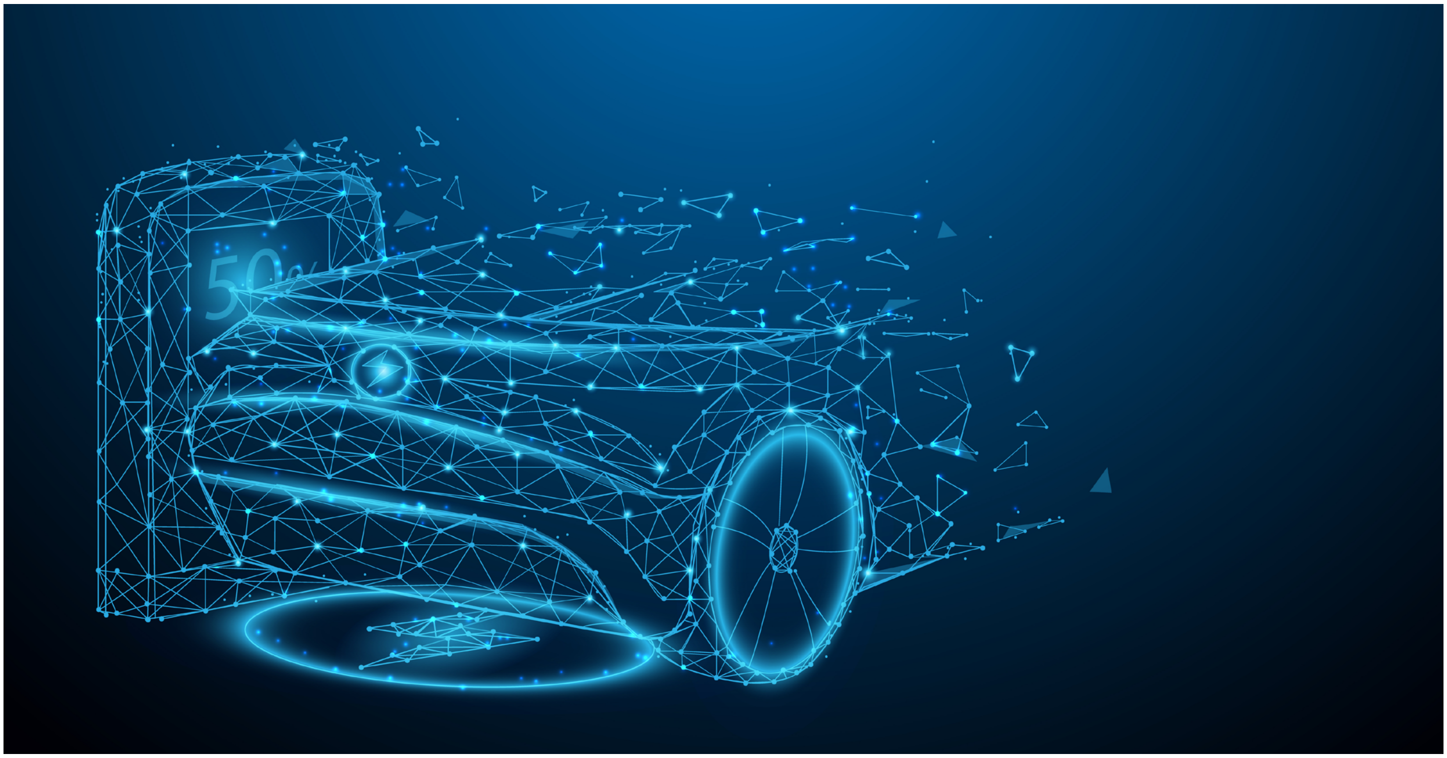
WHITEPAPER

MAKING ELECTRIC VEHICLE WIRELESS CHARGING SYSTEMS A REALITY



As electric vehicle (EV) adoption for both consumer and commercial purposes rapidly grows, so does the need for improved charging infrastructure. In the past several years, the industry has seen vast improvements in charging technology, leading to charging times rapidly decreasing from eight hours for a full charge to less than 30 minutes with newer optimized chargers and vehicles. This huge reduction in charging time is especially impressive considering that vehicle range has also greatly improved at the same time. But as additional regulations on combustion vehicles are implemented and more commercial EVs, including heavy- and light-duty trucks and busses, are introduced, further EV charging innovation is needed.

Currently, wireless charging is the newest EV charging technology evolving. In this white paper, we explore how wireless charging works, identify the challenges presented by wireless charging of EVs both at a system and a component level, and discuss how Knowles Precision Devices' components can help address these challenges so that you can make widespread wireless charging a reality.

