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How To Implement A 5-W Wireless Power System

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Wireless power for handheld products is now a practical solution. While chipsets like the bqTESLA provide the core functionality for the solution, there are a number of additional factors related to external component selection, physical design, and thermal analysis that need to be understood as part of the system-level implementation. This article provides a brief introduction to the Qi industry standard for wireless power transfer, and focuses on issues relevant to the hardware design of a 5-W-capable wireless power transfer system.

A Wireless Power Standard

Wireless power transmission may seem like a revolutionary concept in some ways, but it has existed in various forms for almost a century. However, until now, it was not practical for system design engineers to implement wireless power in a general-purpose, universally compatible form. While wireless power systems (for example, the familiar electric toothbrush) have been available for some time, they were all unique and/or proprietary systems. A specific device was matched to a specific charging base, not adaptable to different applications. In general, efficiency was poor for both high- and low-power modes.

The Wireless Power Consortium, an industry working group that consists of over 91 member companies, has published an interoperability standard that defines a practical method of allowing multiple manufacturers' devices to work with each other seamlessly. This standard, known as Qi, defines the basic requirements for a charging pad, or transmitter, and device, or receiver, to implement a 5-W wireless power transmission system. The word Qi (pronounced *chee*) is taken from the Chinese word meaning force or energy.

Hardware Overview

Fig. 1 shows a block diagram of an inductively-coupled power transmission system that implements the Qi standard. In concept, this is actually similar to any type of inductively-coupled power converter, in that ac energy across a primary coil is transferred to a secondary coil by means of a magnetic field. However, in a conventional application, the primary and secondary coils are wound over a common core. In a wireless power system, they are in separate enclosures. Energy can still be transferred from primary to secondary with reasonable efficiency as will be shown subsequently.

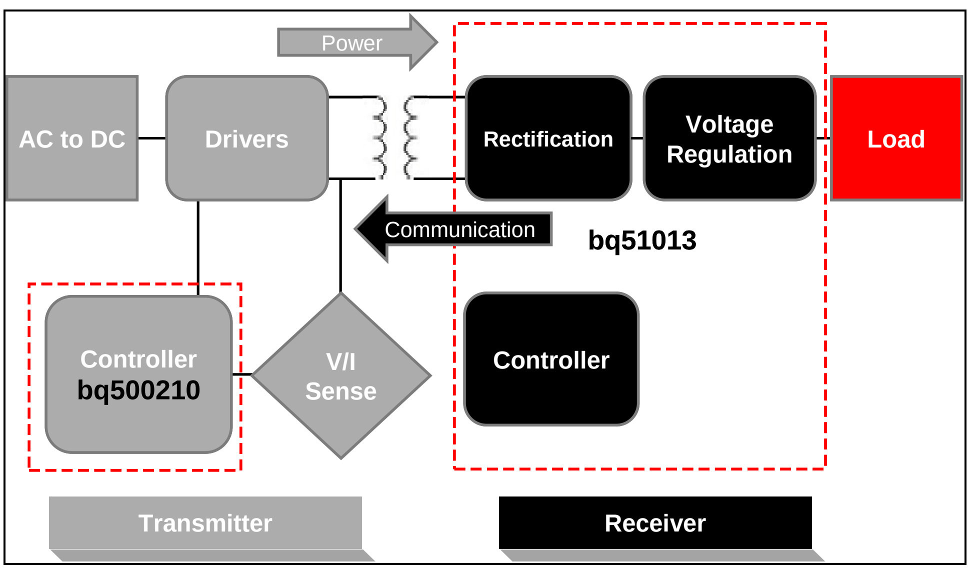

Fig. 1. Inductively coupled wireless power system.

A resonant converter topology was selected for use with the wireless power transmitter circuitry. In this system, the dc input voltage is pulsed across an LC tank using a two-switch (half-bridge) circuit (Fig. 2).

