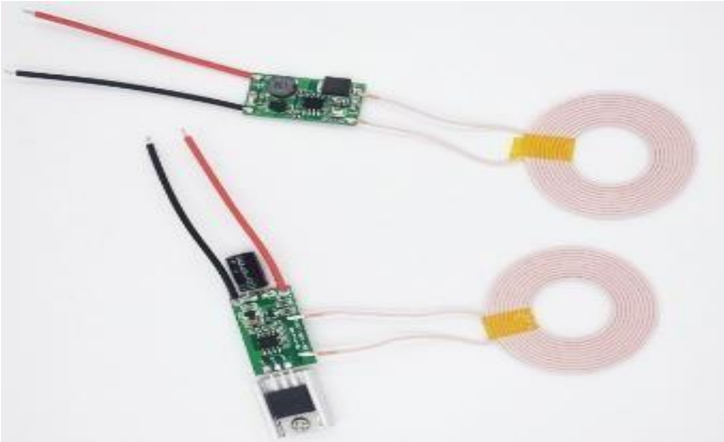

Fig.3- XKT-801 WPT module

Modern WPT modules such as XKT-801 are able to achieve almost 60% efficiency at a distance of one meter. Fig.3- XKT-801 WPT module.

2. Components of UAV

UAV consists of various components like data links, payloads, system user, human element, wireless technology, sensors, support elements, control elements [11-15]. The fig 4 shows different components of UAV. Sensors and wireless communication are interfaced with UAV for smart response. Fig.4- Various components of UAV.

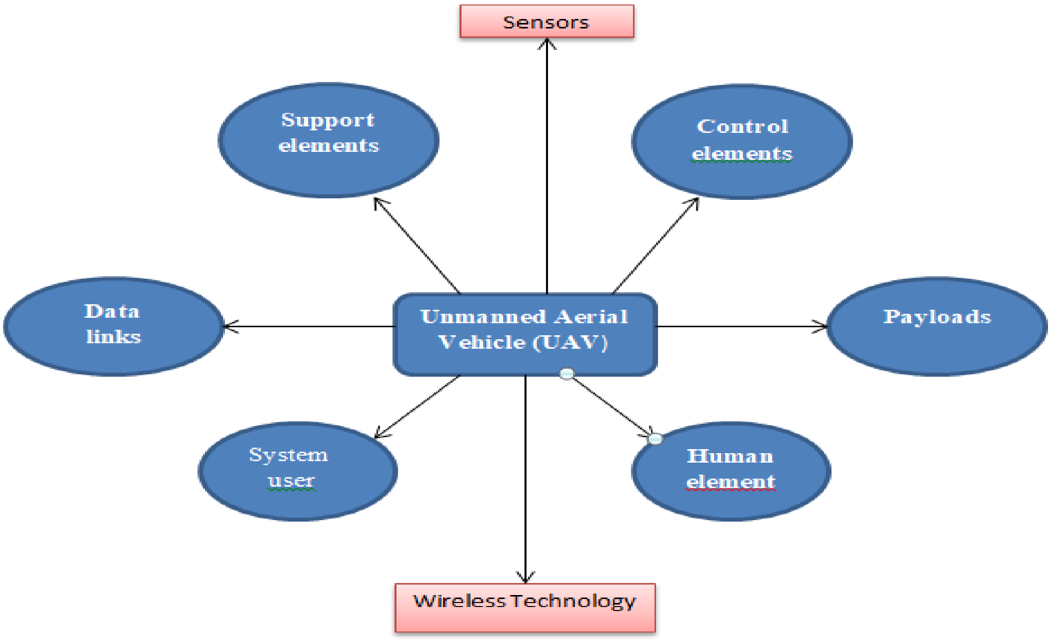

Fig.4- Various components of UAV

3. Wireless Charging of a Drone

It is divided using three methods: In the first method feasibility of using wireless charging module XKT-801 WPT for such an application is checked. In the second method the module is replicated but by using discrete electronic components and a generic microcontroller for controlling it. In the third method, Full Bridge topology is performed for wireless transmission instead of a flyback mode which is used in method 2. Fig.5- Wireless power transfer (WPT) process.