Why is Wireless Charging a Good Option for EVs?

With charging times offered by standard plug-in EV chargers rapidly decreasing, you may be wondering, why do we need wireless charging? There are several potential benefits wireless EV charging could offer versus using a wired charging option:

- **Charging Simplicity** – Static wireless charging is essentially a hassle-free charging option. You simply park your vehicle above the charger, and without plugging it in, your vehicle is automatically charging when parked.
- **Reduced Wear** – You no longer have charging cables that wear down over time due to flexing, which could be really beneficial for heavily used public charging stations.
- **Autonomy** – Plugging-in an EV after it self-parks is challenging. Since self-parking technology is becoming more common, Tesla engineers experimented with developing a robot to plug-in the vehicle once it is parked, but quickly realized it was far too complex and expensive to be a viable option.
- **Charging Heavily Used Commercial EVs** – With wireless charging, commercial vehicles do not need to be taken out of service to charge as frequently. For example, taxis could charge while waiting at ranks and delivery vehicles could charge at strategically placed depots.

How Does Wireless EV Charging Work?

In general, inductive charging, which is the type of wireless power transfer used in wireless EV chargers, works by creating a magnetic-resonance field between a transmitting pad on the ground that is physically connected to a power source and a receiving pad on the bottom of the EV that is connected to the vehicle's battery (Figure 1).

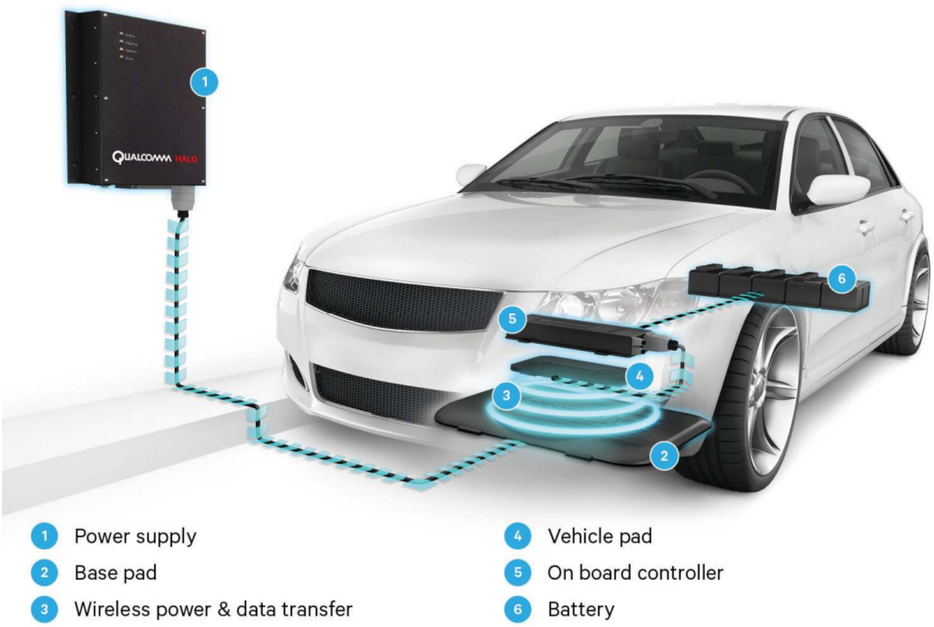


Figure 1 An overview of a wireless charging configuration for an EV. Source.

Today, engineers are working on two different wireless charging methods for EVs – static and dynamic. Static charging occurs when a vehicle is parked, or static, above a wireless charging pad. Dynamic charging involves charging a vehicle while it is in motion. As you can imagine, for dynamic charging to work, a massive amount of charging infrastructure would need to be installed in existing roadways. Therefore, in this whitepaper, we will focus solely on static wireless charging technology.

It is also important to recognize that two different static wireless charging solutions are necessary to meet the needs of all EVs:

- A standard wireless charging set up that is built-in to new EVs
- Wireless charging kits that are affordable and easy to use with existing EVs on the road today

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Whether you are looking to add wireless charging to a new vehicle or developing an aftermarket solution, at a high level, the basic components used for the transmitter, or ground assembly (GA), and receiver, or vehicle assembly (VA), in every wireless charging system is based on the following configuration:

- Transmitter power stages:
  - Mains with an AC power supply of 220V from the AC utility interface
  - High-frequency power inverter
  - Filter
  - Primary LC compensation network
  - Power transfer transmitter coils
- Receiver power stages:
  - Power receiver coils
  - Secondary LC compensation network
  - Filter
  - AC-to-DC rectifier
  - Optional regulator

Communications between the vehicle and energy charging and storage are also required in both the transmitting and receiving stages. A block diagram of a typical wireless charging system is shown in Figure 2.