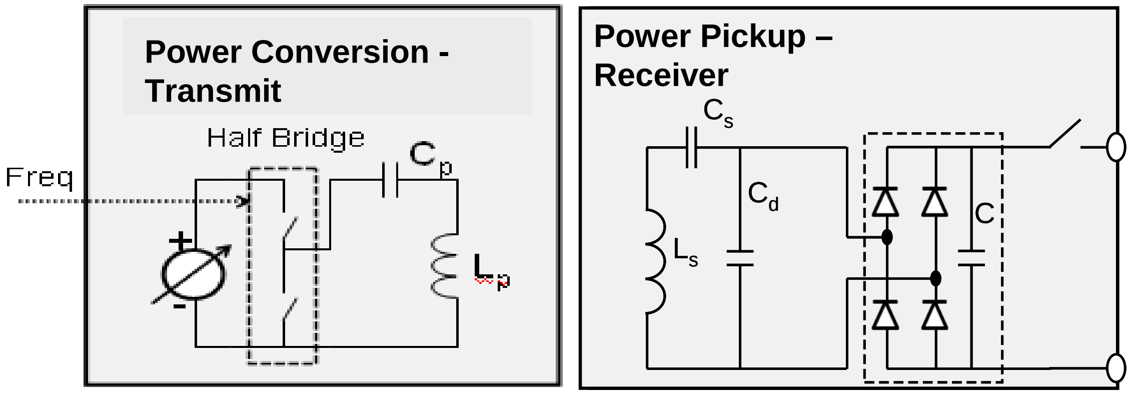

Fig. 2. Resonant converter—simplified block diagram.

When a square wave pulse is applied at the input to the LC tank, the resulting output voltage (generated across the primary coil) is a sinusoidal waveform. The switching frequency of the MOSFETs can be varied by the controller IC, with the peak amplitude across the primary coil corresponding to the resonant frequency. As the switching frequency is varied above (or below) the resonance point, the corresponding amplitude across the primary coil decreases. The resonant frequency is determined by the LC values in equation 1:

$$f_s = \frac{1}{2\pi\sqrt{L_P C_P}} \qquad \text{Eqn. 1}$$

To minimize power consumption in the transmitter equipment when the pad is idle (no device placed on it to be charged), a detection method is used to: a) determine if an object is placed on the pad; and b) validate that the object on the pad is actually a Qi-compliant receiver device capable of receiving power. Until an object is detected and validated, the transmit pad does not generate any appreciable output power.

The means of detection employed by the transmitter circuit consists of an *analog ping*, or a short, periodic test pulse to determine if an object has been placed on the pad. This is followed by a *digital ping*, which is a longer pulse from the transmitter that initiates communication from the receiver device to indicate that the receiver is a valid, Qi-compliant system. If a passive object (for example, coins, keys, etc.) is inadvertently dropped on the transmit pad, its presence will be detected. However, power transmission will not begin because the subsequent digital ping will not yield the appropriate feedback signal.

The analog ping response (TX coil voltage) with and without an object on the pad is shown in Fig. 3. In the case of Fig. 3a, an analog ping with no object on the pad results in a peak-to-peak amplitude in the range of 60 Vpp. Fig. 3b shows the effect of an object placed on the pad, which results in a 30-Vpp primary coil voltage during the pulse as a result of added load on the system.

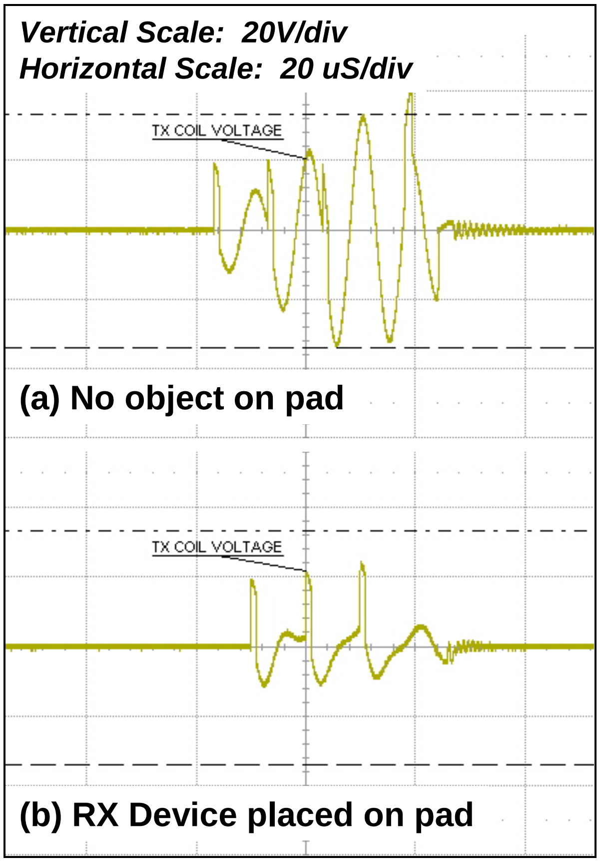

Fig. 3. Analog ping.

