A novel Qi-standard compliant full-bridge wireless power charger for low power devices

M. Galizzi, M. Caldara, V. Re, A. Vitali

Abstract— **In this paper a Qi-standard compliant compact wireless power charger system, composed of a *wireless power transmitter* and a *wireless power receiver,* is presented. The developed system aims to be compliant with the latest revision of Wireless Power Consortium's directives and uses a full-bridge resonant inverter as the main power transmitter architecture. The wireless power transmitter and receiver have been designed with ultra low power and high efficiency electronics components thereby maximizing the overall power transfer efficiency.**

Index Terms— **standard compliant, inductive power transfer, wireless power charger, resonance coupling, battery charger**

I. Introduction

In recent years, the market of consumer products experienced a growing interest in wireless power charging technologies, and several embedded systems are available nowadays for an everyday use. Some of the largest electronics component manufacturers propose their own reference design and system on chip solutions, fulfilling international standard requirements of interoperability. One of the leading proposer of wireless power transfer technology standards is the Wireless Power Consortium (WPC), an organization that describes the interface of the so-called Qi-standard compliant devices.

The Qi-standard defines the main features that certifiable devices have to implement. Such requirements regard operating frequency, minimum system efficiency, power control methods and feedback communication technique.

With Qi-standard devices, high efficiency energy transfer is made possible by means of near field wireless transmission of electrical energy through resonance coupled wire-wound planar inductors [1]. In order to achieve the best coupling between power transmitter and power receiver, magnetically aligned coils have been used and the distance among inductors is limited to few millimeters.

This paper describe a complete solution for wireless battery recharge with an achieved overall peak efficiency comparable with the most advanced solution available on the market [2].

The developed wireless power charger complies with Qi-standard, thus ensuring interoperability with existing systems and promote and spread standard adoption too.

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II. Standard Architectures

A typical wireless battery charger architecture is made of a grid-wired power transmitter and a wireless power receiver embedded into the portable/mobile device. As depicted in the block schematic of Fig. 1 wireless power flows from power transmitter to power receiver and a feedback communication link is provided in the opposite direction [1].

A. Wireless Power Transmitter

Standard compliant wireless power transmitters must have a predefined *Interface Surface* with which any certified power receiver can interact. From the *Interface Surface* point of view each wireless power transmitter should work with any power receiver and vice-versa. WPC defines architectures of wireless power transmitters, including the inverter topology (full/half bridge), the power transfer control method (by varying operating frequency or the supply voltage) and coils geometry.

B. Wireless Power Receiver

A Qi-standard wireless power receiver shall implement a dual resonant tank made of a receiver coil and two resonant capacitors as depicted in Fig. 1. In order to let the transmitter control the total amount of transferred power a feedback path from power receiver to power transmitter must be implemented. In Qi-standard power receivers, feedback information are modulated by means of load modulation technique of the detected power carrier.

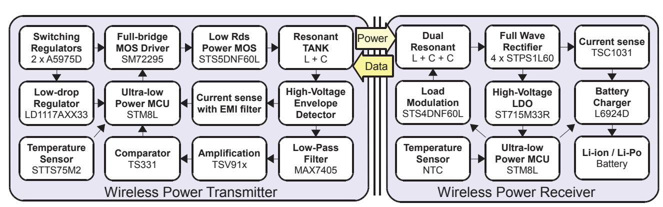

Fig. 1. Detailed block schematic of the developed wireless power battery charger. The power transmitter provides the wireless energy to the portable/mobile device and the power receiver communicates feedback information, in order to ensure a proper power transfer control.

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III. Wireless Power Transmitter

The developed wireless power transmitter complies with type A2 WPC full-bridge topology [1], and differs from typical proposed architectures which usually implement a half-bridge resonant inverter topology [2]. The full-bridge topology simplify the power control method that is achieved by varying the inverter supply instead of frequency and duty cycle [1].

