Adapting Qi-compliant wireless-power solutions to low-power wearable products

By Bill Johns, *Senior Applications Engineer*
Kalyan Siddabattula, *System Engineer*
Upal Sengupta, *Applications & Marketing Manager*

Introduction

A large number of low-power wearable devices such as smart watches, fitness wrist bands and headphones have been introduced to the market (Figure 1). This new family of electronic products is expected to grow and expand rapidly over the next few years. These devices are typically small and thin, with varying form factors and industrial design. Battery sizes might range from 100- to 300-mAh capacity, which determines the required charge rates.

The plug-and-jack style or micro-USB types of connectors have been the traditional way to charge such devices. But even these relatively small connectors are now too large for some of the new ultra-thin wearable applications. Connector contamination is an even greater problem due to the outdoor wearable environment.

Wireless charging is a solution to these problems and offers additional opportunities to designers. Existing semiconductor devices used for the Qi standard established by the Wireless Power Consortium (WPC) can be easily adapted for this lower-power application. The technology uses two planar coils to transfer power though a sealed case. For low-power wearable devices, a small, thin low-power receiver coil easily could fit into the back of the case or wristband area. Qi-compliant devices are a mature solution that can shorten development time, and the products are supported by the existing WPC infrastructure.

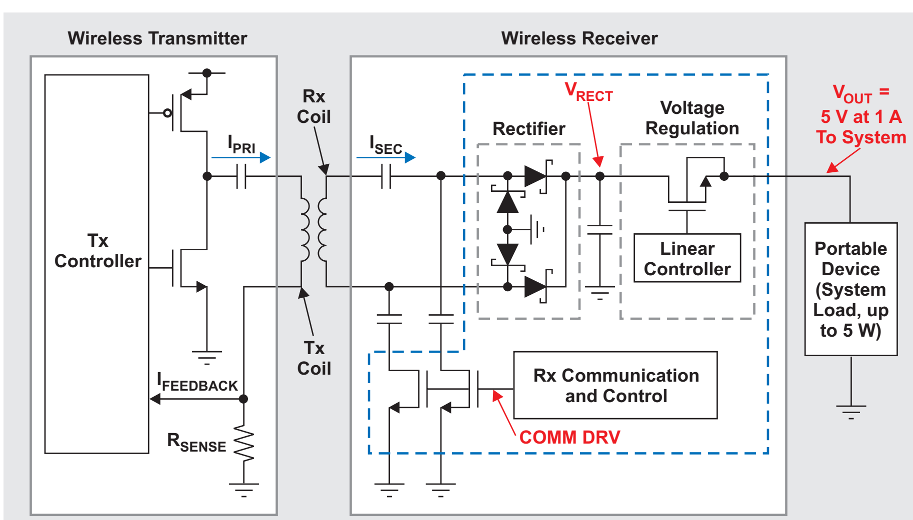
Figure 1. Smart watch with wireless charging

Used with permission from Secret Labs. LLC

Qi-compliant wireless-power system

The typical wireless power system (Figure 2) has a receiver (Rx) in the portable device that provides energy to charge the battery. The transmitter (Tx) is located in a fixed base and is connected to a wall power supply. Input power to the transmitter is converted to AC, then magnetically coupled though the transmitter coil to the receiver coil when they are in close proximity. Output from the receiver is typically 5 V at up to 1 A, which provides input power to a battery charger IC inside the portable device.

Figure 2. Block diagram of a Qi-compliant system



Transmitter operation in this system is controlled by the receiver chip using feedback in the form of digital communications packets sent back over the same magnetic coupling path. The Qi-compliant receiver communicates with the transmitter using load modulation to send information in data packets across the two coils. The transmitter-coil voltage and current are modulated at a 2-kHz rate that is decoded by the transmitter and used for control. The receiver can send several types of packets to the transmitter for control and information purposes. Also, a loss of communications terminates any power transfer.

The Qi-standard's *identification-and-configuration* command packets are very useful to assure that power is only transferred to the correct device, avoiding potentially hazardous situations. *Charge-complete* and *end-power-transfer* packets are also useful commands that stop power transfer when the battery is charged, or when other conditions require that power transfer be stopped.[1] These features assure safe power transfer between the transmitter and receiver using an existing, well-known standard.