If an object is detected, a digital ping is initiated by the TX controller circuit. During a digital ping, a longer pulse of energy is applied to the primary coil. This is set up so that the receiver circuit, if present, can power up from the energy of this pulse and send a communication packet back to the TX pad. (Details of the communication process are provided in Reference 1.) Fig. 4 shows the sequence of events corresponding to placement of a receiver device on the pad and the startup of power transmission.

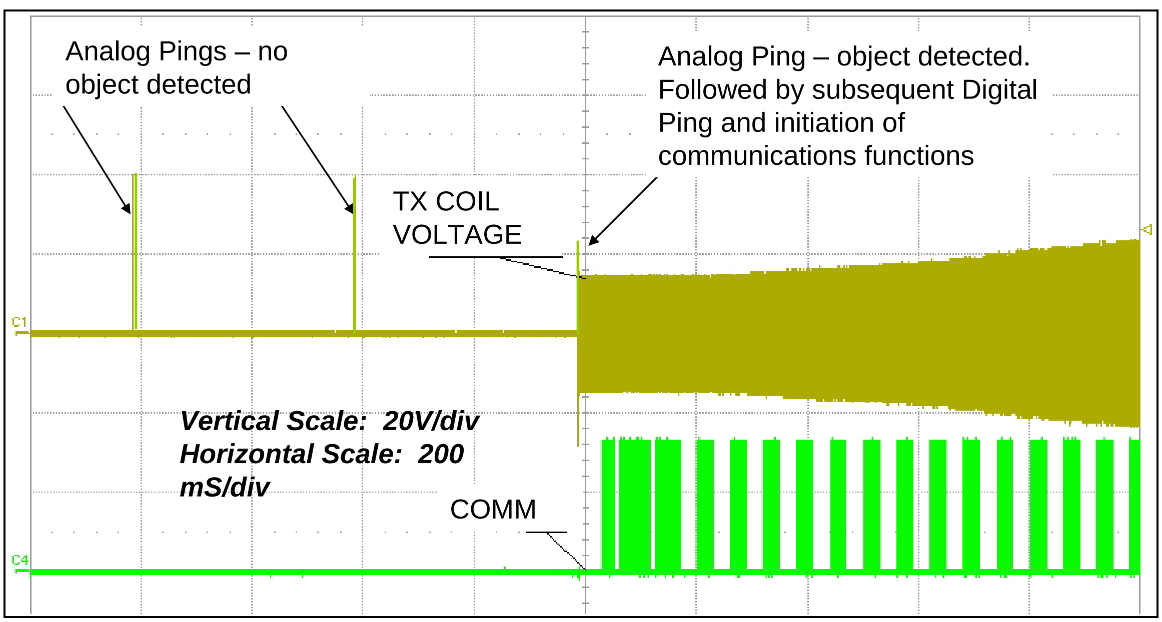

Fig. 4. Analog pings and startup after RX device detection.

Magnetic Components

In addition to the IC devices, of course, the proper selection of magnetic components on both the transmit and receive side of the system is of critical importance. As the Qi standard proliferates through the industry, it is expected that additional types of inductive components will be available off the shelf for the implementation of different system designs as needed. As an example, a description of existing components as used in the TI Evaluation Module (EVM) for the bqTESLA system is provided here. The coil assembly on each side includes the coil itself, as well as the shielding material needed.

The transmit coil is constructed using Litz (multi-stranded) wire to minimize skin effect losses and optimize overall efficiency. The specific coil used in the evaluation kit has been tested and certified to meet the requirements of the WPC Qi standard. Other types of construction could be used in theory, but would need to go through the testing and certification process to prove compliance. A transmit coil assembly is shown in Fig. 5