A. Full-bridge resonant inverter

A type A2 power transmitter generates the alternated electromagnetic field by using a full-bridge resonant inverter made of four power MOSFETs (STMicroelectronics STS5DNF60) driven at a constant frequency of 140kHz by a high efficiency bridge driver (National Semiconductor SM72295) as shown in Fig. 2. The resonance tank is made of a 24µH wire-wound flat spiral coil (Lp) and a 200nF high voltage capacitor (Cp). The resonance frequency of the implemented resonance tank is calculated in (1).

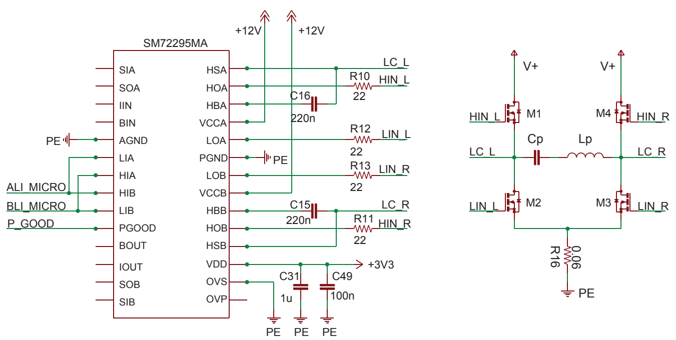

Fig. 2. Full-bridge driver and the resonant inverter for type A2 WPC topology. Lp is the transmitter primary coil, Cp is the 200nF resonant capacitor.

$$f_{res} = 1 / \left(2\pi \sqrt{L_p \cdot C_p}\right) = 72.64kHz \tag{1}$$

B. Full-bridge variable voltage regulator

As described by WPC directives, in type A2 transmitter topology the total amount of transferred power must be controlled by varying the full-bridge supply (V+ as depicted in Fig. 2), in the range of 3-12V with step size resolution better than 50mV [1]. The lower the voltage supply, the lower the total amount of radiated electromagnetic flux by the primary coil.

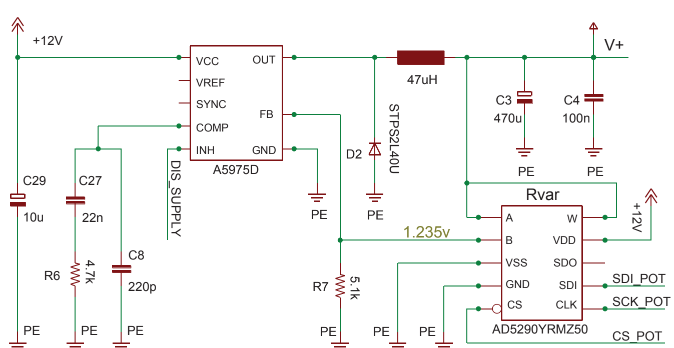

Fig. 3. Electrical schema of the high efficiency run-time variable voltage regulator used to control the full-bridge supply. The voltage regulator consists of a switching regulator and a digital potentiometer, controlled by a microcontroller through SPI bus.

A high efficiency run-time variable voltage generator has been implemented as in Fig. 3; a switching regulator (STMicroelectronics A5975D), whose output voltage is controlled by varying the feedback loop with a digital potentiometer (Analog Devices AD5290), having a 50kΩ full scale and 256 selectable steps [4]. The potentiometer position can be digitally controlled by a power transmitter microcontroller through the SPI bus. The switching regulator output voltage V+ can be calculated given the potentiometer position D with the equation (2):

$$\begin{aligned} &V+ = \left(\frac{R_{var}(D)}{5.1k\Omega} + 1\right) \cdot 1.235V \\ &0 \le D \le 255 \\ &0 \le R_{var}(D) \le 50k\Omega \end{aligned} \tag{2}$$

With this solution the full-bridge supply can be set in the range 1.235-13.34V with a step resolution as in (3).

$$\Delta V+ = (13.34V - 1.235V)/256 = 47.28mV \tag{3}$$

The achieved step size voltage control fulfills WPC directives for type A2 topology [1]; moreover an efficiency of up to 90% is obtainable, due to the use of a switching buck regulator [3].

C. Power carrier envelope demodulator

The power carrier generated by the power transmitter resonant inverter is modulated by the power receiver with the load modulation technique, affecting the power carrier in terms of voltage and current variations into the primary coil Lp.

