

# Exploring the evolution and optimization of wireless power transfer



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**Although Nikola Tesla pioneered the concept of wireless power transfer (WPT) and ushered in the wireless communication age, it was really the latest generation of smartphones that widely introduced the capability to charge a battery without a physical connection. A wide variety of industrial, medical, consumer and automotive applications are quickly applying this technology.**

The benefits of wireless charging – convenience (no plugs or special connectors) and robustness (no contacts that can break and the ability to completely seal the product for use in harsher conditions) – are magnified further in applications that depend on mobility, especially as applications become more autonomous.

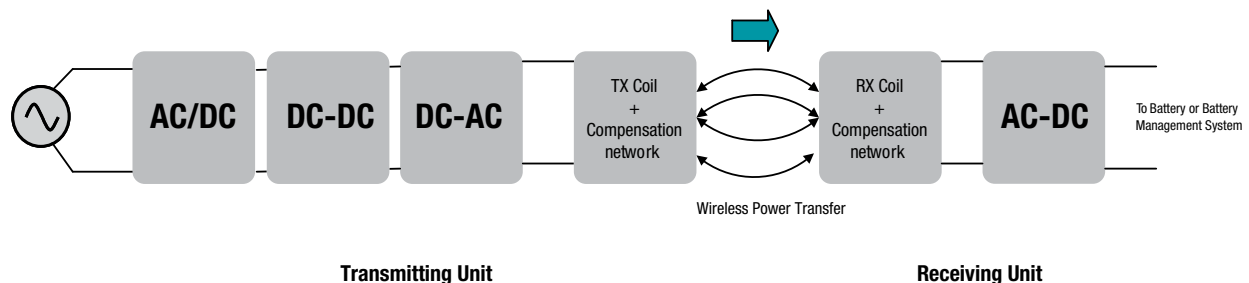
### WPT overview

A typical WPT product comprises a transmitting (TX) base unit that transmits the power and a mobile receiving (RX) unit that receives this power wirelessly and uses it to charge a battery. See **Figure 1**.

The TX base unit is the static piece of the WPT system; it takes power from the AC input and generates a magnetic or electric field that transfers power wirelessly. The TX unit connects to the utility grid and comprises a front-end AC/DC power

factor correction (PFC) converter that converts the utility AC voltage to a known DC voltage. Following the AC/DC converter, you can optionally employ a DC/DC stage to help maintain resonance across the voltage ranges that the receiving load may demand. A DC-AC converter then converts the DC voltage to a high-frequency AC waveform. This high-frequency inverter is typically anywhere from 80-500 kHz, depending on the power level and end application.

For example, the Qi standard – widely used in personal electronics – calls for a 110-205 kHz



*Figure 1. WPT system overview.*

switching frequency, whereas in some high-power applications such as electric vehicles (EVs), it's common to use a lower frequency, like 50-80 kHz. With the advent of wide-bandgap devices such as silicon carbide (SiC) and gallium nitride (GaN), designers are starting to use higher switching frequencies for wireless power systems. The high-frequency inverter (DC-AC) connects to a TX coil and a compensation network that acts as an antenna. The TX coil is responsible for generating the desired electric and/or magnetic fields that couple the energy to the receiving side through a wireless medium.

The RX coil and compensation network then receive the magnetics and/or electric fields transmitted over the wireless medium, which ultimately results in rectified voltages/currents. Most designs use a passive diode-based rectifier. However, given the trend toward higher efficiency, synchronous rectification scheme are increasingly being considered in the design and used. The rectification of the coupled voltage generates a DC voltage that is used by the battery system of the RX unit to charge the battery.

## WPT requirements

In creating a WPT product, it's important to understand several requirements. The priority and trade-offs between these requirements will depend on the WPT application and the goals of the overall system.

- Efficiency: steady state vs. instantaneous; static vs. dynamic. Efficiency invariably involves trade-offs with the other requirements.
- Performance: charging time, power factor, response time and stability are just some of the many factors to consider.
- Reliability: the temperature and mechanical-induced degradation of electronics, magnetics and packaging.

