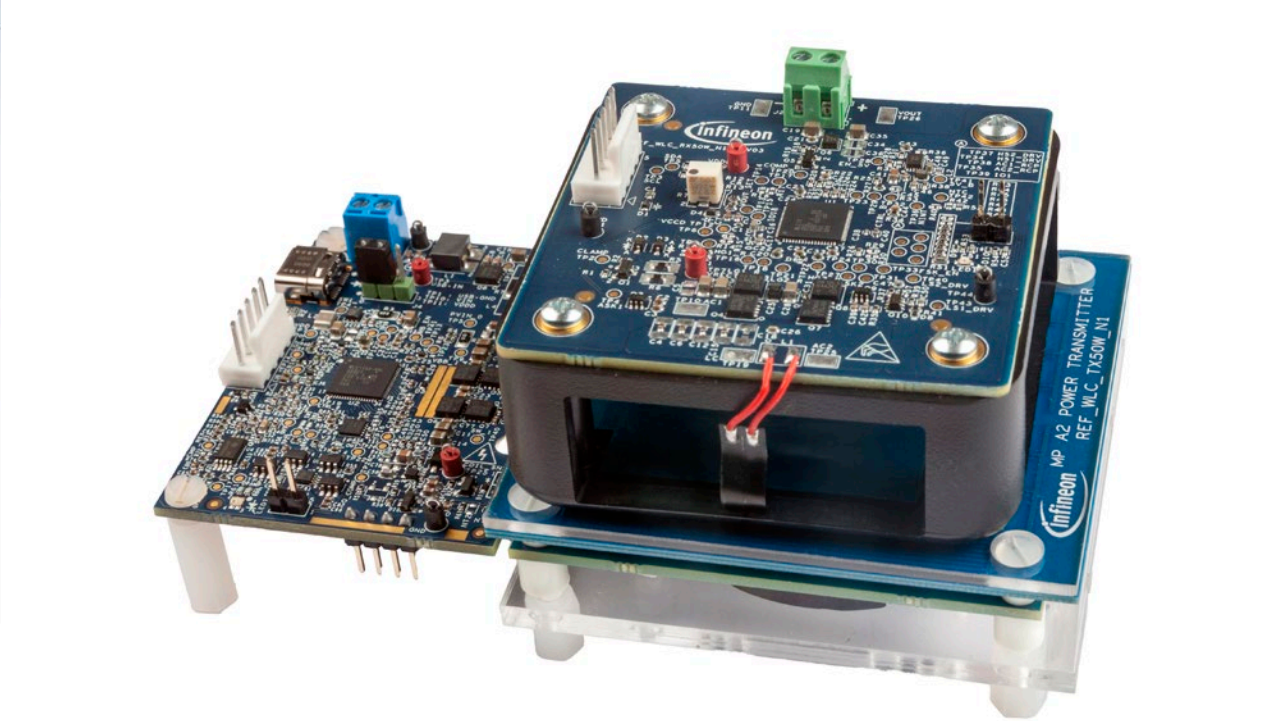
COVER STORY — DESIGN



Expanding Wireless Power Transfer for Higher Power Delivery

High-power wireless transmitters and receivers designed for mobile phone fast-charging and battery-powered applications

*By Nicholaus Smith, principal applications engineer and Hariom Agrawal, senior staff systems engineer, both at **Infineon Technologies***

Over the past decade, wireless-power–transfer functionality has been broadly adopted across various commercial, industrial and automotive applications. Market trends are moving toward battery-powered products requiring higher power charging. The number of products needing charging is increasing, and so is the need for fast-charging, high-capacity batteries.

Wireless charging designs can now deliver much higher power than the mobile phone and wearable markets require. Modern mobile phones can draw up to 50 W but for quite a limited time due to thermal constraints. On the other hand, true high-power applications, such as laptops, tablets, portable kitchen appliances, power tools, robots and drones and light electric vehicles, can sustain higher power delivery and charge for prolonged periods.

However, higher-power designs beyond Qi extended power profile (EPP) are generally considered complex and costly, as standards are still evolving, leading to interoperability and coexistence concerns. The most discussed challenge is related to the IEC-62368 safety requirements for touch-temperature limits on consumer portables. In addition to an efficient charging subsystem, this also implies the need for dynamic foreign-object–detection (FOD) features that ensure protection while enabling charging across the load range, including transients. Therefore, robust communication protocol between the transmitter (Tx) and receiver (Rx) also becomes an essential requirement of such high-power charging.

