Thrust Area 4: Solar (PV Integration)

Non-Contact Energy Delivery for PV System and Wireless Charging Applications

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Description:
Innovative non-contact energy delivery method will be used in photovoltaic energy generation system to accelerate the system deployment. Instead of delivering electric power using cables penetrating through building structures, magnetic field coupling allows power to be transferred wirelessly through building walls and roofs. In the meantime, the DC electric energy from photovoltaic cells is converted to AC energy. This enables the photovoltaic system to be quickly set up or relocated, and the collected solar energy from outdoor system can be conveniently delivered to indoor appliances. Techniques to achieve high efficiency at high power delivery through different building structures will be studied for this plug-and-play architecture.

In addition, the technique and the system can also be used for non-contact charging of electric vehicles. The transmitter/charger can be placed as a mat on garage floor or parking space. The receiver inside vehicle will pick up the energy delivery through magnetic coupling. This eliminates the need of connecting charging wires to vehicles and exposed metal contacts, which is a safer method of charging electric vehicles.

Budget: $ 252,000
Universities: UF

Progress Summary

Power can be transmitted wirelessly using various methods. For moderate distances (up to a few meters), near field coupling through either the electric or magnetic fields is used to achieve high efficiency. Recent publications in scientific and engineering journals and demonstrations in Consumer Electronics Show have generated strong interests. Many companies are now investing resources into research and product development of wireless power systems and creating jobs in this field. In consumer electronics, companies are developing technologies to charge cellular phones and other portable electronic devices wirelessly. In automobile industry, companies are developing technologies to charge electric vehicles through wireless power. High efficiency of wireless power transmission is the key in developing this type of wireless charging technologies. For charging cellular phones, currently there are already products available on the market and engineers are working hard to improve their performances. Considering the vast amount of portable electronic devices in the world and the growing number of electric vehicles, the market of wireless power has a great potential.

This project performed at the Radio Frequency Circuits and Systems Research Group in the University of Florida is focusing on developing wireless power transmission systems for various applications and new technologies to improve their efficiency. Several wireless power systems have been demonstrated and the results have been published.

During the past year, our research results have attracted attentions from many companies in industry. Some companies are interested in licensing the technologies, and some companies have sent their engineers to University of Florida as visiting researchers to establish collaborations. So far, our lab has hosted visiting researchers from NEC (Japan), Research Institute of Industrial Science & Technology (Korea), and Industrial Technologies Research Institute (Taiwan). These companies also sponsor research projects in the lab and plan to hire students from the lab as interns. With new technologies being developed that may lead to potential new intellectual properties, new companies and new jobs in this field is highly possible.

Funds leveraged/new partnerships created:

- New collaboration with NEC (Japan) established.
- New collaboration with Research Institute of Industrial Science & Technology (Korea) established.
- New collaboration with Industrial Technologies Research Institute (Taiwan) established.

2011 Annual Report

Midrange Wireless Power System

Midrange power transmission over moderate distances is investigated for use in transmitting power from a source outside of a building to the interior (i.e. a solar panel) without modifying the structure. Such a system would also be useful in situations where power delivery via physical wires would be impractical or dangerous, or where a lack of physical connection would provide an advantage that offsets the decrease in efficiency (for example, wireless charging at bus stations for electric busses). To this end, a system capable of power transfer over distances of about one meter is investigated and built.

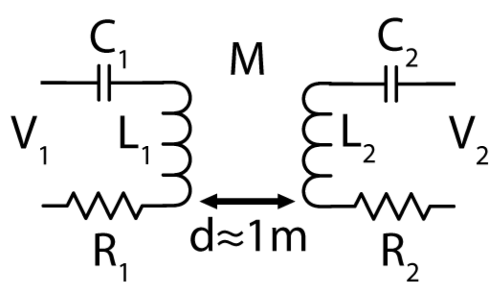

Figure 1: Series resonant arrangement of coils, including coupling, parasitic resistance and tuning capacitor.