Low-power wireless systems

An available Qi-compliant receiver and transmitter can be optimized for a low-power wireless system by carefully tailoring the coil sizes and external component values to match the smaller application. Coils for both the transmitter and receiver can be reduced in size to fit the smaller form factor. Power-section components, in particular for the transmitter, can have reduced power specifications.

The typical WPC-1.1, Qi-compliant system supports up to 5-W output loads, typically 5 V at 1 A. A low-power system for a wearable-device application, on the other hand, might have output power in the range of 5 V at 100 to 250 mA.

Most Qi-compliant features can be used without impact on size or performance. Foreign-object detection (FOD) is an optional feature that protects against power transfer to stray metal objects in the charging area. In a low-power system with FOD, total output power is reduced by more than 50%. Along with reduced charging area, the possibility of introducing an object into the field that will heat up enough to present a problem is greatly reduced. The criticality of the FOD function may depend primarily on the mechanical design of the charging pad or charging cradle for a wearable device. Table 1 summarizes some of the key functions available when using the WPC-1.1 Qi standard that may or may not be required in a customized wearable application.

Table 1. Qi-compliant standard versus wearable solution

FEATURE	QI-COMPLIANT?	WEARABLE?
Identify Rx before power transfer	Yes	Yes
Stop power transfer on Rx command	Yes	Yes
Charge complete indications	Yes	Yes
Foreign object detection	Yes	Optional
Power transfer up to 5 W	Yes	Optional
Inter-operability with other devices	Yes	Optional

Low-power system coils

Coils can be reduced in size to a point, but must still transfer power and communicate with the transmitter. Typical coil construction is a round planar coil made of copper wire on a shield. Alternate configurations are PCB or flex-circuit coils. Typically, these alternates could have higher DC resistance (lower efficiency) but can be very thin, a desirable feature for small, low-power applications. The shield prevents AC fields from entering the electronics and battery, which also can improve coil performance.

Assuming that the Rx and Tx coils are aligned in the x-y plane, there are two key factors that determine the coupling factor, k. The first is coil-to-coil (z) distance, and the second is the ratio of diameters of the two coils. The best coupling (highest k) results when the coils are closer together and matched in diameter.[2] To ensure close x-y alignment from the start, the mechanical design of the charging base or cradle for a wearable device should include a physical means of aiding proper placement of the device in the cradle. Because the receiver coils are very small in this application, a slight misalignment between the Rx and Tx coils can result in a significant reduction in coupling factor and very poor power-transfer efficiency.

In a coupled-inductor system such as WPC/Qi, the coupling coefficient (k) between the primary and secondary coil generally is in the range of 0.5 to 0.7. A typical transformer can have a much higher k, such as 0.99. When the coupling factor is low, a higher inductance value is required on the secondary (receiver) side to ensure that the output power demands can be met. As a result, small low-power devices that may have low coupling actually require a larger secondary inductance than the standard 5-W designs.[3] A higher-inductance receiver coil with more turns and larger shield may be needed to achieve the required voltage gain.

Coil design

Design trade-offs of the receiver coil size include the wire diameter, shield size and thickness. Coil DC-resistance shows up as a reduction in receiver efficiency. The receiver coil design requires a specific number of turns to achieve the desired inductance. As previously noted, the required inductance of a small coil will be higher than a large coil due to a decrease in coupling factor. As the number of turns increases to achieve the higher inductance value in a smaller space, the wire diameter decreases. The combined effect of smaller wires and more turns will drive the DC-resistance higher and lower efficiency.

The shield provides a low-impedance path for the magnetic flux and increases coil inductance. Also the shield prevents the AC field from entering the battery and surrounding metal in the receiver. A larger and thicker shield is better because thinner shields run the risk of saturation in high-flux fields. Transmitter coil designs have fewer physical restrictions. The coil can be larger and have lower inductance.

A typical coil used for standard 5-W WPC applications is the A11 coil type. This circular coil is approximately 50-mm in diameter and has a thick ferrite shield behind it. While this coil has been tested in a wide range of applications with many types of receivers, it works best for the higher power levels (3 to 5 W). For lower-power and reduced-range receivers, many coil dimensions can be reduced.