To meet these stringent system and regulatory requirements for higher-power wireless charging, Infineon developed a broad range of highly integrated wireless charging ICs. These include a USB-PD/PPS sink with an on-chip 32-bit ARM Cortex-M0 processor, 128-KB flash, 16-KB RAM and 32-KB ROM. They are also equipped with various analog and digital peripherals, integrated gate drivers and DC/DC controllers. The ICs are offered together with a system solution and a software stack based on Infineon's high-power charging protocol with unique identification and configurable protection features to maintain safe, high-power charging environments. In addition to the proprietary mode, Infineon's ***WLCx family of products*** also supports the latest Wireless Power Consortium (WPC) Qi EPP (≤15 W) specifications[1] to enable compliant and interoperable solutions.

In the following sections, we present an overview of a typical wireless power system and some insight into designing the solution for optimal thermal management, take a deeper dive into coil design and present an overview of Infineon's solution features and a couple of applications to explain why wireless power is a suitable and convenient choice for high-power products in any environment.

WIRELESS POWER SYSTEMS AND DESIGN CONSIDERATIONS

Wireless power systems are unique power-management solutions that include mixed-signal analog and digital sensing, communication circuits alongside AC and DC power-conversion stages and, most importantly, a software stack to provide a reliable handshake between the Tx and Rx side. The block diagram in Figure 1 shows the main functional blocks of a typical high-power inductive wireless system.

In Figure 1, the incoming power source will be a DC power supply based on USB-C (PPS or PD) or fixed-rail–voltage supply. This supply can be passed directly to or converted by an intermediate

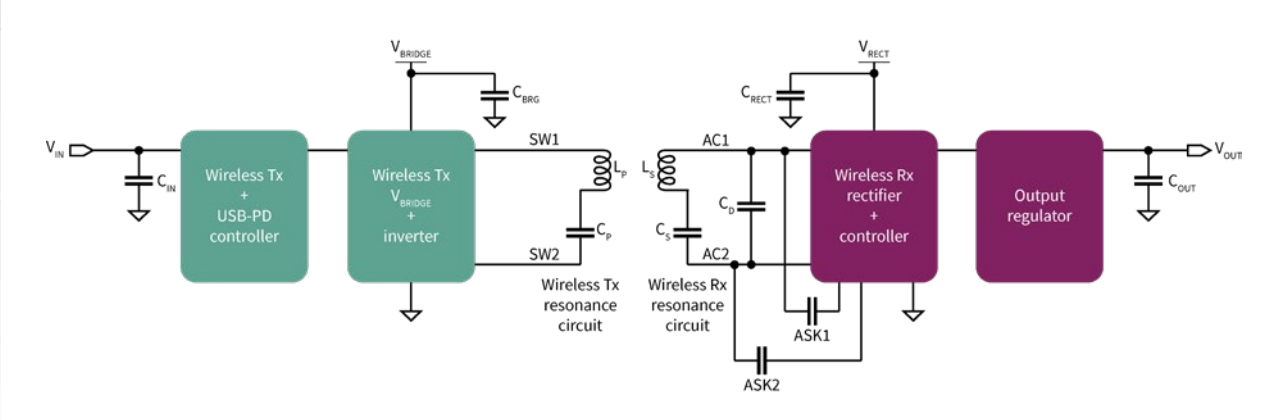


Figure 1: Block diagram of a wireless power system

DC/DC regulator to power the DC-to-AC power inverter. The inverter creates an alternating magnetic field using an L_P and C_P series resonance tank to transmit power to the receiver. On the receiver side of the system, series resonance components L_S and C_S convert the incoming magnetic field to current, and a high-power rectifier converts the AC current into a DC voltage. Finally, an output regulator is used to provide a stable DC voltage to a load that can be a specific work function of a product or a battery charger.

There are several additions to the typical wireless power system (≤15 W) to qualify as a high-power solution (>15 W). The first is an increased need to improve the performance of the magnetics to reduce power loss and the associated heat developed due to power loss during transmission. Additional guidance for high-power designs will include extra safety and authentication procedures to prevent counterfeit designs from drawing or providing high power. At the same time, it will ensure that proper FOD mechanisms are in place to safely and efficiently deliver high power to receivers and their loads. Most end products will use the Rx output to charge a battery; however, there can be standalone applications, such as pool lighting and washlets, in which wireless power is simply the means to power the load without a battery.