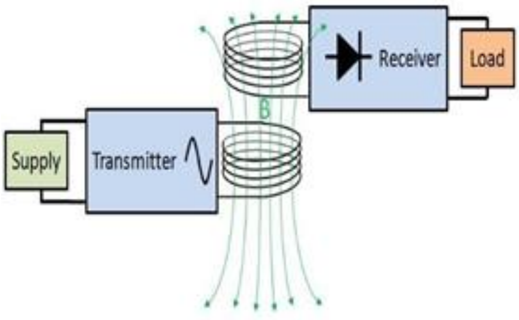

Fig.5- Wireless power transfer (WPT) process

3.1 Method 1(WPT Module)

XKT-801 WPT module is used in this method for charging our UAV. The module can be connected to the charging base station which will be incorporating an ac-dc converter in order to provide a well-regulated dc supply to the module. The module requires 24V volts to operate optimally. The dc input is then converted into ac using some switching topology like a full or a half bridge converter. The tx coil (i.e. densely braided copper wire) of our base module acts like a transmitter or in simple words primary of our base. The ac waveform is then transmitted to the secondary or rx coil by the process of Electromagnetic induction. This ac waveform on the secondary is then rectified and filtered into a regulated dc voltage which then can be used to charge the batteries of the UAV. An additional Li-Po charging module like TP4056 is required on the secondary side for balanced charging of the batteries. Several such balanced charging modules can be placed in series in case the battery pack consists of 'n' number of cells in series. The above method provides an easy way for WPT although such modules are expensive and the scope for customizing (i.e. improving efficiency, Output power, switching frequency etc.) is limited due to the proprietary nature of such commercial modules. It also renders the project from being more open source and the ability to modify the working. Method 2 and 3 will focus more on techniques that can be implemented without using dedicated WPT modules. Instead they will be implemented using a Microcontroller and some discrete power components. Fig.6- XKT-801 WPT module.

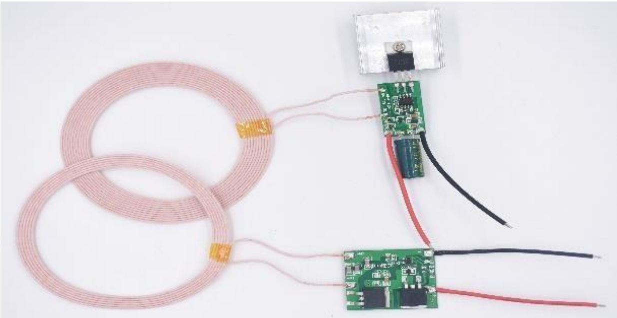

Fig.6-XKT-801 WPT module

3.2 Method 2 (flyback dc-dc wireless transmission)

In this method, custom made flyback dc-dc wireless transmission method is executed to wirelessly transmit power from the base charging station to the secondary drone winding. This method does not depend on a dedicated wireless charging module rather it would use a Microcontroller to execute the task.

This method is based on the principle of EMI across two mutually coupled inductors also known as a fly back transformer. Using two specially braided copper windings which will be based on a flat ferrite core material. Fig.7- Wireless charging method.

Fig.7- Wireless charging method

These windings will be used as a primary in the base charging station and as a secondary in the drone. With a high switching frequency power will be transmitted from the primary to the secondary in accordance with the principle of mutual coupling. The efficiency in this case will be highly based on the various losses along the distance between both the windings. A higher distance will cause a lot of power loss at the secondary due to loose coupling along with an increase in leakage inductances. A proper duty cycle along with the no of turns and winding method plays a crucial part in setting up the above required power parameters. The entire operation of setting up the duty cycle, switching frequencies and the getting the feedback from the secondary will be performed by microcontroller thus making this entire method completely open source and highly customizable.

