A High Efficiency Wireless DC-DC Converter

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***Abstract*— This paper will present a converter design targeted to push the performance in respect of efficiency and power density for a 50W Wireless Charger for portable devices. The innovation will come from the topology, magnetic structure and the control method.**

I. INTRODUCTION

The design target was a 50W Wireless DC-DC battery charger operating from an input voltage range of 10.8V to 13.2V with an output voltage regulated at 12V and a nominal air gap of 4mm. The output current should reach 4.2A. The implementation has to reach very high efficiency, higher than 90% at full load, very high power density and very low profile. The power density of the power train which includes the magnetic, input and output switching elements, the driving circuits, current and temperature sensors has to reach 6.44 W/cm^3. The maximum height of both transmitter and receiver does not exceed 2.2 mm. In order to reach the efficiency and power density target, the converter has to operate in soft switching mode for the primary switchers regardless of the loading condition. In order for the transmitter to send the proper amount of energy to the receiver, a way of communication between the two is established. The traditional method used to regulate the output voltage for wireless power converters is to employ a further power processing stage with its own regulation [1]. Such solutions are not suitable for reaching high efficiency [2]. To be able to satisfy the efficiency requirements the receiver extra power processing stage is eliminated and both the transmitter and receiver work together to achieve regulation.

II. TOPOLOGY SELECTION

Figure 1 presents the resonant topology employed in this application. It contains a CLLC resonant tank. In the transmitter side we have a half bridge structure which operates at nearly 50% constant duty cycle. The half bridge capacitors are part of the resonant tank. Regulation is accomplished by the variation of the switching frequency of the two primary transistors. To achieve a very high power density the converter is designed to operate at very high switching frequency. In the secondary side we are using voltage doubler configuration and for the rectifiers means we are using synchronous rectifiers. The receiver side also contains a chopper transistor used for secondary side regulation. The two voltage doubler capacitors are part of the CLLC resonant tank. Due to the fact that the transformer air gap is very high the leakage inductance value is very large, which makes it suitable for using it as the resonant tank series inductance. In our particular case, the coupling of the transformer is 70%. Figure 2 depicts the transmitter transformer structure which is symmetrical to the receiver transformer structure. The transformer core is a custom pot shaped circular core with 50 mm diameter and 3C95 soft ferrite material. The primary inductance measured with the secondary present at 4 mm gap is 0.8 µH. The transformer turns ration is 1:1 with 3 turns primary and 3 turns secondary.

Fig. 1 CLLC resonant topology

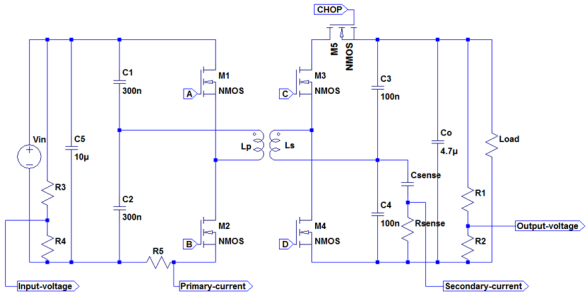
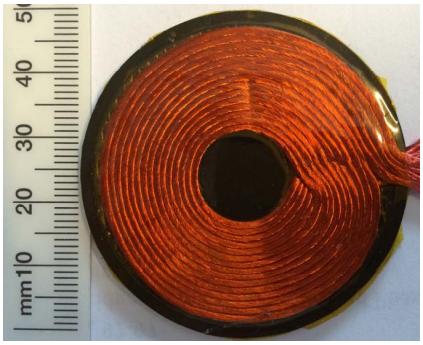


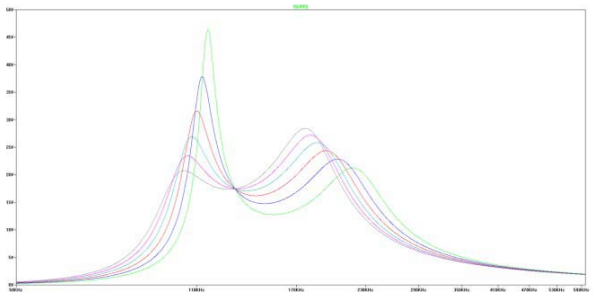
Fig. 2 Transformer structure



One of the major advantages of this structure is the fact that ZVS is accomplished in the primary switchers regardless of the load. ZCS is also accomplished in the secondary synchronous rectifiers. The synchronous rectifiers are driven by the

transformer resonant current waveform and are enabled one by one only if there is current present through them. The chopper transistor is synchronized to the receiver switching node to avoid voltage avalanches. Figure 3 shows the converter gain vs. operating frequency.