DESIGN FOR BETTER THERMAL MANAGEMENT: COOLING OPTIONS

There are concerns that the heat development and the efficiency of higher-power wireless systems may impede or delay meeting safety requirements. Still, these can be mitigated by designing for heat dissipation and optimal efficiency. A full stackup of a Tx-Rx coupled inductive wireless charger is shown in Figure 2 to better understand the avenues for heat trapping and cooling.

The physical construction of the PCB can influence the operating temperature of the system as well. The copper surface areas connected to power components and the board thickness will play a role in the final operating temperature. Thinner PCB designs will transfer more heat between inner layers due to the lower thermal resistance and the larger areas. Designing a thin PCB will improve

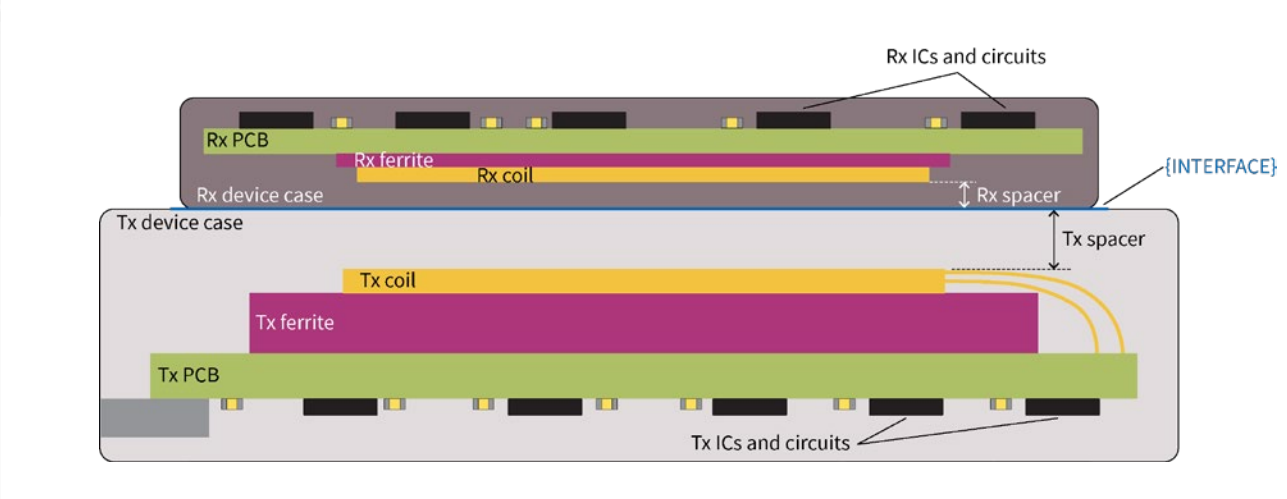


Figure 2: Stackup of a typical wireless charging system

thermal performance compared with thicker PCBs having more dielectric FR-4 between copper layers. Other solutions include adding a fan to force airflow across the circuits and the interface (Figure 3). If forced air is used, it is crucial to provide tunnels or airflow channels in the interface by either designing grooves so the air may flow through or using semi-porous materials that allow the air to flow freely.

At this stage of the evolving higher-wireless–power market, the most common application is a mobile phone. Some mobile phones can draw up to 50 W but for a very limited time. As the emerging market takes shape, laptops, robotics and other similar high-power applications will be able to sustain power delivery indefinitely. Also, because the charging stands and devices are typically quite small, high power dissipation is challenging without using a fan to move the warmer air from the products' interface, where touch temperatures are measured.