Every Qi-standard compliant power transmitter must be able to demodulate the stream of bits sent back by power receivers on the power carrier. The implemented demodulator uses a high voltage diode-based envelope detector, which extracts the digital data from the resonant tank as depicted in Fig. 4. The envelope is then shifted, removing the high DC voltage, and is filtered with an 8th order switched capacitor low pass filter (Maxim MAX7405). The maximum frequency of the modulated stream, as defined by WPC, is 2kHz so, the cut-off frequency of the switched capacitor filter has been set to 2.2kHz (the capacitor C21 defines the cut-off frequency of the filter) [5].

The switched capacitor filter output is then amplified and the demodulated bits are discriminated with a fixed-threshold comparator. Figure 5 shows the signals along the demodulation chain, up to the clean digital data read by the power transmitter microcontroller.

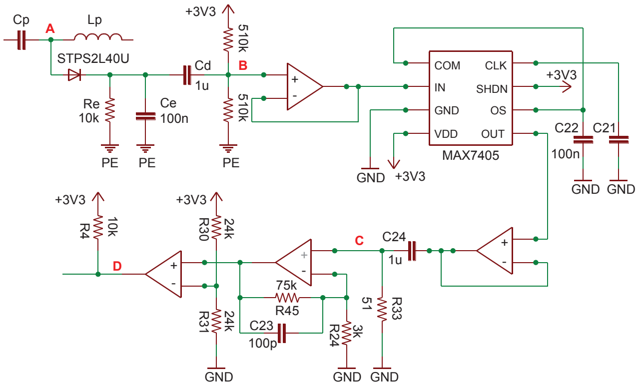

Fig. 4. Wireless Power Transmitter's power carrier demodulator. Signals waveforms are depicted in Fig. 5.

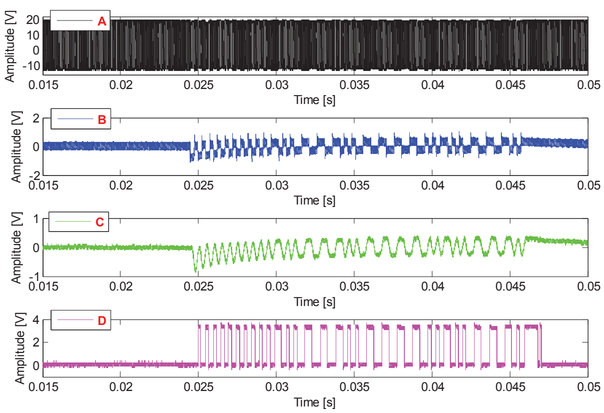

Fig. 5. Measured with an oscilloscope, the waveform **A** is the Power Transmitter's modulated power carrier, signal **B** is the output of envelope detector, signal **C** is the switched capacitor filter output and signal **D** is the stream of bits discriminated by the comparator.

D. Prototype status

A complete (62mm × 75mm) PCB prototype has been realized with the circuitry solutions described above. Figure 6 shows the assembled wireless power transmitter with the primary coil connected to the full-bridge resonant inverter.

The mean system stand-by consumption is only 147mW, with digital ping enable every 5 seconds to discover the presence of a compliant wireless power receiver placed upon the *Interface Surface* (i.e. the primary coil). Presently the microcontroller firmware manages all v1.1.1 Qi-standard packets transmitted by power receiver (except proprietary and reserved packets that are ignored) and the floating point WPC power control PID algorithm is fully implemented and tested.

A digital temperature sensor (STMicroelectronics STTS75) is placed on the board in order to continuously monitor the system temperature and an NTC resistor is used to monitor the coil temperature while transferring power. These temperature monitoring sensors ensure safe operation while transferring power and stops transmission in case of system or near metal objects overheating.