In previous works, a system capable of wireless charging over short distances was developed. A magnetic field is generated in the near-field and a receiving coil is placed physically close to the source in order to achieve high efficiency transfer. This idea is extended to moderate distances (about one meter) by increasing the size of transmit and receive coils to increase the mutual inductance and choosing the appropriate conductor to minimize resistive losses. A series resonant circuit (Figure 1) is used to obtain high-efficiency power transfer. In this configuration the efficiency can be written as:

$$\eta = \frac{\omega^2 M^2 R_L}{(R_2 + R_L)^2 R_1 + (R_2 + R_L)\omega^2 M^2}$$

It can be seen that there are two methods to increase efficiency. First, the mutual inductance can be increased. In the two systems to be presented, the mutual inductance is increased by making the characteristic size of the coupling coils similar to the distance desired (one meter flat square spiral and one meter diameter helix) and using multi-turn coils. Second, the efficiency can be increased by reducing the parasitic resistance (R_1 and R_2) of the coils themselves (as well as the series resistance of any other components). To minimize these values, litz wire as well as ¼" copper pipe are used in the construction of the coils.

Two coils made of litz wire on wooden forms comprise the first system (Figure 2). Fixed film capacitors are used for series tuning. A full-bridge amplifier using IRF530 MOSFETs and a HIP4081A driver is used to power the system at 500 kHz. The maximum power transferred using this system is 38.3W with 76% efficiency. The transmitted power is limited primarily by the high voltage that develops as a result of the series resonant circuit. The high voltage will cause arcing between turns of the litz wire and breakdown of the capacitor used to tune the circuit. These faults can damage the driving amplifier.

Figure 2: The first wireless power system achieving 38.3W with 76% efficiency. The coils are made of litz wire: 6 turns, 1 m each side, 1725 strand, 48 AWG.

Several methods are used to combat the above issues and increase the transmitted power further. The most obvious issue is the breakdown of the capacitor. The capacitors used initially have a very low ESR (less than 0.1 ohm) at the operating frequency, but are only rated for 600 V. Higher rating capacitors of similar values are available, however the losses in the capacitors approach the magnitude of the losses caused by the resistance of the coils.

The second system utilizes ¼" copper pipe (Figure 3) to form two 1 m diameter helical coils on PVC coil forms. A higher voltage rated capacitor is formed from several film capacitors in parallel with a 10 kV vacuum variable capacitor for fine tuning. With this system a maximum power of 114 W was delivered to a 25 ohm load with 65% efficiency at one meter separation. Virtually all of the dissipated power is lost to the resistances of the coils, not in the amplifier, thus the amplifier should be able to supply up to 450 W without further modification, which should allow for received power to approach 300 W.

Figure 3: The second wireless power system achieving 114 W and 65% efficiency. The coils are made of ¼" copper tubing on PVC form: 9 turns, 1 m diameter.

High Efficiency Power Amplifier

The power amplifier in transmitter is the most important active component in the system. Several different designs of power amplifier have been studied in this research. These include Class-E, Class-D, and full-bridge Class-D. It was found out that the full-bridge Class-D amplifier is the best for midrange wireless power system. The efficiency remains constant when power level is changed. It is less sensitive to variation in distance when compared to Class-E. The full-bridge Class-D also requires half of the supply voltage of Class-D. Figure 4 shows a picture of the full-bridge Class-D amplifier. A detailed study and results were described in the previous report.

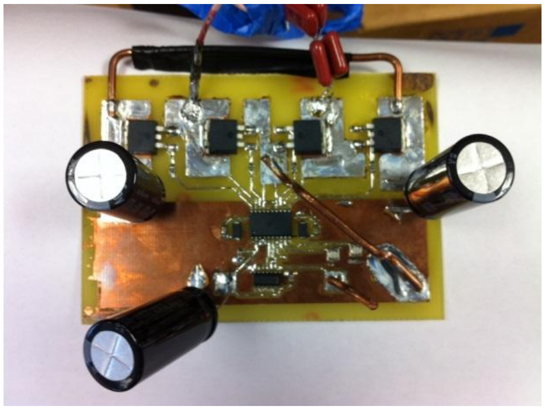

Figure 4: Full-bridge Class-D amplifier.

For some wireless power applications requiring smaller size with less power, operating at higher frequency is more suitable. For wireless charging of portable devices at a fixed short distance, Class-E is a good topology because its power output at a fixed supply voltage is higher than that of Class-D. High efficiency Class-E power amplifiers at 13.56 MHz are developed. 13.56 MHz is a popular Radio Frequency Identification (RFID) frequency band. The improvement of power amplifier efficiency will benefit the widely used RFID systems at this frequency and potentially can be applied to many other wireless communication devices and systems.