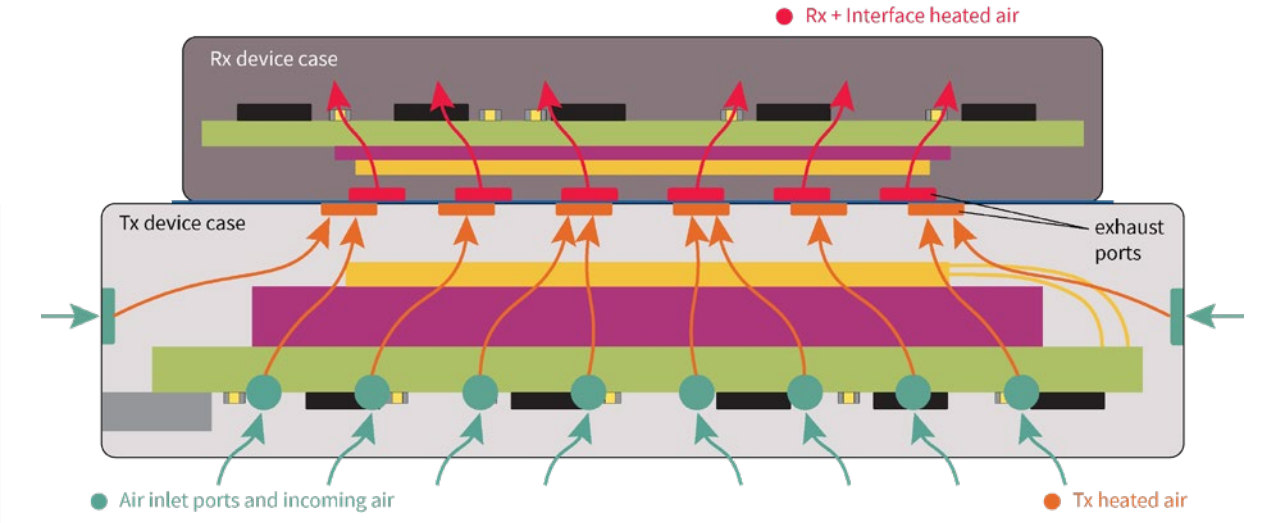


Figure 3: Example of utilizing channels to allow the airflow at the interface forced from the Tx

Figure 3 shows how air channels can be created to allow forced air to pass over the Tx circuits and reach the interface, where it can cool both coils without interfering with the interface spacing or power transfer. The air is pulled in from the Tx side, and the air channels are designed on the Tx and Rx to have more surface area. In this way, the interface will be under lower pressure, and all the forced air will evacuate at the interface, thus cooling the Tx and Rx coils simultaneously.

DESIGN FOR BETTER THERMAL MANAGEMENT: IMPROVING COIL EFFICIENCY, ROUTING

In inductive wireless charging systems, one of the most prominent sources of thermal concern is the magnetics themselves. Hence, the main idea behind improving efficiency is to use a higher-quality Rx coil. For example, a Litz wire coil with a nanocrystalline shield can substantially reduce the interface temperature compared with multi-stranded wires or PCB coils. There is usually a tradeoff between cost and performance, where the superior performing Litz wire Rx coil designs tend to be the most expensive while the PCB-type coils cost less and are the least efficient.

Nanocrystalline shields will yield high saturation levels in thinner materials and are superior in performance compared with a standard, sintered ferrite core. When using PCB-type coils, it is beneficial to utilize heavier copper foil weights (i.e., 2-ounce or 4-ounce copper as opposed to the standard 0.5 ounces found on most flexible PCB substrates). Because these conductors carry high currents and are typically relatively large, they serve as heat dissipators as well as current conductors. Therefore, an essential mitigation technique is connecting large copper planes to the Tx and Rx coil contacts and other heat-generating sources, such as power MOSFETs, inductors and ICs. In this case, it is critical to include significant areas of copper planes to absorb the developed heat resulting from power consumption by the electronics.