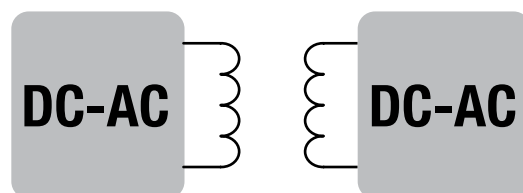
- Safety: the transmission of high power through electromagnetic fields, electrical safety and the detection of foreign objects.
- Form factor: sizing for the application while making trade-offs for the components, including heat dissipation, electromagnetic interference (EMI) capability and overall system reliability.
- Operating conditions: encompassing humidity, temperature, magnetic and EMI interference, mechanical stress, exposure, and contaminants.
- Deployment: consider the challenges more specific to interacting systems. For example, you can produce a perfect wireless charging receiver for a car, but are you building the transmission infrastructure as well? Does your product also need to accommodate working in a system with a wired interface?
- Cost: always a factor in any product to ensure success and competitiveness in the market.

## WPT transfer types

Depending on the choice of TX/RX structure and the mechanism of power transfer, WPT systems can be classified in three categories: inductive, resonant and capacitive.

### Inductive

As **Figure 2** illustrates, in an inductive-type WPT system, the TX and RX coils act as a closely coupled transformer. This type of charging is widely used for mobile phones and personal electronics where the RX unit is in close proximity to the TX

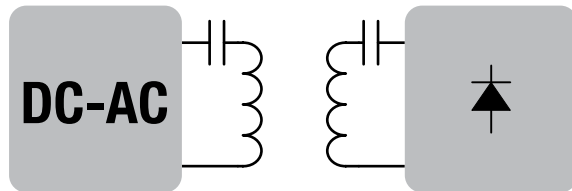


**Figure 2.** TX and RX coils in an inductive WPT system.

units. The TX DC/AC generates a high-frequency AC that results in a changing magnetic flux owing to Ampere’s law. This flux couples through the air to the coils of the RX unit, where by Faraday’s law a current is induced, so power can transfer from the TX side to the RX side wirelessly.

## Inductive-Resonant

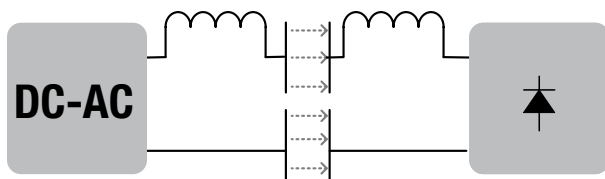
Given that applications such as EVs demand an increasing distance between the TX and RX sides, inductive power transfer is impractical because of reduced efficiency. A resonant scheme cancels out system impedances and provides reasonable power transfer efficiency, even with increased distances. There are several ways to achieve resonance, including compensation schemes with series capacitors, parallel capacitors and inductors. Depending on the system requirements, each has its unique advantages. See **Figure 3**.



**Figure 3.** TX and RX coils in a resonant WPT system.

## Capacitive

Instead of a magnetic field, an electric field can also couple power from TX to RX. In this case, as shown in **Figure 4**, a capacitive WPT system uses plates instead of coils. Although this type is not widely



**Figure 4.** TX and RX plates in a capacitive WPT system.

popular because of the higher switching frequencies and lower power capacity than the inductive or inductive-resonant types, it is applicable in some scenarios.

## Design and control challenges

The controllers are the key components of a WPT system because they control the compensator (and often the converter), establishing power conversion and transfer. Communication to provide status, current, voltage and monitoring between TX and RX controllers is crucial for efficient, safe and reliable products. Wireless communication standards (*Bluetooth*<sup>®</sup>, *Wi-Fi*<sup>®</sup>, radio frequency) are common because of the physical separation.

The goal of the system is to deliver power to the secondary side as efficiently as possible.

## Multicoil control

A major issue for a WPT system is to transmit power under varying orientation and alignments between the TX and RX sides. To accommodate these wide variations, the TX unit can have multiple sets of TX coil and compensation network, which are excited in specific patterns based on orientation and alignment. Furthermore, in a personal mobile device charging applications, a TX unit may have to charge more than one device at a time for which it may need to control power in multiple TX coils.

The scalable Texas Instruments (TI) C2000<sup>™</sup> microcontroller (MCU) architecture enables several system design options. For example, for the TX unit shown with a block diagram in **Figure 1**, a typical power stage diagram is shown in **Figure 5** below. The AC/DC, DC/DC and DC/AC power stage can be controlled in a variety of manner and different variants of specific power topologies may be chosen for each one of them.