Typical inductance of the A11 coil is 6.3 µH. This value should be maintained for best performance. Wire diameter can be reduced to allow a smaller coil size, however, this increases DC-resistance losses. Further size reduction can be achieved with a reduction in shield thickness. Several types of shields are available that provide good performance.

Tests with a 30-mm round transmitter coil have been conducted with good results (Figure 3). Smaller solutions are possible, but the designer must take care that the DC resistance is not increased significantly. In the case of the resonant-converter architecture used in most WPC transmitters, current flows in the primary coil even at minimal loads. To avoid excessive power loss, the DC resistance of the Tx coil must be as low as is practically possible, given the size constraints of the product.

Low-power receiver

The bq51003 is one device in the TI bq51xxx family of wireless-power receivers that is adapted specifically for lower-power applications. The key change in the device is optimizing the behavior of a few features for lower output current.

This family of devices features Dynamic Rectifier Control™ to improve load-transient behavior. The Qi standard has a relatively slow global feedback loop and may require up to 100 ms to change the operating point. This means that a load-step can reduce output voltage and result in system resets. To provide enough voltage to operate though a transient, the V_{RECT} operating point is set high at low loads. This feature helps with load-step, but reduces light-load efficiency. To solve this problem, Dynamic Efficiency Scaling™ is used to tailor the light-load voltage to maximum output load. Maximum output current is set using a resistor.

Table 2. Dynamic Rectifier Control for wireless receiver (bq51003)

OUTPUT CURRENT PERCENTAGE	R_{ILIM} = 1116 Ω I_{MAX} = 250 mA	R_{ILIM} = 488 Ω I_{MAX} = 500 mA	V_{RECT}
0 to 10%	0 to 25 mA	0 to 50 mA	7.08 V
10 to 20%	25 to 50 mA	50 to 100 mA	6.28 V
20 to 40%	50 to 100 mA	100 to 200 mA	5.53 V
>40%	>100 mA	>200 mA	5.11 V

Due to the reduced PCB area for power dissipation, thermal paths also should be taken into consideration. Since the typical application requires charging a small battery with reduced charge current, power dissipation can be managed.

Figure 3. Standard transceiver coil and 30-mm, low-power coil

As mentioned previously, the bq51003 (and other constant-voltage output receivers such as bq51013B) work in tandem with a second IC to regulate and manage current flow to a Li-Ion battery. These batteries require a precise constant-current/constant-voltage charge-control profile, which can be implemented using a device such as the bq24232 (Figure 4). For low-power applications, a simple low-cost linear charger is usually the best choice. One key factor in deciding the charger device is to verify that it can control the low charge-current levels needed by the small batteries used in wearable devices. The bq24232 can regulate down to 25-mA constant-current levels, if needed, and has been implemented in applications with small battery sizes. Refer to the bq24232 data sheet for additional details on the charge control functionality required for Li-Ion batteries.

Low-power transmitter

For the typical 5-W application, there are many Qi transmitter types available with a wide range of features. The bq50xxx family supports 5-W or greater receiver output power. The bq500211 is a good starting point for low-power applications. The standard EVM kits are provided with the single-coil 5-V input, A11 type of transmitter coil. However, as discussed previously, this coil can be replaced with a smaller component for the lower-power wearable applications. This unit has the option to operate from a USB port or low-power 5-V adapter. The transmitter design has the option to be small and low cost.

The bq500211 Qi-transmitter controller has an input power-limiting option. The input current to the transmitter can be limited to 500 mA, which allows operation from a