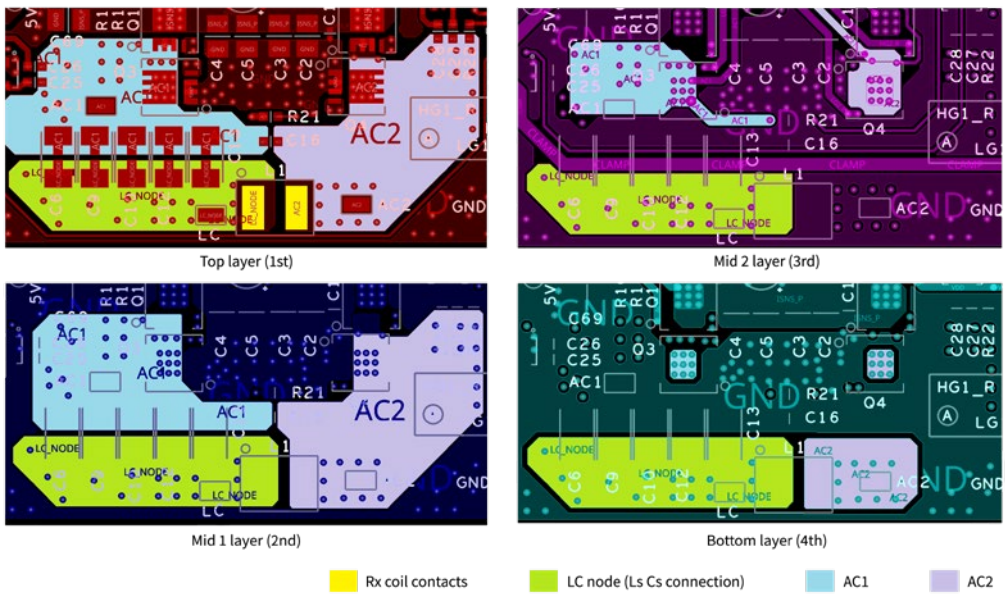


Figure 4: WLC1x layout example of AC nodes using parallel planes to distribute heat and reduce resistance

Figure 4 shows a layout of the WLC1x high-power four-layer Rx PCB, in which the Rx coil contacts are shown to have multiple parallel planes stitched together with multiple vias to transfer current and heat using each parallel plane. All of the AC current-carrying nodes (LC, or L_S and C_S, common connection node and the AC1 and AC2 nodes), as shown in Figure 1, should be utilized to transfer heat and current in high-power designs. Notice that the coil contacts (top layer, yellow contacts) have connections to all four layers on the LC node and three out of four layers on the AC2 node. Furthermore, AC1 is duplicated as space permits on three out of four layers. With multiple parallel vias, these techniques can reduce thermal resistance significantly. As a result, there are lower operating temperatures for all components being in contact with these nodes. It should also be noted that each rectifier MOSFET has an array of nine heat and current transfer vias directly in the drain connection pad/pin.

DESIGN FOR COEXISTENCE: HIGHER-POWER, BACKWARD-COMPATIBLE WITH QI

Indeed, several factors will impact the selection or design criteria of the Tx and Rx inductive power transfer system. In order to simplify this problem, we suggest starting with a standard WPC-defined extended power coil (or coils, such as MP-A2 or MP-A11) and then matching the resonance tank design specification to maintain compatibility with standard Qi Rx devices and facilitate delivering high power. These coils are proven to operate well with the InterOperability Platform (IOP). Due to a heavy-gauge Litz wire, the current-carrying capacity is sufficient to deliver much higher power without introducing excessive power loss in the coil or the large ferrite shielding. After selecting one of the standard coils or making some minor modifications due to specific system requirements, the design of the Rx coil should commence (for mated systems). If the design is Tx only, then best practices and layout guidelines should be followed to complete it.

When the solution requires creating a custom coil, it should be noted that wireless power systems demonstrate optimal performance when the combined air gap (Rx and Tx interface height or the space from the coil-to-coil facing surfaces) is between 3 and 8 mm, depending on the final geometries. This will help to ensure the coupling factor is between 0.5 and 0.85, which is the sweet spot for inductive wireless power systems. Consequently, this enables the design to meet appropriate mutual inductance values when the Tx and Rx coil inductances are kept within a range of about ±25% of each other. In addition, it ensures that the gain curve is neither too steep nor too shallow to allow proper power-regulation steps throughout the operating voltage and frequency range.

Utilizing the First Harmonic Approximation (FHA) analysis, many parameters and most operating modes can be modeled and simulated. Infineon's ***High Power Tx Design Guide***[2] includes the necessary derivations, the recommended model and comprehensive system design guidelines. For example, this design guide can be used to create the graph shown in Figure 5. In this graph, the typical Tx coil power versus frequency slope indicates how the gain responds to changes in