The simulation that performed is only for the proof of the above theory and working and its actual implementation will require a lot more analysis along with other factors to improve the efficiency. One disadvantage of the simulated example is that it doesn't use the full flux swing of the ferrite core hence it renders the overall efficiency of the circuit. Some loss elements like Mosfet on resistance, diode losses have been considered.

A Midcom Flyback transformer with an air gap model from Wurth electronics has been used in the simulations which effectively represent the respective windings of base charging station and the load which in the case is the UAV. Fig.8- Wireless charging process.

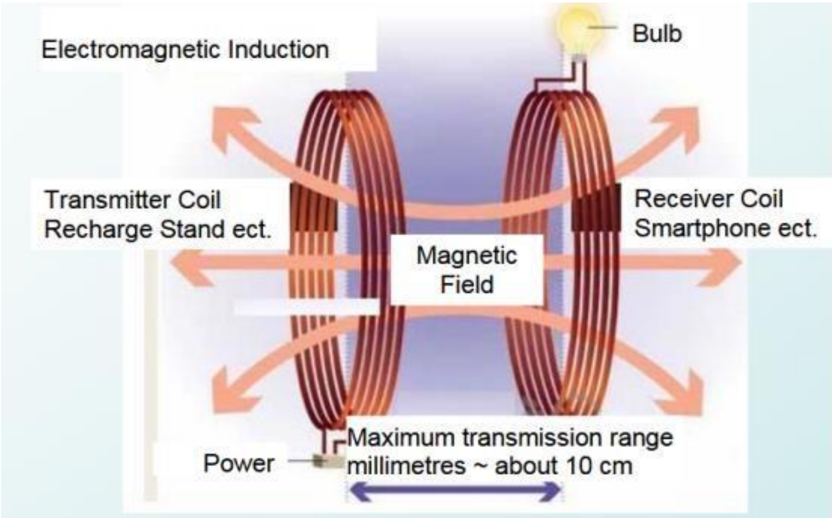

Fig.8- Wireless charging process

3.3 Method 3 (Full bridge converter method)

The Method 2 which explores the usage of a flyback mode for wireless power transmission suffers from a big disadvantage i.e. the half usage of BH curve. This prevents us from completely utilizing the ferrite plate core. Hence Method 3 overcomes this issue by using a full Bridge topology for wireless transmission. The efficiency is improved greatly by utilizing a full flux swing for the magnetics. Almost 70% of efficiency is achieved if the mosfet losses are overlooked. A full bridge method also avoids core saturation as compared to that of a flyback thus greatly influencing the overall efficiency. In this experiment the perfect coupling of K=1 is considered. However, in real word scenario this may not be so, thus the output power is increased from 17 watts to 24 watts in order to make up for the losses which may occur due to loose coupling and leakage inductance.

4. Result/ Simulation

4.1 flyback dc-dc wireless transmission

LTspice Simulation tool is used to execute the wireless charging of drone using a custom flyback dc-dc transmission mode with a gate circuit. It consists of primary base charging station and UAV/Drone with receiver charging port. Fig.9- Wireless Charging of UAV/drone gives a simulation to charge the drone/UAV. In the primary station different transistors are used to step up dc voltage from the input. In the receiver end filter circuit is used.