For example, for the AC/DC stage which is the front end rectifier, the requirement is to provide good output voltage regulation, maintain good power factor, be high efficiency and be compact/high power density. Depending on the power level of the TX unit being designed, either a single phase AC input or three phase AC input may be used. For the single phase AC input, in applications such as level-1 charging for EV/HEV WPT systems the Totem Pole Power Factor Correction (PFC) topologies are an attractive choice as they are able to meet the requirements of the power stage very well. Piccolo™ F280049 MCU can control the advanced power topology of totem pole PFC easily, whether it be [Continuous Conduction Mode \(CCM\) mode](#) variant or the [Critical Mode \(CrM\) mode](#). For three phase AC input, in applications such as level3 type charging systems for EV/HEV WPT systems, Vienna Rectifier topology is attractive with its benefits of three level switching. The [Vienna Rectifier-Based Three Phase](#)

[Power Correction Factor Reference Design Using C2000 MCU](#) can be a great start for implementing this converter.

For the DC/DC and DC/AC an additional C2000 MCU can be used. Depending on the application, the MCU may need to control one or multiple coils i.e. multiple DC/AC converters. **Figure 5** shows one way to generate the high-frequency AC using a full-bridge circuit. Though other options, such as using a half-bridge circuit may be used depending on the power level of the system. The F280049 has 16 pulse-width modulation (PWM) channels and can therefore control up to eight high-frequency half-bridge inverters or four full-bridge inverters for a multi-coil TX unit when the DC-DC converter is not needed.

For a more integrated approach, one can use a single C2000 MCU from the Delfino™ family. The F2837xD is a dual-core MCU, where PFC control can run on one core and the other core can control a high-frequency inverter.

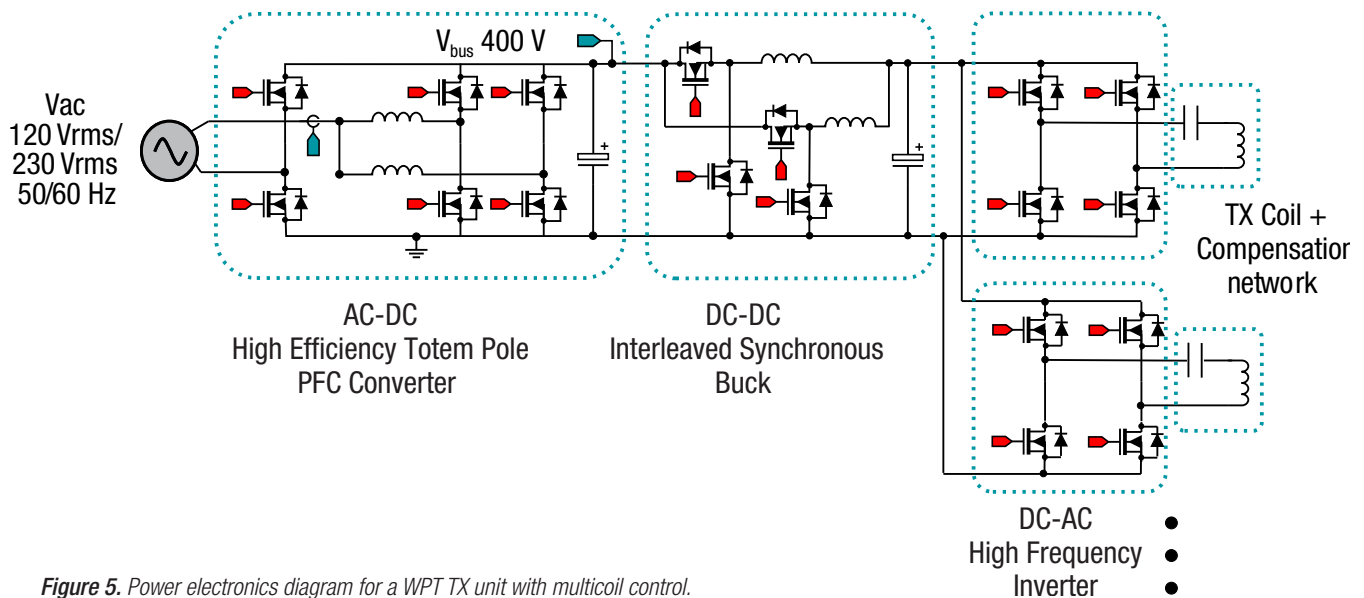
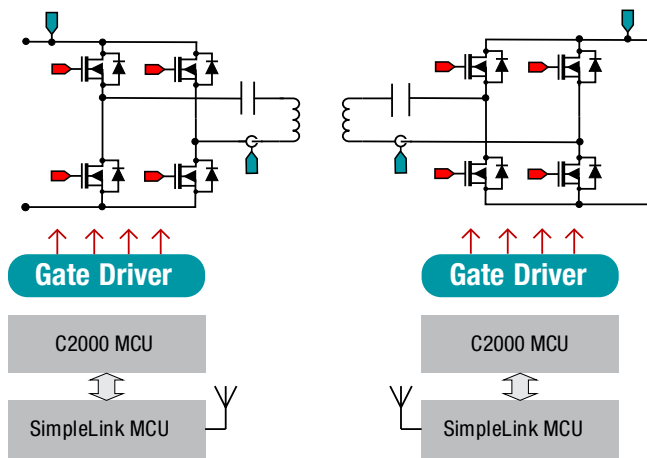