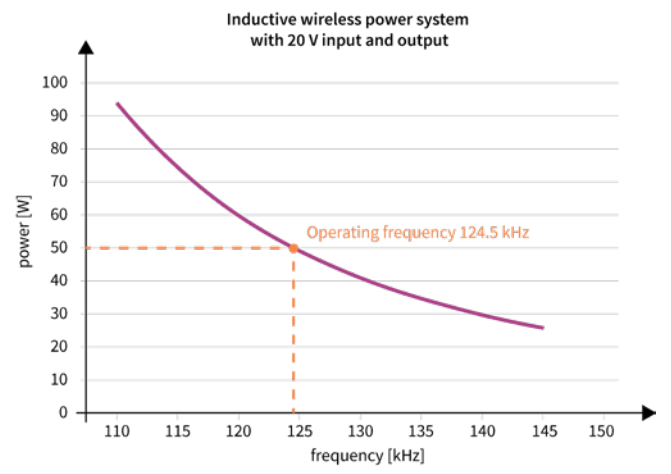


Figure 5: Typical power vs. frequency curve for an inductive wireless power system with 20-V input and output

operating frequency. A nice linear curve is preferred in order to have a predictable response to frequency (or voltage) changes on the Rx side. However, a steep curve or exponential curve will have variable power-level changes for the same frequency step size, which can make the control loop more complicated.

Looking at Figure 5 and considering the MP-A2 wireless power Tx specification, we found that the operating frequency range is limited to 110 to 148 kHz. By inspecting the curve, it is evident that, in this range, the response is quite linear as the frequency changes while providing plenty of power for the Rx. With this as a target from the ***Design Calculator***,[2] using FHA simulations aids in coil design without the requirement of running complicated magnetics simulations (though these are always encouraged). After utilizing the Tx design guide, the following guidelines can be used to generate Rx coil prototypes in parallel with simulations or design calculations to expedite the design phase and start narrowing down the final magnetic design:

- The Tx and Rx coil geometries (inner diameter/outer diameter) should be within ±25% of each other.
- The number of turns should be similar (within ±3).
- Free-air inductance should be within ±20% of each other.
- The Rx shielding should be nanocrystalline or fractured ferrite types and as thick as possible (up to 2 mm is sufficient).
- Relative permeability (μr) should be in the 500–900 range.
- The AC and DC resistance should be minimized. Using Litz wire, multi-strand conducted wire or wide/thick copper foil on PCB can increase the amount of “skin” of the conductor.
- Ideally, shielding should be continuous and exceed the outer coil diameter by at least 1 mm up to 3 mm (as space permits).

By following these guidelines, the coupling factor, mutual inductance and magnetic field volume will be appropriate to operate and provide decent active areas in lieu of complex iterative simulations. The above guidelines aim to prepare coil prototypes immediately so that testing and final design adjustments can be completed by checking efficiency, transient response and communication fidelity across load and voltage. It is recommended to get a few prototypes of Rx coils with different permeabilities and inductances and experiment with the air gap, if possible, to find the optimal configuration and coil design. For additional details and descriptions of the governing equations, see the ***WLC1150 Design Guide.***[2]

The next major design decision will be operating voltage after defining the required output power. The output power can then be used to estimate the power losses of the rest of the system going back to the incoming DC power supply to the Tx. This will enable thermal modeling and help determine limits for the resistance and the $R_{DS(on)}$ value of the MOSFETs. It should be noted that the highest efficiency is achieved by operating the system at the highest possible voltage to reduce the current and the associated I^2R power losses. For example, a 50-W output is best suited to use a 20-V output at 2.5 A instead of a 10-V output at 5 A. The reason is that the higher rectifier voltages require lower rectifier currents leading to a lower coil current, and the bulk of Rx losses will occur in the rectifier and Rx coil. It is a good assumption that the root-mean-square Rx coil and rectifier currents will be ~1.11× the rectified DC current (assuming a fairly sinusoidal waveshape). Again, the ***WLC1150 Design Guide***[2] offers comprehensive insight, recommendations and estimates of the operating points for high-power wireless transmitter designs.

Using these reference guides will allow making power-loss estimations for the rectifier MOSFETs and the Rx LC tank and the Tx pre-regulator (if used), inverter and Tx coil. It will become evident that the AC losses in the coil are dominant, and thus, this resistance should be reduced as much as possible by using heavier-gauge Litz wire, multifilar stranded wire or parallel thick copper PCB tracks to create the Rx inductor while meeting the cost and thickness requirements of the end product.

Moving back to the output, once the output power and voltage are determined, the post-regulator between V_{rect} and V_{out} should be considered. In general, for high-voltage output (>15 V), the LDO-type output is more efficient, as V_{rect} and V_{out} will be within 0.2 V of each other. Thus, the output regulator losses and coil currents will be minimized. The output stage power calculations are simplified, and by using the power and voltage, the rectifier DC current can be calculated. Then the rectifier and Rx coil current can be found, as it is nearly equal to the output current (controller IC quiescent current and switching currents have to be added to the output current to get rectified current).