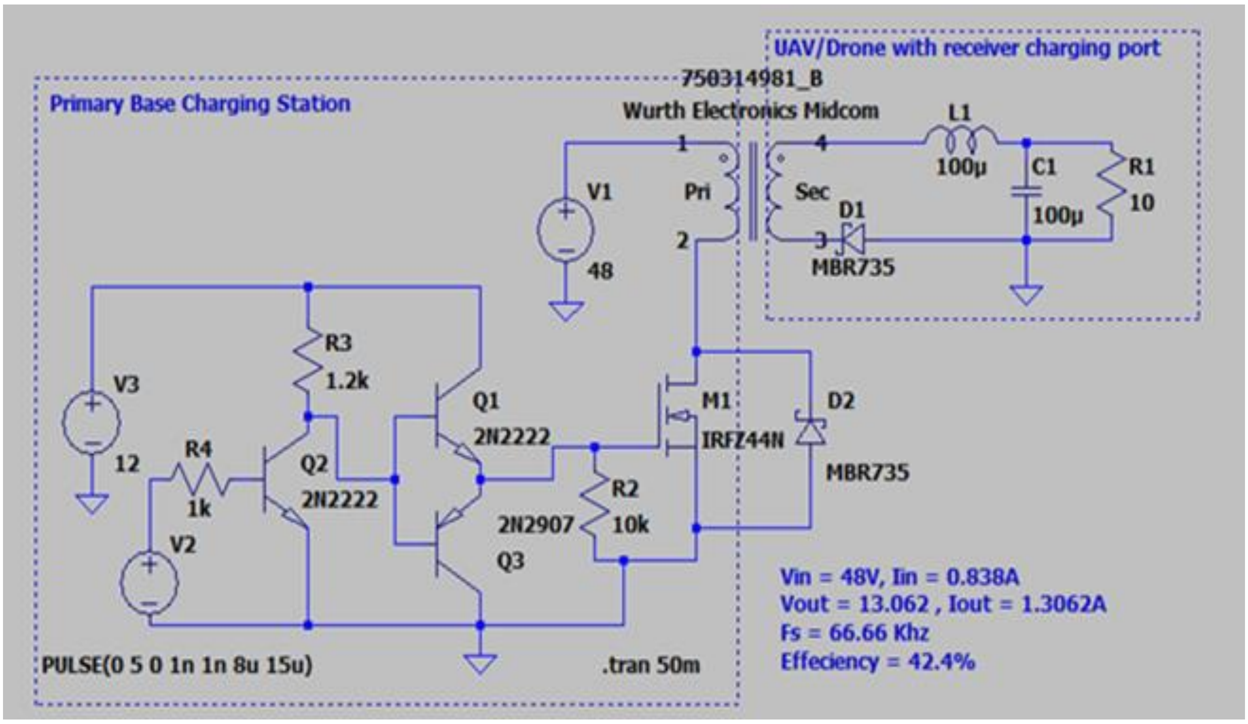

Fig.9- Wireless Charging of UAV/drone

Output and Waveforms

Fig.10a & Fig.10b represents the overall charging of UAV. It indicates the overall output voltage and current obtained for charging. Biggest advantage of method 2 over method 1 is that the dependence on a commercial wireless charging module is completely removed along with additional advantage of customizability of the application.

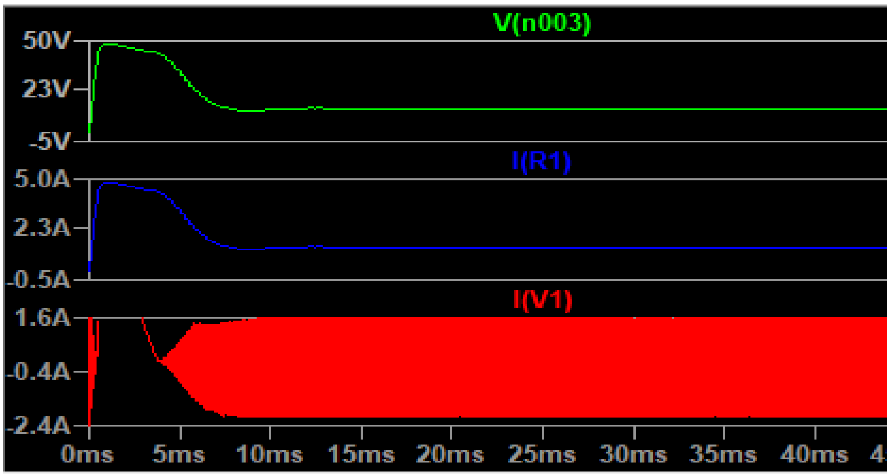

Fig.10.a- UAV Charging process

The steady state output voltage and current of the above-mentioned method is about 13V and 1.3A respectively. A total dc output of almost 17 watts is obtained by this method with an efficiency of 42.4%.

