

A Wireless Battery Charger for Mobile Device

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Abstract: *In this research, an innovative design of a wireless battery charger for portable electronic devices is proposed. The wireless power transfer is implemented through the magnetic coupling between a power transmitter, which is connected to the grid, and a power receiver, which is integrated inside the load device. An innovative receiver architecture which heavily improves the power conversion efficiency is presented. A laboratory prototype of the proposed wireless battery charger has been realized and tested to evaluate system performances. over the entire range of operating conditions the receiver efficiency lies within the 96.5% to 99.9% range.*

1. Introduction

Wireless transfer has been employed since long time in telecommunications. Radio waves, cellular transmissions and Internet WiFi are only a few examples of wireless transmission. Recently, there's been a growing interest towards the experimentation of a deeply challenging idea for wireless applications: supplying electronic devices without cords. The development, application and spread of this new concept could make consumers life enormously easier, since wired chargers are often perceived as annoying and bulky objects. By magnetic induction, the power transmitter is represented by a grid-connected magnetic pad while the power receiver is integrated inside the load device. Users should only place their portable device upon the magnetic pad. Magnetic coupling allows several devices to be simultaneously charged. In order to spread wireless battery charging, compatibility between chargers and devices is a key issue to deal with. Recently the Wireless Power Consortium (WPC) has built an international standard, also known as "Qi-standard", which aims at promoting the complete interoperability between power charging stations and rechargeable devices.

2. Wireless Battery Charger

Fig. 1 shows the schematic block diagram of a wireless battery charger. On the left, the power transmitter which is connected to the electrical grid, on the right the power receiver which is integrated into the load device is shown. In both the power transmitter and the power receiver, the key element for signal transfer is represented by a resonant tank, comprising both coupled inductors: on the transmitter side, there is the primary coil; on the receiver side, there is the secondary coil. A comparative study of different resonant topologies is proposed in. As suggested by Fig.1, the signal flow does not only consist of the power signal from the power transmitter to the power

receiver, but also of communication data streaming in the opposite direction. Since the power transmitter needs to be continuously informed about battery power needs and state of charge, a communication link is required. The communications channel is implemented through an amplitude modulation of the power drawn from the transmitter. In the power transmitter section, an AC-DC stage converts the AC voltage provided by the electrical grid into a DC bus level. A DC-AC converter, supplied by the DC bus level, generates the AC power signal. In the power receiver section, a rectifier converts the AC power signal out of the resonant tank into a DC voltage level, suitable for battery charging. The DC bus rail out of the rectifier has been chosen equal to a 7V value. Information towards the power transmitter is generated through a power modulation of the coupling circuit resonant curve. The load modulation follows a differential bi-phase encoding scheme, as described in Qi-standard specifications.

The amount of transmitted power is controlled by varying

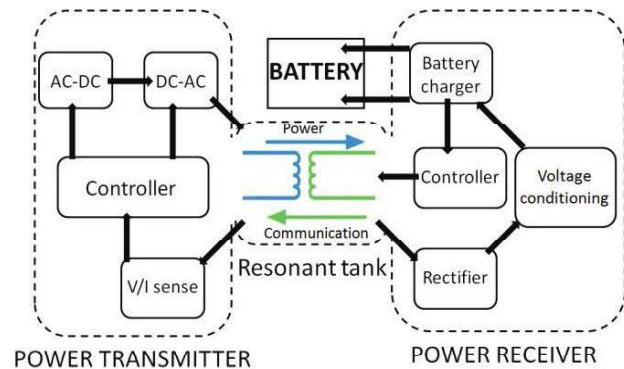


Figure 1 – General architecture of a wireless battery charger

the frequency and duty-cycle of the half-bridge stage. A frequency range of 110k 205kHz and a duty-cycle range of 10% 50% are fixed by the PC standard. Since for low power levels the total power dissipation is mainly affected by switching losses, the half-bridge configuration is more suitable than a full-bridge one. Conduction losses could be reasonably neglected for the specific application.

The modulation network consists of two parts: one is connected to the AC-side of the rectifier; the other is connected to the DC-side. The load device is modeled through a current generator. The system has been simulated in SPICE environment to evaluate system performances in terms of power conversion efficiency. Several simulation sessions have been carried out under

different operating conditions. Fig. 2 shows simulation results under a 380mA load current. At the top in green the output voltage V(out), in red the secondary-coil voltage waveforms are shown. At the bottom, in blue the diode's current in green the output voltage waveforms are plotted. The receiver's average efficiency, evaluated between the secondary coil and the load current source, turns out to be equal to 59.7% when MOD is high and to 91.3% when MOD is low. As highlighted by simulation results, most of the dissipated power is due to the passive rectifier and the resistive modulation. This one is interested by more than 70% of the total wasted power. Power losses in the biasing circuit of the modulation network only represent a small fraction of the total wasted power, instead.