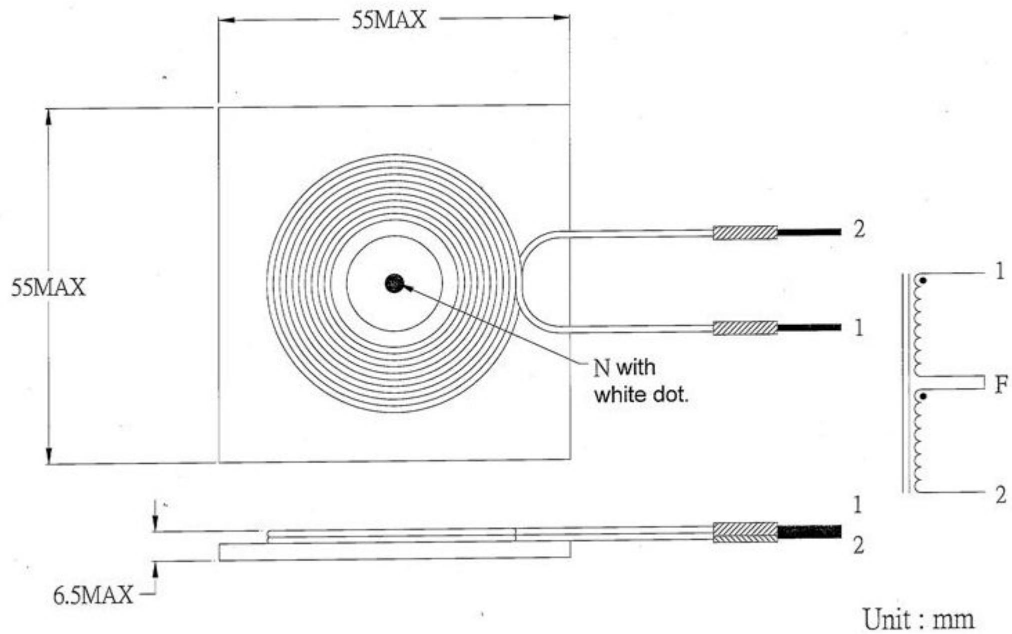

Fig. 5. TX coil assembly.

Because the receiver coil is intended to be built into the housing of small (handheld) equipment, small size (and especially thin z-dimension) is critical. This assembly is shown in Fig. 6**.**

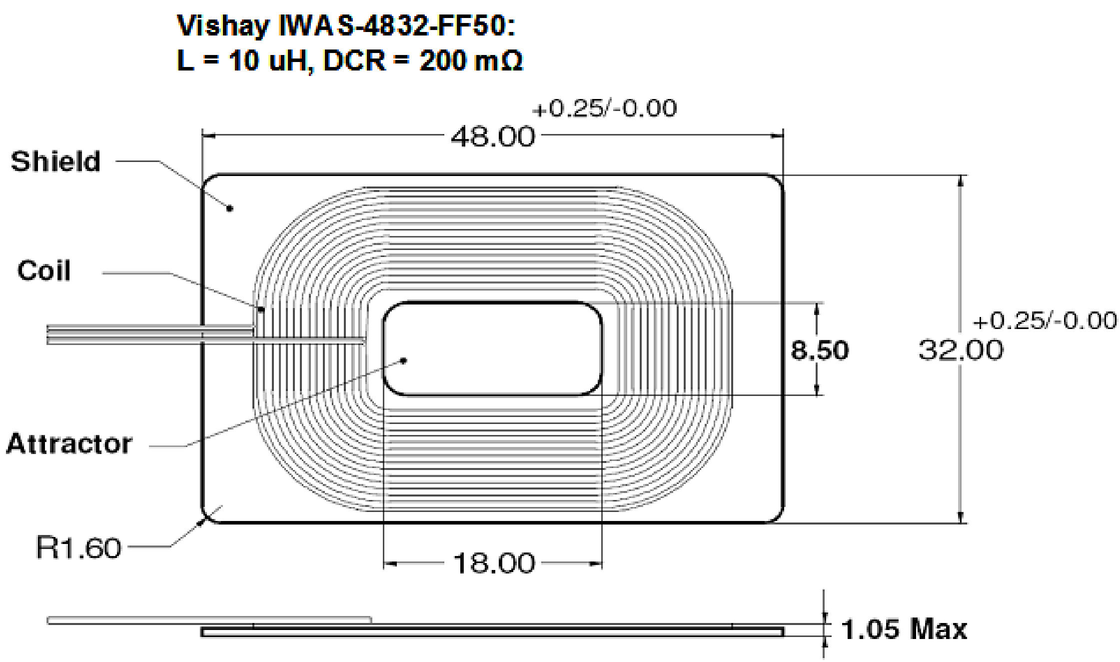

Fig. 6. RX coil assembly.

Overall Efficiency

In the past, inductively-coupled wireless power systems often have had relatively low efficiency due to losses between power transmitter and power receiver modules, which were poorly coupled. However, using the proper geometry and close spacing between transmit and receive coils, high coupling efficiency (in the range of 90 percent or greater) can be achieved. See Reference 2 for additional discussion and theory.