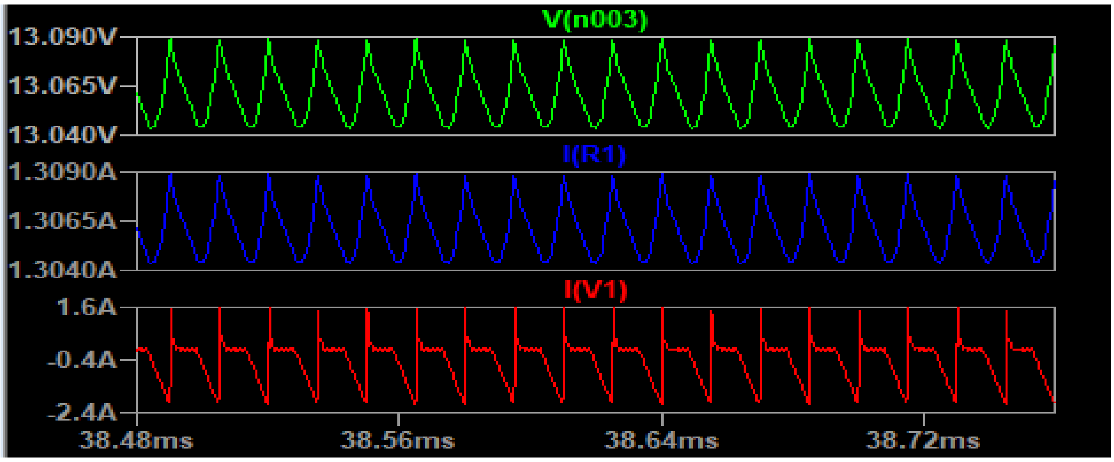

Fig.10.b- UAV Charging process

The ripple content of voltage and current waveforms are about 50mV and 50mA respectively which is 0.386% and 3.86% of the main dc waveforms, which is very low and thus can power up sensitive electric circuits that don't have much tolerances with respect to unregulated input power.

4.2 Full bridge converter method

The schematic diagram of Full Bridge Wireless transmission circuit (Fig.11). It is mainly used to reduce the loss and improve the overall efficiency of the system. Input as well as output side full bridge circuit is used. The transistor at the input is IRF5305 used and output is zener diode MBR735. When 12V,3A input is applied then the output at the receiver end is 11V and 2.2A . Thus the overall efffciency of the system is 69.14%.