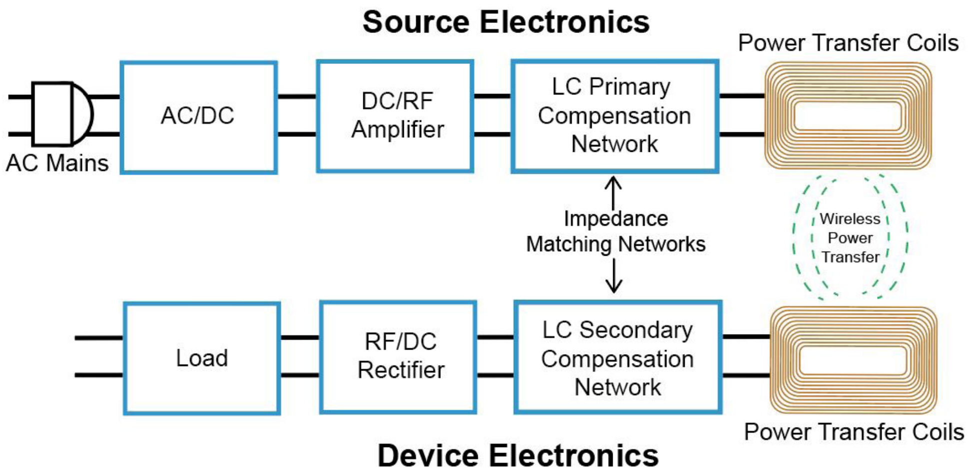

Figure 2 A block diagram of a typical wireless charger setup for EVs that highlights both the source and device electronics.

What are the Main Challenges of Developing Wireless Chargers for EVs?

For consumers to want to replace their standard EV cabled charger with a wireless charger, the wireless charging solution needs to offer clear benefits over cabled charging and must be convenient and easy to use. This is why challenges with interoperability and standardization are some of the biggest hurdles EV and wireless charging manufacturers are currently trying to overcome. While the design of different wireless chargers may vary by manufacturer, just as wired chargers must have the same standard plug configuration to ensure interoperability, the components used within the wireless receiver and transmitter need to have a level of standardization.

As a starting point to address these issues, in 2020 the Society of Automotive Engineers (SAE) announced the first standard for wireless EV chargers – [SAE J2954](). This standard applies to inductive charging systems up to 11 kW and, according to SAE, it *"Defines industry-wide specifications for acceptable criteria for interoperability, electromagnetic compatibility, EMF, minimum performance, safety, and testing for wireless power transfer (WPT) of light-duty plug-in electric vehicles."* In the diagram in Figure 3, you can see how this standard, and other SAE standards, are applicable throughout both the GA and VA.

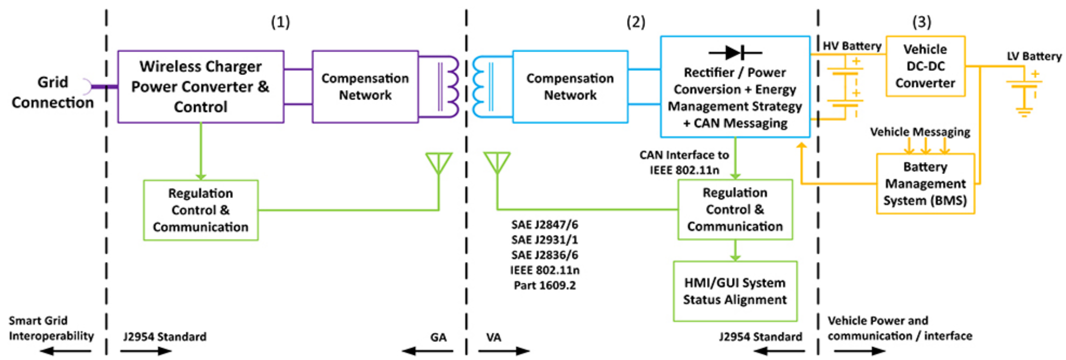

Figure 3 A diagram demonstrating how SAE standards can be incorporated into the GA and VA to help ensure interoperability. [Source.]()

Beyond issues with interoperability, there are several other challenges facing the engineers designing EVs and wireless charging devices for EVs. First, since it is generally challenging to efficiently wirelessly transmit power through an "air gap," alignment between the GA and VA needs to be precise. This means an easy way for the driver to determine if the vehicle is parked in the correct position with the transmitter right below the receiver is required. Similarly, a foreign object/living object detection system also needs to be included – you need to be sure that if your cat is taking a nap on the warm GA, the system does not turn on and cause harm to the animal. Additionally, charging efficiency must be greater than or equal to 85 percent and the cost of wireless charging must remain competitive with the cost of a vehicle with a plug-in charger.