For systems that will use <15-V output, the buck regulator is advantageous because the system can regulate the V_{rect} at higher voltages and step down the output. This allows lower coil currents while enabling high output currents at lower voltages. System specifics may impact the decision between LDO and buck (especially near the 15-V V_{out} target value) and should be considered before the design launch, depending on which output type maximizes the efficiency. With the Infineon solution, these tests can be run quickly and easily due to the configurable design concept. With the buck regulator used, the rectifier current can also be estimated by dividing the output current by the ratio of V_{rect}/V_{out}.

Once the Rx side of the system has been estimated, appropriate components can be selected and designed while thermal modeling is conducted. The final components may be determined within a couple of design iterations, and the PCB design may start. Using the determined Rx coil current and

the coupling factor (use of k ≈ 0.65 is good guidance to account for optimal to misaligned charging conditions), Tx coil currents and power calculations may now be estimated (assuming the above coil guidance is utilized) using the ***WLC1150 Design Guide***.[2]

The Tx coil and inverter currents can be determined using the Design Guide and the selected output power and input/output voltages. Also, the Tx coil AC resistance, Tx coil and inverter MOSFET selection may take place to meet efficiency targets. It should be noted that MOSFETs with lower $R_{DS(on)}$ have a higher parasitic capacitance, thus increasing the switching losses. Therefore, simply reducing $R_{DS(on)}$ will not always result in better performance. In general, MOSFETs in the range of 10- to 20-mΩ $R_{DS(on)}$ will have a reasonable balance between switching and conduction losses and are ideal for wireless power systems. For systems with a pre-regulator between the DC input and the inverter (variable voltage or hybrid-variable voltage and variable-frequency systems), the DC/DC regulator needs to be designed to handle wide input-to-output differences to the V_{BRG} range of 4 V to 19 V and be designed to deliver at least 3 A of current. Note that V_{BRG} should be designed to operate from the designated V_{IN} voltage range (typically 12 V to 20 V).

The Tx input power is now easily estimated by dividing the Rx output power by the target system efficiency (90% for Litz wire coils and 85% for PCB wire Rx coils, i.e., dividing by 0.9 or 0.85). Then the BRG power is estimated using the design calculator (or assuming a 4% to 5% loss if using the

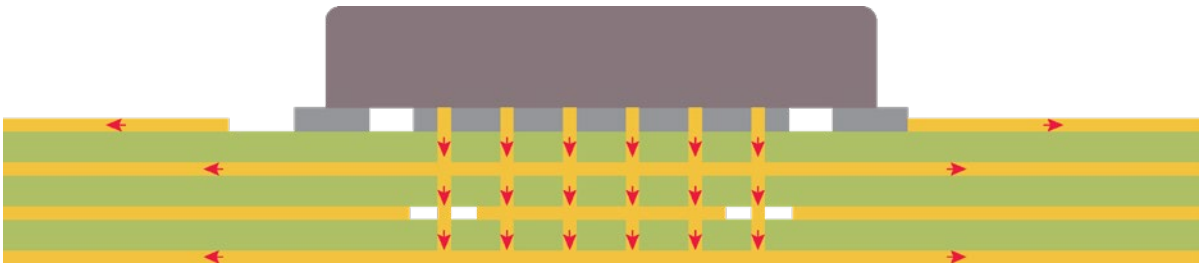


Figure 6: Heat paths from power components into PCB spread on inner and outer layers to reduce operating temperature

WLC1150 to power the inverter). When placing the MOSFETs, multiple layers should be used to connect to the drains and sources. Also, wide copper planes should be used to transfer the heat to the PCB, where it can be spread to reduce the device's operating temperature. The simplified diagram in Figure 6 shows the heat paths created by having solid copper planes connected with multiple vias to inner layers for heat distribution. Outer layers are the most effective, but internal layers should also be utilized whenever possible.

There are also several additions to the typical wireless power system to move from the standard power levels to the high-power realm. These include, but are not limited to, faster FSK patterns to

reduce the communication throughput required for sending messages to the Rx. It is also important to force authentication, or at least a soft credential check using encryption, to avoid the possibility that a counterfeit product can power and charge devices at high power. The primary reason for this is to prevent damaging the high-voltage sensitive electronics and limit the voltages and currents of the inverter and rectifier to safe values.