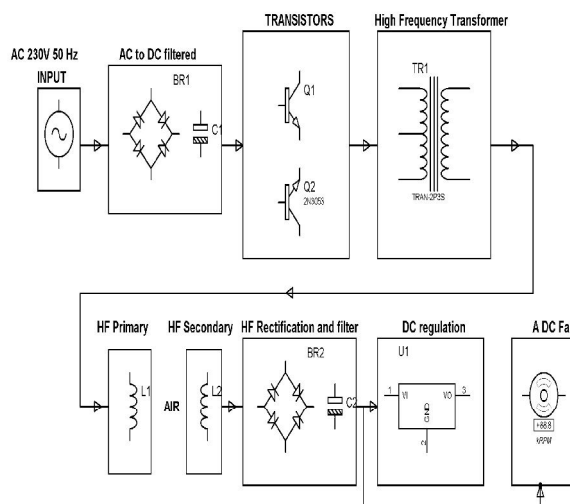


Fig.2 Block Diagram of Wireless Charger

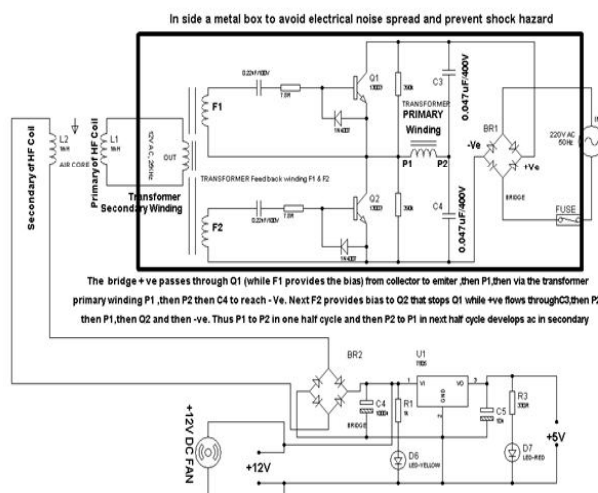


Figure-3: Schematic Diagram of Wireless Charger

3. Circuit Description

The line voltage is rectified by the full-bridge rectifier, generating a semi-sinusoidal voltage at double the line frequency. The frequency of oscillation then depends mainly upon the size and maximum flux density of the ferrite core used in the feedback transformer, and the storage time of the transistors. When the cycle has started, the current in the feedback transformer increases until the core saturates. At this point the feedback drive of the active transistors is therefore removed, and, once its storage time has passed, it turns off. In this application the oscillation frequency would be 25 to 40 kHz. The dependence upon the storage time is minimized by the RC network at the base of the transistor, which increases the rate of charge extraction from the base at turn-off. The network also serves to decouple the base from the oscillation caused by the base transformer at turn-off, preventing spurious turn-on of the device.

4. Proposed Method

Faraday's law of induction is a basic law of electromagnetism that predicts how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF). It is the fundamental operating principle of transformers, inductors, and many types of electrical motors, generators and solenoids. The production of emfs and currents by the changing magnetic field through a conducting loop is called induction.

4.1 Magnetic Flux

The magnetic field through a loop can be changed either by changing the magnitude of the field or by changing the area of the loop. To be able to quantitatively describe these changes, **magnetic flux** is defined as $\Phi = BA \cos \theta$, where θ is the angle between **B** and the direction perpendicular to the plane of the loop (along the axis of the loop).

4.2 Faraday's Law

Changing the magnetic flux through a loop of wire induces a current. **Faraday's law** states that the emf induced in a wire is proportional to the rate of the flux through the loop. Mathematically,

$$\mathcal{E} = -N \frac{\Delta \Phi}{\Delta t}$$

where N is the number of loops, $\Delta \Phi$ is the change of flux in time, Δt . The minus sign indicates the polarity of the induced emf.

This project works similar to that of Faraday's Law.

4.3 Mutual inductance and self-inductance

Mutual inductance occurs when two circuits are arranged so that the change in current in one causes an emf to be induced in the other. Imagine a simple circuit of a switch,

a coil, and a battery. When the switch is closed, the current through the coil sets up a magnetic field. As the current is increasing, the magnetic flux through the coil is also changing. This changing magnetic flux generates an emf opposing that of the battery. This effect occurs only while the current is either increasing to its steady state value immediately after the switch is closed or decreasing to zero when the switch is opened. This effect is called self-inductance. The proportional constant between the self-induced emf and the time rate of change of the current is called inductance (L) and is given by

$$\varepsilon = -L \frac{\Delta I}{\Delta t}$$

The SI unit for inductance is the henry, and 1 henry = 1(Vs/A). Using Faraday's law, inductance can be expressed in terms of the change of flux and current:

$$L = \frac{N\phi}{I}$$

where N is the number of turns of the coil.

5. Experimental Results

A laboratory prototype of the here proposed wireless battery charger solution has been realized and experimental tests have been performed in order to evaluate the power conversion efficiency. A 500mA electronic load has been connected to the receiver output. Efficiency has been calculated as the ratio between the DC output power and the average power on expressed in Watt. The dotted line refers to a high-level modulation signal, while the solid trace represents a low-level modulation signal. Fig. 9 shows on the horizontal axis the output power instead of operating frequency. As shown by experimental results, the measured efficiency of the proposed receiver lies within the range 96.5% to 99.9%, so that the overall system's power losses can only be imputed to the magnetic coupling.

6. Conclusions

In this research, an innovative design of a wireless battery charger has been proposed and experimental results have been shown in order to evaluate the power conversion efficiency. A comparison between the conventional and the proposed receiver architectures has been carried out by SPICE simulations. As shown by simulation results, a power efficiency increase of about 40% under active modulation and about 7% without modulation is provided by the proposed solution.

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