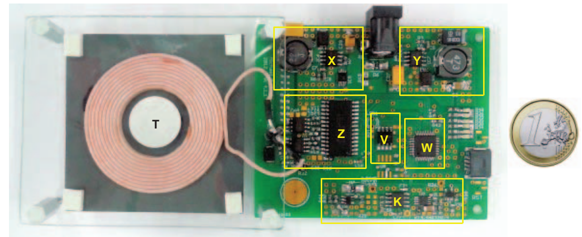

Fig. 6. The developed wireless power transmitter. The block **X** is the run-time variable switching regulator for full-bridge (**Z**) supply, the block **W** is the microcontroller supplied with another switching regulator (**Y**). The block **K** is the power carrier demodulator and **V** is the digital temperature sensor. **T** is the primary coil (i.e. a 24µH wire-wound planar inductor). The PCB can be placed under the primary coil to reduce space use.

IV. WIRELESS POWER RECEIVER

The alternating electromagnetic flux is converted into an alternating electrical signal in the power receiver, by means of a dual resonant tank. The developed wireless power receiver hosts the load modulator of detected power carrier used to communicate digital information to the power transmitter.

A. Dual resonant tank

The load modulation method is left as a design choice by Wireless Power Consortium; resistive, capacitive and inductive schemes are allowed [1]. In the developed power receiver both capacitive and resistive load modulation techniques have been implemented in order to ensure a proper modulation depth in all power receiver conditions (low power and high power received).

In Fig. 7 the transistor M2A and M2B are used to modulate the two capacitive loads C1 and C2; at the same time transistor M3 modulates the resistive load R17 and R27. The MODULATE signal that drives the MOSFETs is used to modulate the UART-like stream of bits with a clock signal frequency of 2kHz and differential bi-phase coding data

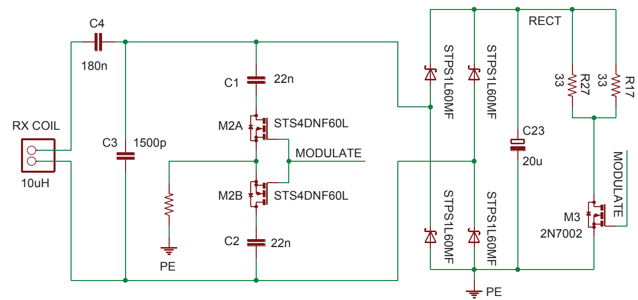

Fig. 7. The dual resonance tank power receiver with AC side capacitive modulation and DC side resistive modulation as defined in WPC directives. The rectified voltage (RECT) is then provided directly to the battery charger.

structure [1], as in Fig. 5. The information communicated from the power receiver on power transmitter power carrier are structured in well defined packets and such information are used by the power transmitter to control the total amount of transferred power, in agreements with the control packets sent by the receiver.

B. Power Control

The power receiver controls the total amount of received power with an ultra low power microcontroller (STMicroelectronics STM8L) that continuously monitors the received power by means of a current sense amplifier (an STMicroelectronics TSC103I with EMI filters) and reads the rectified voltage through a simple voltage divider with the microcontroller's ADC. The microcontroller computes the difference between the needed and actual received power and periodically (every 250ms, as defined by WPC) communicates this information (also known as Control Error Packet) to the power transmitter. Other information such as Received Power Packets, and information related to the battery charge status are also communicated, as specified by WPC's communication interface.

C. Follow-voltage Battery Charger

A Li-ion and Li-Po battery charger (STMicroelectronics L6924D) has been implemented into the power receiver and supplied directly with the rectified voltage. The L6924D is able to charge batteries with currents up to 1A, but its power dissipation strictly depends on the voltage drop between the battery voltage and the battery charger supply. To reduce power dissipation and thus increase the overall charging efficiency, a battery voltage follower algorithm has been implemented into the power receiver microcontroller. While charging the battery, the power receiver microcontroller communicates to the power transmitter to adjust the transmitted power so to minimize the voltage drop across the battery charger.

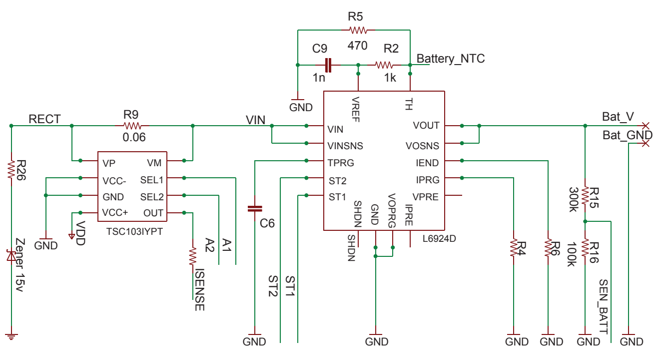

Fig. 8. Schema of Li-ion battery charger supplied with the rectified voltage. The received power is real-time monitored with a current sense amplifier.