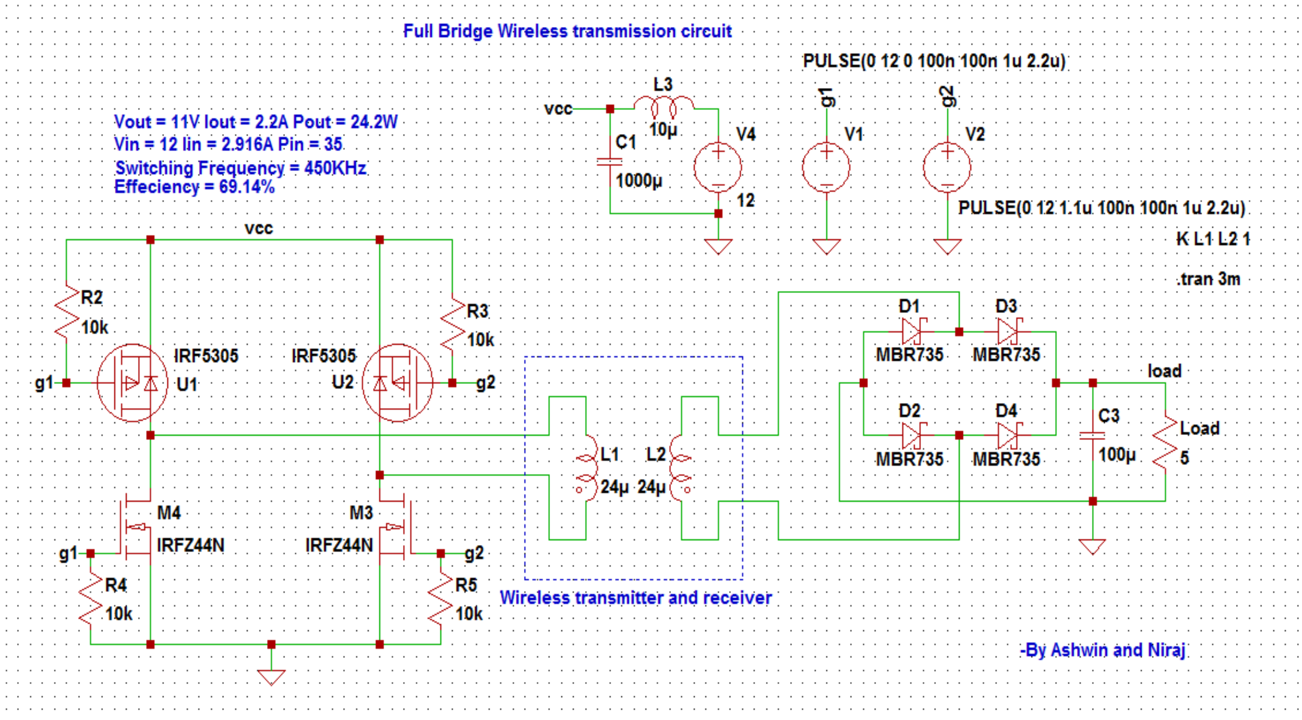

Fig.11- Full Bridge Wireless transmission circuit

Output and Waveforms: -

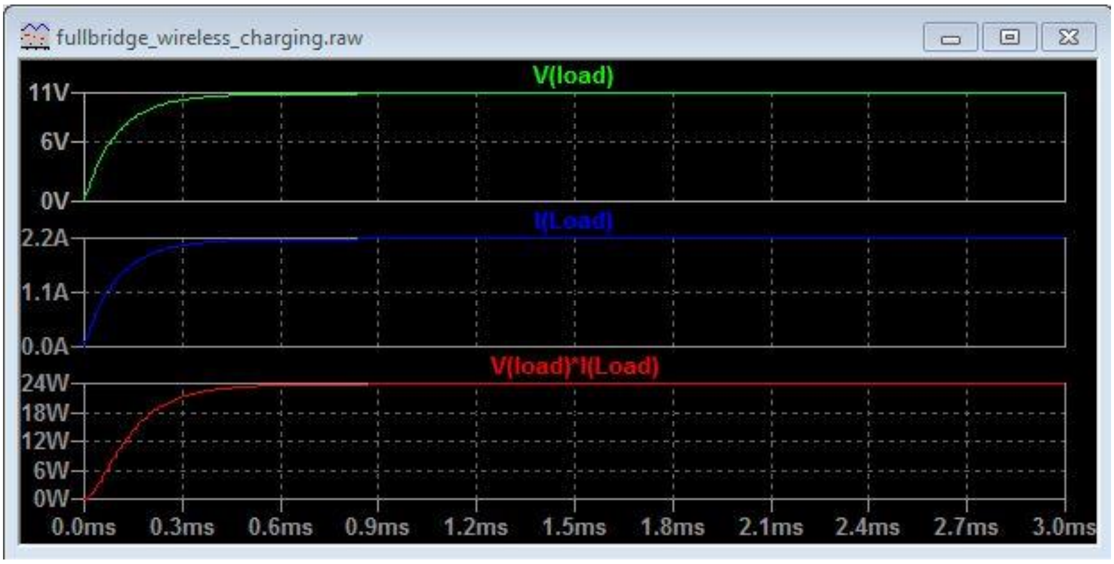

Fig.12a- Full Bridge Wireless charging

For the given input the Full bridge method (Fig12a) provided an output of 12V and 2.9A almost leading up to a power output of 36 watts with an efficiency of 70% . The ripple content (Fig 12b) in this particular technique is less than 0.3% which can be considered to be almost nonexistent. Thus, this method proves to be much superior to method 2.