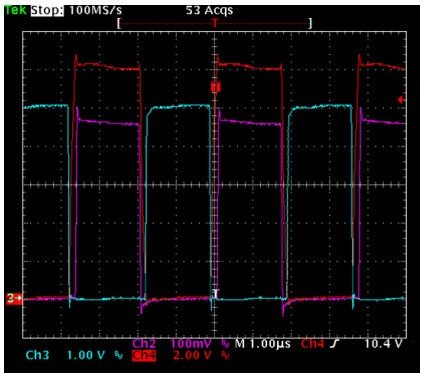
Fig. 3 Gain vs. operating frequency



III. CONTROL METHODOLOGY

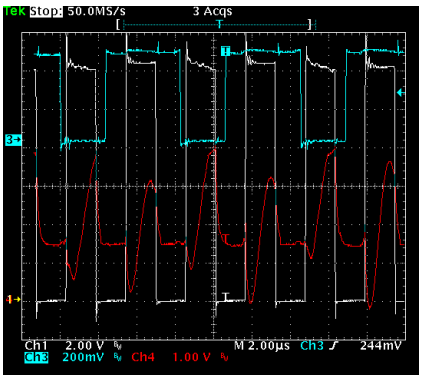
The control for this converter is implemented with two digital signal microcontrollers, one in the transmitter and one in the receiver. The transmitter microcontroller measures input current, input voltage and transmitter temperature and controls the switching frequency and dead-times. The receiver microcontroller measures the output voltage, and temperature and controls the secondary side chopper transistor. The receiver microcontroller regulates output power by opening and closing the chopper transistor with a frequency proportional to the secondary winding transformer frequency, while changing the duty cycle. When the receiver chopper transistor is closed the power is transmitted to the load and the shape of the primary current is sinusoidal. When the receiver chopper transistor is opened, output voltage is sustained by the output capacitance and the primary current becomes triangular shaped. Changing the primary current shape is the means of communicating via the power transformer from the receiver to the transmitter. The transmitter microcontroller reads the current waveform and synchronizes the reading points with the PWM to detect sinusoidal or triangular current shapes.

Fig. 4 Receiver SR drive signals



When a triangular current shape is detected, the transmitted power is higher than the required power and the switching frequency is increased. Two digital PI loops maintain regulation: the receiver loop has a reference value of 12.0V and is fed with the measured output voltage. The output of the loop represents the duty cycle applied to the chopper transistor. The transmitter loop adjusts the primary switching frequency until the number of triangular shaped current reads reaches a minimum imposed set point. In Figure 5 Ch1 is the primary switch node, Ch3 is the receiver chopping signal and Ch4 is the primary current waveform. In Figure 4 Ch2 and Ch3 are the SR drive signals while Ch4 is the secondary switching node.

Fig. 5 Current shape with and without chopping



IV. EXPERIMENTAL RESULTS

Figure 6 presents the efficiency vs. output current at nominal input voltage and 12V output. As this can be seen, the efficiency reaches over 91% at full load. The picture of the

Fig. 6 Efficiency vs Iout

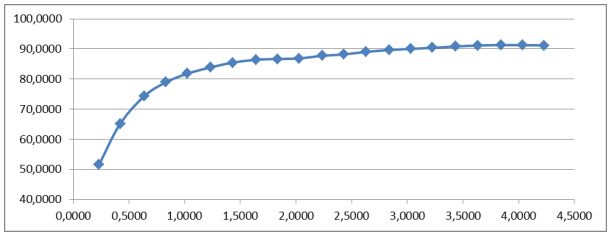
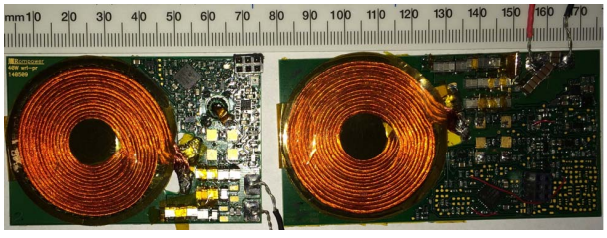


Fig. 7 Experimental prototype



receiver and transmitter is presented in Figure 7. The application is implemented in a 2-layer PCB structure of 3oz. copper. In order to keep a very low profile the prepreg has a 0.3mm thickness.

V. CONCLUSIONS AND FUTURE WORK

This paper presents a topology structure employing divided resonance across the transformer in the primary and secondary side. It uses the concept of integrated transformer where the leakage inductance is part of the resonant tank. The high efficiency is obtained by minimizing transformer winding losses by reducing the AC to DC ratio. Elimination of the receiver extra power processing stage is accomplished by communicating with the transmitter using the power transformer while regulating the output voltage. Almost instant feedback is received by the transmitter, allowing the handling of large load transients with minimum output voltage drop. The use of intelligent power processing enables the synchronization of the receiver chopper transistor with the switching node, turning the chopper transistor off at a zero current condition, thus increasing the efficiency. The analog SR drive is simple and robust, uses very few components and ensures that cross-conduction doesn't happen under any condition.

The optimization of the power train in conjunction with intelligent power processing allows us to obtain very high efficiency and high power density compared to the industry standard.

REFERENCES

[1] Qi low power specification, http://www.wirelesspowerconsortium.com/downloads/wireless-power-specification-part-1.html

[2] WPC Performance Requirements Specification http://www.wirelesspowerconsortium.com/downloads

[3] A.Savu, A Radoi, A. Florescu, "Transformer Analysis for Wireless Power DC-DC Converters", International Review of Electrical Engineering(I.R.E.E.), Vol. 9, Nr. 1, 2014

[4] Ionel D. Jitaru "Higher efficiency Power conversion through intelligent power processing" , PCIM Europe 2009, pp. 70-74

[5] C. Fernández, P. Zumel, A. Lázaro, A. Barrado, "A simple approach to design a contact-less power supply for a moving load", Proceedings of the Applied Power Electronics Conference (APEC) 2007, p.1607