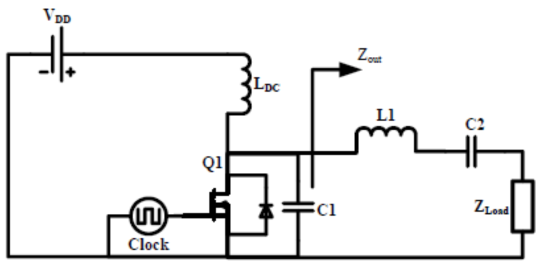

Figure 5: Class-E power amplifier

The schematic of Class-E amplifier is shown in Figure 5. Operating at 13.56 MHz brought up a few challenges:

1. The internal shunt capacitance across the drain and source of the transistor is not negligible. In most cases, this parasitic is larger than the value determined for C1, not allowing an optimal implementation.
2. Ideally, we want a high Q on the load to only allow a single tone to pass through the filter. However, there is a tradeoff between the Q and the size of the inductor L2. If L2 is too large, the parasitic resistance is very large (~5-10 ohms), which will cause power loss across it. Therefore, a low Q is preferable (but not less than 1.8) to maximize efficiency. In the case of wireless power transmission system, the quality of the output signal does not have to be a perfect sine wave since the objective is to transmit energy.

Shunt Capacitance and GaN transistor:
The parasitic shunt capacitance across the drain and the source of the transistor is significantly larger in power MOSFETs at 13.56 MHz than at lower frequencies. Various MOSFET's were tested, in simulation and on the test bench, but failed to work due to either long rise and falling times (fully switch from ON to OFF was not possible at 13.56 MHz) and/or the internal shunt capacitance was too large. Given these constraints, a different transistor technology GaN was considered. This type of transistor is significantly smaller, more efficient, and capable for handling large current and drain voltages, which means high power delivery is possible. Most importantly, it works well at 13.56 MHz, having fast fall and rise times as well as small Cgs.

Circuit Implementation:
The shunt capacitance was removed since the internal shunt capacitance of the GaN transistor was large enough to satisfy the design criteria. The Q of the load was set to 5 to allow a small inductor on the load network, minimizing the parasitic and power loss across the inductor L2. The values of circuit components are shown in Table 1 (refer to Figure 6).

M1	EPC1010	C1	690pF
Gate Driver	IXDI502	C2	0.1uF
Oscillator	K50-HC	C3	0.1uF
L1	50uH	C4	0.1uF
L2	0.3uH	C5	22uF
Rload	13ohm	C6	0.1uF
		C7	22uF

Table 1: Component values

A complete Class-E transmitter consisting of an oscillator, a gate driver, and a Class-E amplifier was set up (Figure 6 & Figure 7). The gate voltage was varied from 4V to 6V with the purpose of finding an optimal point at which the highest efficiency is achieved. Unlike a power MOSFET, the GaN transistor is very delicate, causing it to break when the maximum gate voltage is exceeded.