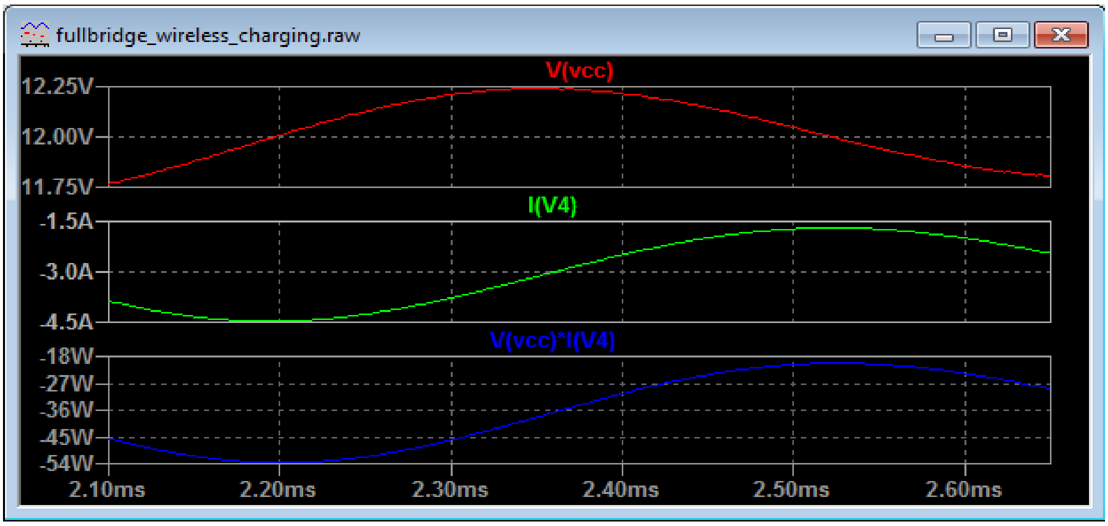

Fig.12b- Full Bridge Wireless charging

4. Wireless UAV Charging Process

An experiment conducted where UAV acts as host and it's considered as a surveillance drone which falls in the heavy payload category. The drone will be powered by a 3s 2p 1500 mAh9 Li-Po battery pack. Considering a very conservative and safe charging rate of 1C, battery pack is charged to 1.3A.

Calculations of required power parameters:

Required charging Voltage = 3*4.2V

= 12.6V

To keep a buffer range and to counteract the unreliable contact distance between the base charging station and the UAV charging secondary winding will maintain the output voltage at 13V. Also, to ensure a long and safe battery life battery pack is charged by a current value which has a rate of 0.86C of nominal value i.e. 1.3A.

Charging current = 1.3A
Required Output Power = 13V * 1.3A
= 16.9 W

The kind of input voltage i.e. the voltage fed to the base charging station is of little importance as far as it does the job of providing with the above output power requirements. A power source of 48V/ 2A is used in this case due to the fact it is one of the standard available SMPS power supply.

5. Conclusion

In this paper, the scope of wireless charging for unmanned aerial vehicles (UAV) such as Drones is discussed using 3 methods, one using WPT module & another one without using it. In method 1, basic theories of WPT and analysis based on distance between transmitter and receiver is discussed for various voltage values. In method 2 the module replicated but by using a flyback transformer, discrete electronic components and a generic microcontroller. The microcontroller used makes this entire method completely open source and highly customizable. The edge, method 2 gives over method 1 is that the dependence on a commercial wireless charging module is completely removed. However, method 2 prevents us from completely utilizing the ferrite plate core. Hence method 3 can be executed to overcome this issue. Hence, charging stations can be used by drones for recharging and also routines tasks of drones can be finished accordingly. After a short time of charging, drones can repeat the mission again.

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