Figure 4. Wireless power receiver with battery charger for low-power application

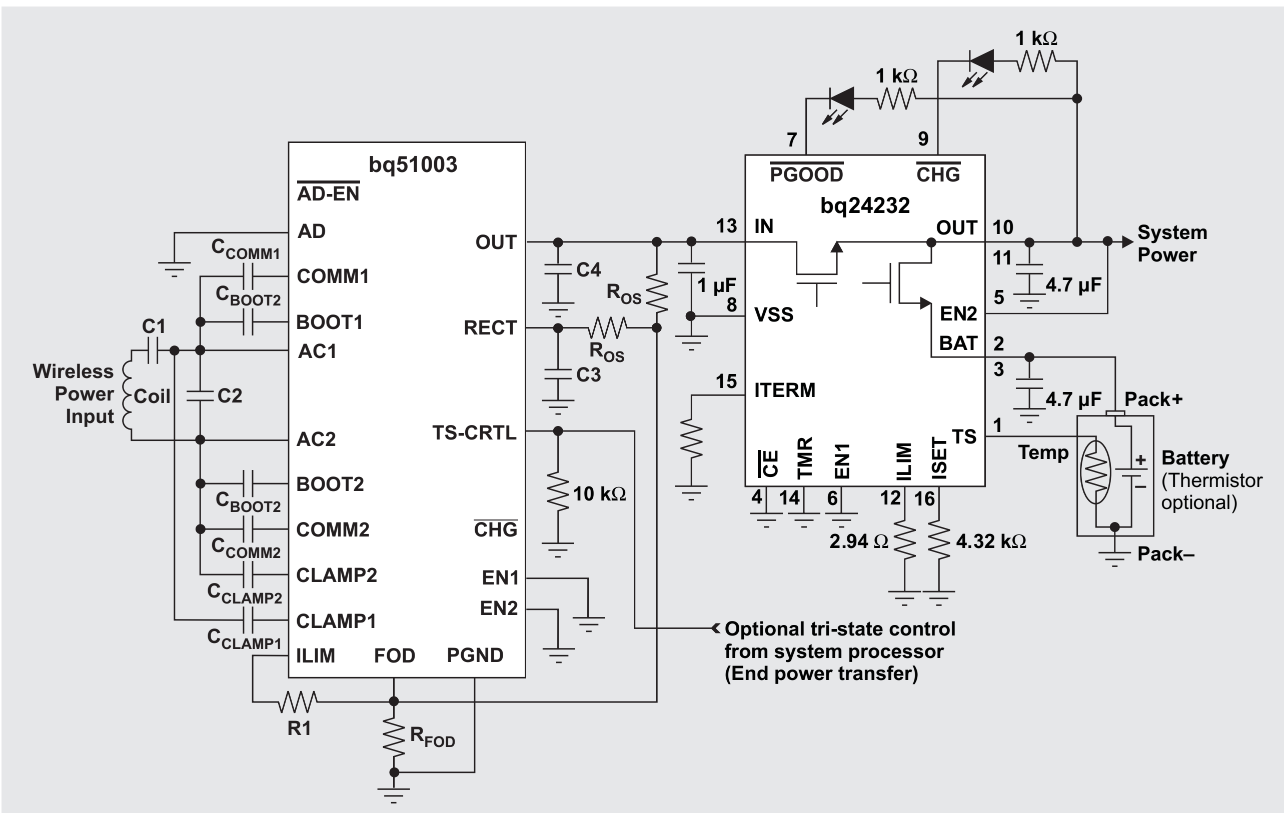
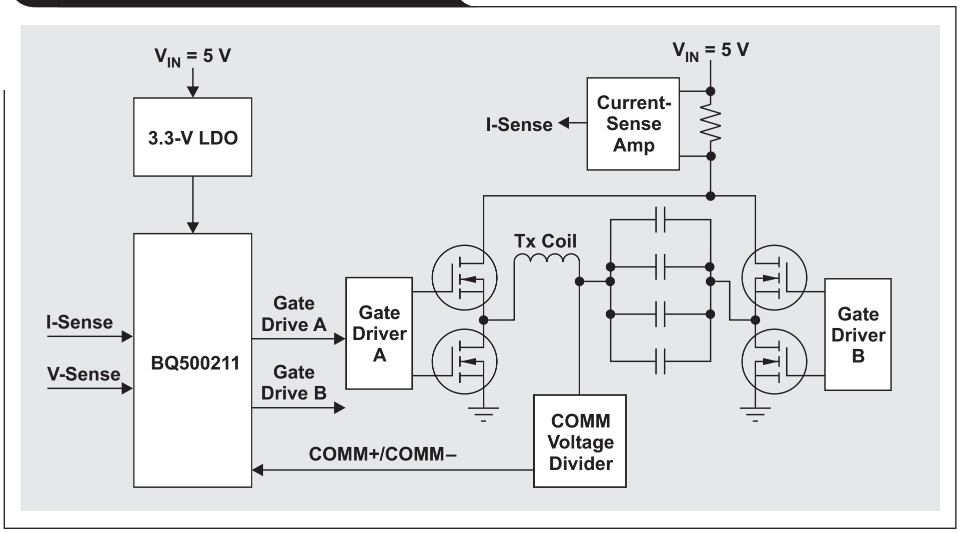