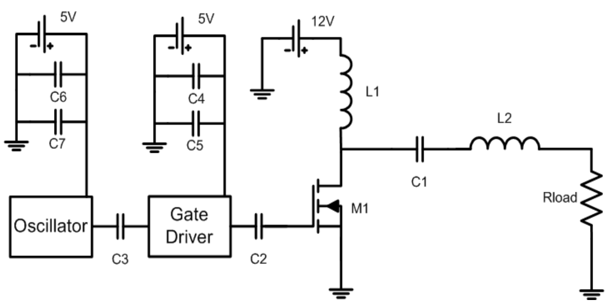

Figure 6: Complete Class-E transmitter with load

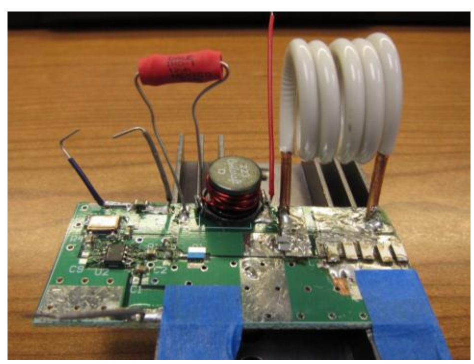

Figure 7: Picture of Class E amplifier

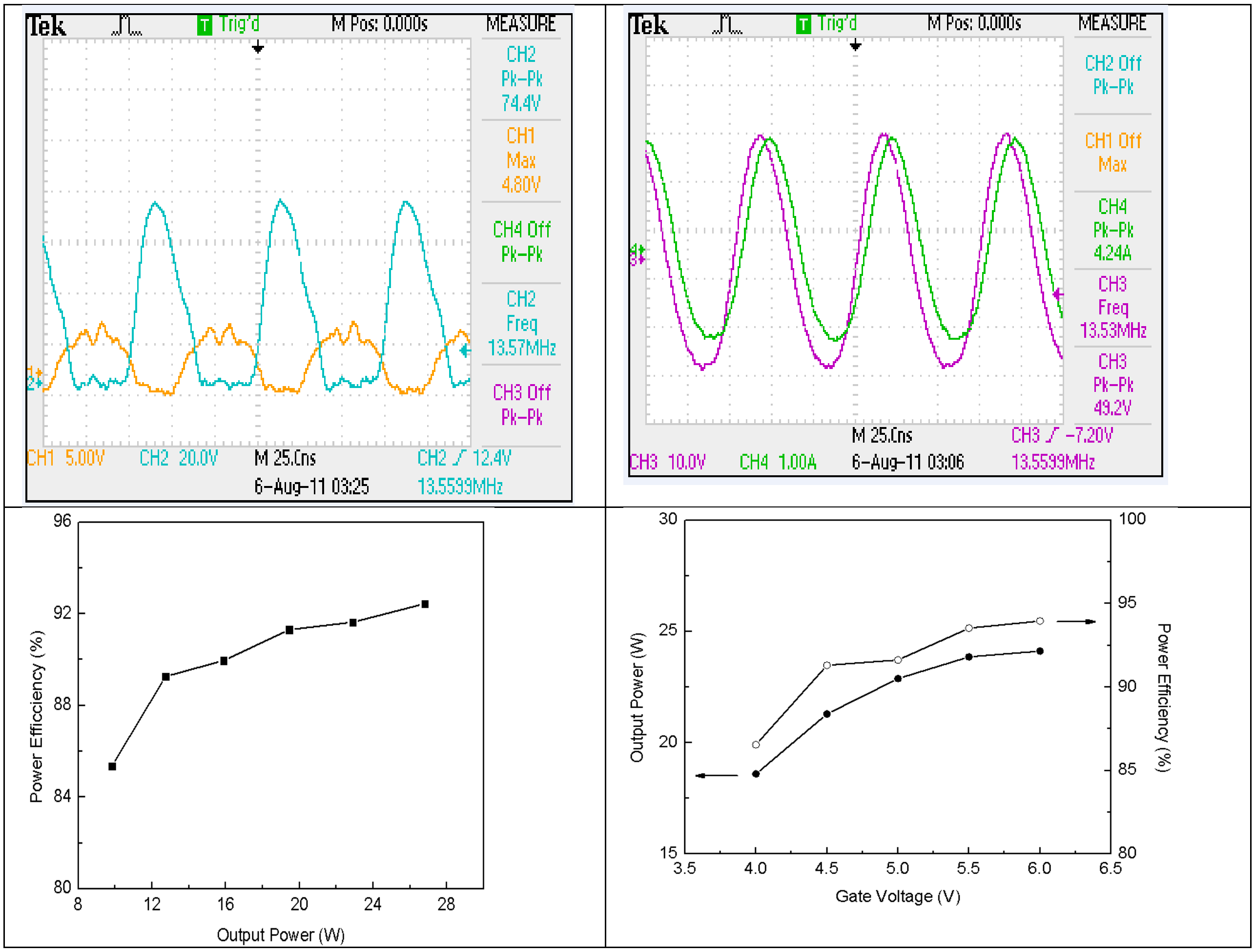

Figure 8: Measurement results of Class-E power amplifier

Figure 8 shows the measurement results obtained. In the top left, the drain waveform shows a proper ZVS is attained, which is critical for a high efficient Class-E amplifier. On the right, the output voltage and

current waveforms are slightly out of phase. This is due to parasitics of the resistor and the probing of the system (voltage probe has a capacitance of 15pF). As shown, a 94% drain efficiency is achieved with an output of 27W (overall efficiency including driving circuit drops to 92%). Theoretically, a Class-E can yield 100% efficiency. However, the parasitics of components as well as the switching losses of the transistors reduce the efficiency.

In summary, the implementation of a Class-E amplifier used as an inverter for wireless power transmission systems has been successfully achieved. Using a GaN transistor, it was possible to deal with the internal shunt capacitance problem as well as the slow rising and falling times of a power MOSFET. In addition, compared to the power MOSFET, the GaN transistor is much smaller in size for the same power capability.