Improper control of the primary LC tank can lead to excessively high-voltages within the inverter LC tank and on the rectifier. These high-power systems are carefully designed to avoid operating cases where damage may occur. Still, counterfeit solutions may not be so cautious, and this could be destructive if there are sudden coupling improvements or large transient load dumps while the incoming magnetic field strength is too strong for the Rx to handle or is sustained for long periods. These systems are designed to have reactive power clamps to absorb excess incoming energy when needed.

CURRENT TRENDS AND INFINEON'S SOLUTIONS

Aside from being designed to charge at 50 W safely, the Infineon ***WLC1150 Tx*** solution has some differentiating key features to safely provide higher power. These include:

- High-voltage (up to 24 V) with high-side current sensing
- Integrated USB-PD controller
- Direct-voltage control from USB-C PPS adapters
- Integrated gate drivers for full-bridge inverters and DC/DC
- Adaptive FOD algorithms
- Customizable configurations with full-stack software
- Safe magnetic-field operating range based on the output power levels

In addition, Infineon offers the complete solution, including the upcoming WLC1x Rx, which supports either LDO or buck output for post-regulators; thus, the transmitter can be adjusted for cost and power supply type (Figure 7).

High-power wireless systems are very useful for powering and charging larger devices like laptops, vacuums and drones. These designs are perfect for high-humidity environments or where condensation is expected due to the lack of exposed contacts. These designs also reduce ESD-related failures, as the electronics are further isolated from outside environments where static charge is typical.

The high-power solutions are scaled-up versions of the low-power counterparts while still relying on the same design fundamentals. They require attention to the placement and routing of the PCB, particularly the current-loop area of switching regulators. In addition, it is important to use wide copper planes to reduce the I^2R voltage drops in the conduction path and spread heat away from

the power components. Using a robust in-band communication scheme with variable modulation depths based on operating conditions, the system reliably, safely and conveniently transfers high power to any load via the mated Tx and Rx coil pairs.

In industrial settings, these systems are great because they can eliminate the need to have wires and cables present while supporting corrosion-free charging that lasts for years. A high-power design is slightly more complicated and requires the use of higher-current–rated and lower-resistance components to reduce power losses throughout the system. However, they can efficiently be designed by following the recommendations of this article and Infineon's high-quality reference designs and design guidelines.[2]

High-power wireless systems require multiple improvements to maximize performance, but the sequential step from 15 W to 50 W does not result in proportional design time or challenges. The desired increase in power can be achieved with a minor scaling of some key components when utilizing Infineon's high-power solution to deliver the highest wireless power possible in the market today.

Click ***here*** to find out more information and support for our highly integrated wireless charging ICs that offer advanced customizability options to meet industry compliance standards and proprietary requirements.

The WLC1x high-power four-layer Rx PCB will launch soon. Click ***here*** to request engineering samples.

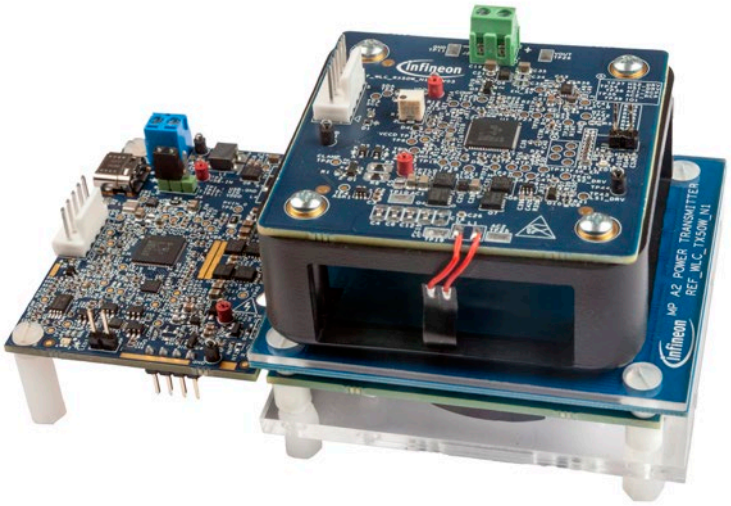


Figure 7: WLC1x high-power solution with MP A2 power transmitter and receiver

References

- [1]**Wireless Power Consortium. "1.3 Qi Specification."**
- [2]**Infineon Technologies. "WLC1150 Design Calculator."**