Figure 5. Low-power transmitter



USB port or small adapter. This works very well with low-power receivers with low current demand. A block diagram example is shown in Figure 5. Input current is sensed across a resistor and amplified through a current-sense amplifier. The power section uses power-stage MOSFETS with integrated drivers. But independent drivers and low-loss MOSFETS could be used to reduce cost. As discussed earlier, at lower output power, FOD protection may be optional; the circuit shown does not have the FOD feature implemented. Also, for simplicity and cost reduction, the design in Figure 5 does not show the optional circuitry for low-power standby mode. Reference 4 has more information about this design.

Conclusion

Implementing wireless inductive charging in a low-power, wearable design is possible now using existing off-the-shelf devices. Among the key factors to design a working solution in the 500- to 1500-mW power range is optimization of the magnetic components—specifically, matching the smaller-size receiver coils to correspondingly smaller transmitter coils to maintain the best coupling factor. Also important is implementation of appropriate external circuit modifications with the bq500211 transmitter and bq51003 low-power receiver to minimize system power losses.

References

1. Bill Johns, "An Introduction to the Wireless Power Consortium standard and TI's compliant solutions," *Analog Applications Journal* (1Q 2011). Available: www.ti.com/2q14-slyt401
2. E. Waffenschmidt and Toine Staring, "Limitation of inductive power transfer for consumer applications," *13th European Conference on Power Electronics and Applications* (EPE2009), Barcelona, Spain, 8-10 Sept 2009, paper #0607.
3. Bill Johns, Tony Antonacci and Kalyan Siddabattula. "Designing a Qi-compliant receiver coil for wireless power systems," *Analog Applications Journal* (3Q 2012). Available: www.ti.com/2q14-slyt479
4. Bill Johns, "Low Power Transmitter Reference Design, bq500211," Reference Design (April 2014). Available: www.ti.com/2q14-slua705

Related Web sites

Wireless power products:
www.ti.com/2q14-wireless

www.ti.com/2q14-bq51003

www.ti.com/2q14-bq500211

www.ti.com/2q14-bq24232

Subscribe to the AAJ:
www.ti.com/subscribe-aaj

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page
support.ti.com

TI E2E™ Community Home Page
e2e.ti.com

Product Information Centers

Americas	Phone	+1(512) 434-1560
Brazil	Phone	0800-891-2616
Mexico	Phone	0800-670-7544
	Fax	+1(972) 927-6377
	Internet/Email	support.ti.com/sc/pic/americas.htm

Europe, Middle East, and Africa

Phone

European Free Call	00800-ASK-TEXAS (00800 275 83927)
International	+49 (0) 8161 80 2121
Russian Support	+7 (4) 95 98 10 701

Note: The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Fax	+(49) (0) 8161 80 2045
Internet	www.ti.com/asktexas
Direct Email	asktexas@ti.com

Japan

Fax	International	+81-3-3344-5317
	Domestic	0120-81-0036
Internet/Email	International	support.ti.com/sc/pic/japan.htm
	Domestic	www.tij.co.jp/pic

Asia

Phone — Toll-Free Number

Note: Toll-free numbers may not support mobile and IP phones.

Australia	1-800-999-084
China	800-820-8682
Hong Kong	800-96-5941
India	000-800-100-8888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
New Zealand	0800-446-934
Philippines	1-800-765-7404
Singapore	800-886-1028
Taiwan	0800-006800
Thailand	001-800-886-0010

International	+86-21-23073444
Fax	+86-21-23073686
Email	tiasia@ti.com or ti-china@ti.com
Internet	support.ti.com/sc/pic/asia.htm

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265