Measured data extracted from the TI Evaluation kit shows that overall system efficiency, when measured from the dc input to the transmit pad to the dc output of the receiver module, is in the range of 74 percent end-to-end. Roughly speaking, this is the product of three subsystem efficiencies (each of which are in the ~ 90 percent range):

1. Transmitter circuit conversion efficiency (dc-ac)
2. TX-coil to RX-coil coupling efficiency (ac-ac)
3. Receiver circuit rectification/regulation efficiency (ac-dc)

In our example, the bqTESLA150LP kit takes a +19-Vdc input to the TX circuit, and generates +5 V at up to 1-A output on the receiver module. An overall plot of the complete dc-dc conversion efficiency for the wireless converter system is shown in Fig. 7

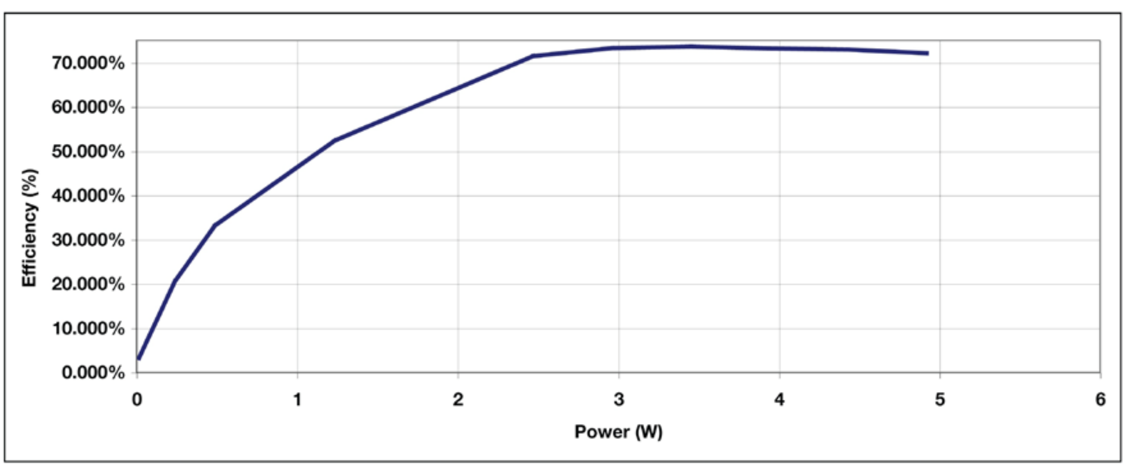

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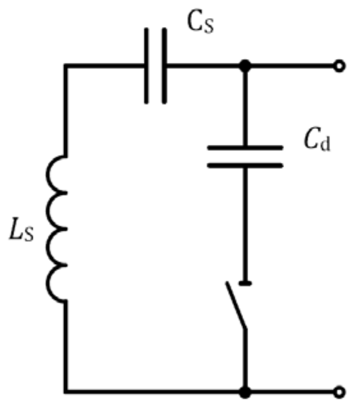
Fig.7. Overall system efficiency.

One parameter of concern for a wireless power transmit pad, perhaps even more significant than the maximum output power conversion efficiency, is the standby power consumption. This is because a wireless charging pad may spend a large portion of time not charging anything but merely plugged into the wall with no device attached to it. The transmit power, using a bq500210 system implementation for example, can be less than 100 mW in idle mode.

Receiver Component Selection

The resonant LC circuit on the receiver side actually has two capacitors (Fig. 8**)**. The series capacitor C_S is set to match the resonant frequency of the transmitter side (roughly 100 KHz) to allow for maximum power transfer from transmitter to receiver. The second capacitor, designated C_D, is used for the object detection process (analog ping), so that when the receiver is placed on the transmit pad, a known impedance (and therefore a known effect on the observed TX coil voltage) results.



L_s = Inductance of secondary coil away from magnetic material (away from transmit pad)

L'_s = Inductance of secondary coil when placed on transmitter pad

Fig. 8. Resonant receiver circuit.

The effective inductance of the receiver system can change due to interaction between the receiver coil and other components in close proximity, for instance battery pack, shield assembly, etc. Because of this shift, the default values of C_D and C_S need to be tuned to the application's physical design to achieve optimum performance.