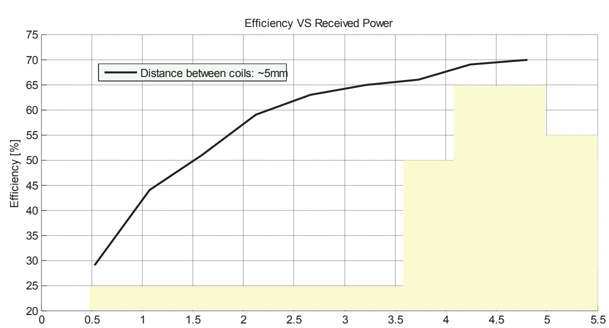

Fig. 9. Overall system efficiency, measured as the ratio of received power provided to a battery and the whole transmitter supply consumption. The yellow area is the recommended minimum system efficiency [1].

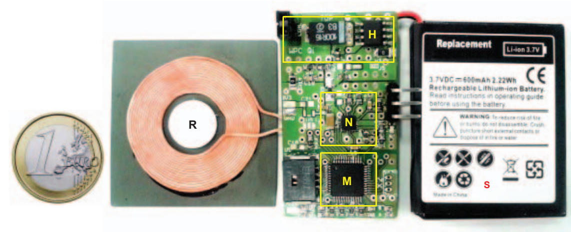

Fig. 10. The developed wireless power receiver. The block **H** is the dual resonance tank with capacitive and resistive load modulation. The block **N** is the battery charger used to charge the Li-ion battery (**S**). Block **M** the microcontroller for power control. Current sense block is on bottom side.

V. Overall Performance

In this paper, schemes regarding realization of type A2 topology wireless power transmitter has been shown and a simple, compliant power receiver has been illustrated. The realized prototypes have been tested with other certified wireless power systems and have proven to work as designed.

Power transfer efficiency has been carefully measured and Fig. 9 shows that the overall efficiency strictly depends on received power. An overall peak efficiency of 70% is obtained at the maximum power, thereby respecting WPC efficiency requirements [1].

VI. Conclusion

A complete solution of wireless power charger architecture has been developed with high power transfer efficiency. The developed system is suitable for portable and mobile application in which a galvanically insulated package is required for safety reasons, such as in biomedical devices [7].

The power receiver draws no current while is not placed on a power transmitter, and the power transmitter stand-by consumption when is grid-connected is only 147mW, thus the system is Energy Star compliant too [6].

References

[1] Wireless Power Consortium, System description wireless power transfer Vol.1, v1.1.1, Part I, II and III.

[2] V. Boscaino, F. Pellitteri, G. Capponi, R. La Rosa, "A Wireless Battery Charger Architecture for Consumer Electronics", *IEEE Second International Conference on Consumer Electronics*, September 2012, Page(s): 84-88.

[3] "A5975D Up to 3A step-down switching regulator for automotive applications", *STMicroelectronics Datasheet*, April 2011.

[4] "AD5290 Compact +30 V/±15 V 256-Position Digital Potentiometer", *Analog Devices Datasheet*, 2011.

[5] "MAX7405 8th-Order, Lowpass, Bessel, Switched-Capacitor Filters", *MAXIM Datasheet*, 1999.

[6] "ENERGY STAR® Program Requirements for Single Voltage External Ac-Dc and Ac-Ac Power Supplies" V.2, Energy Star Eligibility Criteria.

[7] M. Caldara, C. Colleoni, M. Galizzi, E. Guido, V. Re, G. Rosace, A. Vitali, "Low power textile-based wearable sensor platform for pH and temperature monitoring with wireless battery recharge", *IEEE Sensors*, October 2012, Page(s): 29-32.