Figure 5. Power electronics diagram for a WPT TX unit with multicoil control.

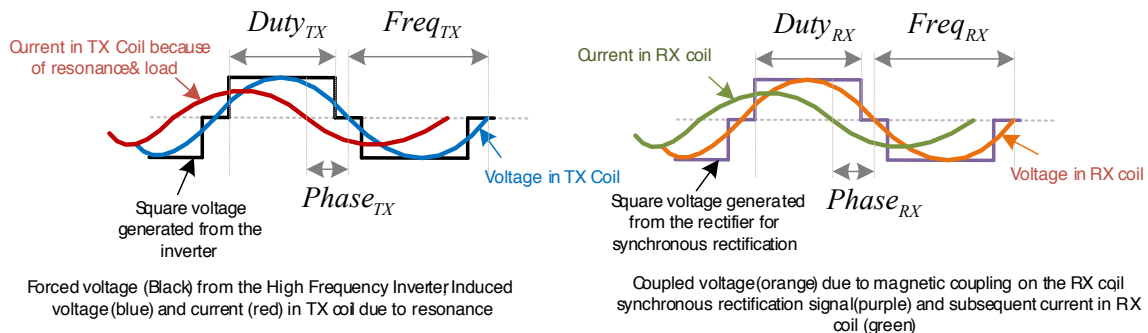
## Wireless communication between the TX and RX unit

The goal of the WPT system typically is to charge a battery on the RX unit (which can take either constant voltage or constant current mode-type charging with varying power levels). As no physical connection exists between the TX and RX unit, this information must be communicated over a wireless link to the TX unit. A typical WPT system with TX and RX units using C2000 MCU for the power control and using TI's SimpleLink™ MCUs to communicate over a wireless medium such as *Bluetooth* or *Wi-Fi* is shown in **Figure 6**.



**Figure 6.** TX and RX unit MCU architecture.

The power (voltage and current set points) desired from the RX unit is then transmitted over the wireless medium and is used by the TX unit, to control the inverter frequency, amplitude, phase etc. The



**Figure 7.** PWM generation and control parameters for TX and RX coil converters.

reliability of the TX link is also critical, as some critical system-level algorithms such as foreign body detection use information from both the TX and RX sides to compare information such as efficiency.

## PWM control requirement

A closed-loop system needs to be executed on the TX-side C2000 MCU, which takes feedback from the TX-side inverter and information from the secondary-side RX of the power desired. For optimal efficiency in power delivery, the goal of a WPT system is to operate at the tuned frequency between the primary and secondary coils. As in a practical application, the designed compensation circuit and coil have variances over time, aging and load. Different techniques such as capacitor banks or phase control have been shown to achieve varying degree of tunability.