If we define the parameter L_S as the inductance of the coil itself (when in the receiver system away from the TX pad), and L_S' as the inductance of the coil in proximity of the TX pad, we can calculate the best value of C_S to maximize power transfer capability and optimize C_D for most reliable receiver detection.

Note that L_S and L_S' must be measured using an LCR meter or equivalent equipment with the coil assembled into the physical design of the receiver unit being used. (For example, if using the bqTESLA evaluation kit, a battery can be placed in the hollow space just above the RX coil shield.)

- L_S is measured when the coil, shield, and battery are assembled together, away from the TX pad.
- L_S' is measured with the coil, shield, and battery are assembled together, but placed on a passive TX simulator pad (Fig. 9**)**.

A procedure for doing this is outlined in the WPC specification (Reference 1), section 4.2.2.1. Inductance should be measured with an excitation signal of 1-V RMS amplitude and 100-kHz frequency.

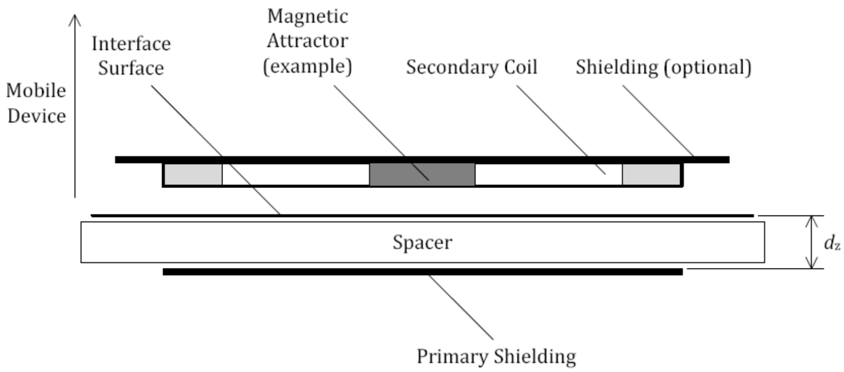


Fig. 9. TX pad "simulator" setup for measuring effective inductance L_S'. (Copied from System Description Wireless Power Transfer, Volume 1: Low Power, Part 1 Interface Definition, Version 1.0.1, Figure 4-3)

After values of L_S and L_S' are measured, they can be substituted into the equations 2 and 3 to determine C_S and C_D. See Reference 4 (EVM guide) for typical component values used. To minimize ESR, improve capacitor derating performance, and maximize efficiency, multiple capacitors in parallel are used to implement the C_S and C_D values.

Receiver C_S and C_D design equations using measured L_S and L_S' values:

$$f_s = \frac{1}{2\pi\sqrt{L_S' C_S}} = 100^{+x}_{-y}\, kHz \qquad \text{Eqn. 2}$$

$$f_d = \frac{1}{2\pi\sqrt{L_S\left(\frac{1}{C_S}+\frac{1}{C_d}\right)^{-1}}} = 1000^{\pm 10\%}\, kHz \qquad \text{Eqn. 3}$$

(Equations 2 and 3 were copied from System Description Wireless Power Transfer, Volume 1: Low Power, Part 1 Interface Definition, Version 1.0.1, Section 4.2.2.1)

Summary

The bqTESLA chipset from Texas Instruments provides a straightforward means of implementing a wireless power system that is compatible with emerging industry standards. The Qi standard and communication protocol ensure that power is transferred only when needed, and only to a recognized receiver device.

Since all of the details regarding communication protocol are built into the TX and RX controller devices, the system designer can focus on hardware aspects such as coil performance and coupling efficiency. Understanding that the effective inductance of the RX coil assembly can shift based on the physical design of the receiver unit, the series resonant capacitor (C_S) and detection capacitor (C_D) values can be optimized to yield peak performance

References

1. Qi System Description - Wireless Power Transfer Volume I: Low Power Part 1: Interface Definition, Version 1.0, July 2010.
2. Transfer Efficiency by Dries van Wageningen and Eberhard Waffenschmidt, Wireless Power Consortium website, 2011.
3. An introduction to the Wireless Power Consortium standard and TI's Compliant Solutions, by Bill Johns, TI Analog Applications Journal, 1Q 2011.
4. bqTESLA EVM user guide, Texas Instruments, 2011.

5. Engadget Primed: How Wireless and Inductive Charging Works, by Brad Molen, Engadget, June 24, 2011.

About The Authors

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