For example, to get optimal performance the TX coil can modulate not just the frequency of the square wave generated of the inverter but also the duty cycle. The phase differences between the current and voltages in the resonant tank may need to be measured to adjust other schemes in the compensation network that tune the circuit. This involves adjusting the excitation signals (PWMs) in frequency, duty and phase relation. In addition to this, on the RX coil for an effective implementation of synchronous rectification, similar features from the PWMs are desired. The PWM signal and resulting voltage and current in the TX and RX coils are shown in **Figure 7**.

The C2000 MCU's advanced PWM module enables generation of these frequency- and phase-controlled signals easily. For example in a multi coil system, when multiple PWM modules are used to control the different TX coils, due to system requirements accurate phase and duty control is needed even when frequency itself varies to operate the system at resonance. For reliable operation, the changing frequencies must not produce any glitches or irregular PWM behavior. Guaranteeing correct PWM waveform generation with changing frequencies under all operating conditions can be challenging for the controller because the safe time to update the PWM parameters decreases as switching frequencies or the number of interleaved phases increase. The C2000 MCU's implementation of a global one-shot reload is a key mechanism to ensure the correct generation of the PWM waveform. Global one-shot reload ensures that all duty, phase and deadband updates take effect within the switching cycle where the new frequency is needed. This provides a clean transition from one frequency to the other for all phases.

## Protection

For safety analog mechanism of protection are required. For example, the current in the TX coil or input current is typically measured in a WPT system. The C2000 comparator subsystem (CMPSS) integrates the components required to implement protection mechanisms such as comparators and reference/trip point generators on chip. Thus protection for overcurrent and overvoltage conditions can be achieved without the use of any external circuitry, making the board smaller and lower in cost. Furthermore, the flexible crossbar architecture enables the combination of trip events from multiple sources such as CMPSS and general-purpose input/outputs that signal gate-driver faults quickly and easily – again, without the need for external logic or circuitry.

## Sensing

Sensing system parameters such as voltage and current and additional sensors such as temperature are important aspects for good control. The analog-to-digital converter on the C2000 MCU enables highly accurate sampling and measurement, resulting in better and more precise efficiency measurements on the TX and RX sides which is used to implement key feature in a WPT system such as foreign body detection.

Together, the PWM and CMPSS offer the ability to measure the phase angle between voltages and currents in the TX or RX coils directly, without the need for extra hardware. The phase angle information can be used in WPT applications to adjust the PWM signals and change compensation network to bring the system closer to resonance point and thus operate at higher efficiency.

## Processing

An optimized central processing unit (CPU) enables fast execution of the control loop. The on-chip trigonometric math unit (TMU) accelerates trigonometric operations, which imparts additional speed in control-loop execution and reduces the overall million-instructions-per-second (MIPS) requirement. In a wireless power system, you may need to compute the impedances to adjust the duty, frequency and phase of the high-frequency inverter; this can be a trigonometric-heavy operation. Thus, accelerating trigonometric operations can offer significant improvements in the control execution, which C2000 MCUs enable.

## Multiloop control

The control law accelerator (CLA) is a secondary core that offloads control-type tasks from the main CPU (C28x), which frees up bandwidth on the C28x for other operations and tasks. Additionally, the CLA can act as a parallel processing unit to run the



control loop faster, thus enabling higher switching frequency control. In the case of WPT, the CLA can control the analog front end in an integrated WPT TX unit, with the control of the high-frequency inverter realized on the C28x CPU.

## Conclusion

With the goal of making battery-powered applications easier to use and more robust – from the simple low-power inductive type used in personal electronics to the more complicated high-power resonant type used for dynamic and often autonomous applications – WPT systems will soon become commonplace. In higher-powered applications where efficiency is more critical, C2000 MCUs offer differentiated capability in signal sensing, processing, flexible high-resolution PWM control of the high-frequency inverter, and system protection mechanisms. Examples of these techniques and power topologies are available through reference designs in the TI Designs reference designs library.

## Related websites

[Interleaved CCM Totem Pole Bridgeless Power Factor Correction \(PFC\) Reference Design](#)

[Highly Efficient, 1.6 kW High Density GaN Based 1 MHz CrM Totem-pole PFC Converter Reference Design](#)

[98.5% Efficiency, 6.6-kW Totem-Pole PFC Reference Design for HEV/EV Onboard Charger](#)

[C2000 Solar & Digital Power Solutions](#)

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