Diving Deeper: Optimizing Wireless Power Transfer Efficiency

To optimize the efficiency of static wireless charging systems, a good place to start is to determine the best topology for the compensation networks required for wireless power transfer between the ground transmitter and the vehicle receiver. A popular trend we have seen in the industry is to use a resonant LC compensation network, which relies on a resonant tank circuit (also known as an LC or tuned circuit).

An LC circuit stores energy and transfers it back and forth repeatedly between the inductor (L), which stores energy in a magnetic field, and a capacitor (C), which stores energy in an electric field. When the two components are working at the same frequency, the resonant frequency, the circuit is considered tuned. For a wireless charging application specifically, the resonant network circulates the electric current and, as a result, the energy is circulated and delivered to the lead through the transformer. The two resonant networks required for a wireless charging application our outlined in the diagram in Figure 4.

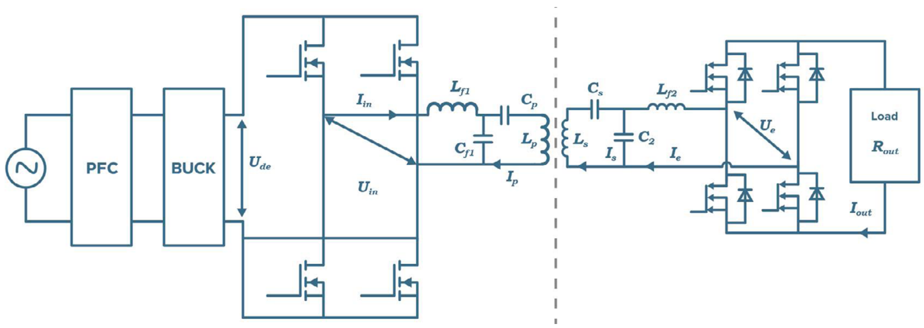

Figure 4 In this diagram, the ground side resonant compensation network is represented by Lf1, Lp, CF1, and Cp while the car side resonant compensation network is represented by Ls, Lf2, Cs, and C2.

Since capacitors are a key part of an LC circuit, is important to choose capacitors that will support an efficient and stable resonant circuit. Let's now explore how to sort through the many capacitor options in the market today to ensure the efficiency and stability of the tuned resonant circuit needed for your LC compensation network.

What You Need from Your Resonant Capacitor, and How Knowles Precisions Devices Delivers

In short, you need resonant capacitors that will ensure the reliability and efficiency of your LC compensation network, which will in turn ensure the reliability and efficiency of your wireless charging application. More specifically, some of the key characteristics you need in the capacitors that will serve as resonant capacitors include stable capacitance and tight tolerances as well as low dissipation to prevent overheating.

While resonant capacitor applications today are mainly dominated by film capacitor technology, at Knowles Precision Devices, we believe that multilayer ceramic capacitors (MLCCs), and particularly MLCCs built with our ceramics, are a much better alternative for several reasons. In general, ceramics offer better stability over film as there is better handling of reflow and there is not any deformation like there is with film.

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Even if the benefits of using ceramic over film are clear to you, it's also important to know that not all ceramics are created equal, which means not all ceramics are a great option for a resonant capacitor. Class 2 dielectrics, such as X7R, are prone to decreases in capacitance with DC voltage as a result of DC bias. Plus, capacitance can change with increased thickness of dielectric layers, causing the capacitance value to behave differently than the expected rated capacitance when certain DC voltages are applied. These issues with instability make it difficult for capacitors designed with X7R to maintain resonance, which means this is not an ideal option for a resonant circuit.

Instead, MLCCs built with our Class 1 C0G dielectrics address these issues with stability and provide many additional advantages over using plastic film, including the following:

- Reduced capacitor footprint
- Low equivalent series resistance (ESR) and equivalent series inductance (ESL)
- Higher maximum operating temperature of 125°C
- Higher dv/dt rates
- Less susceptible to moisture failures

The graph in Figure 5 shows a comparison of temperature stability across a variety of dielectrics.

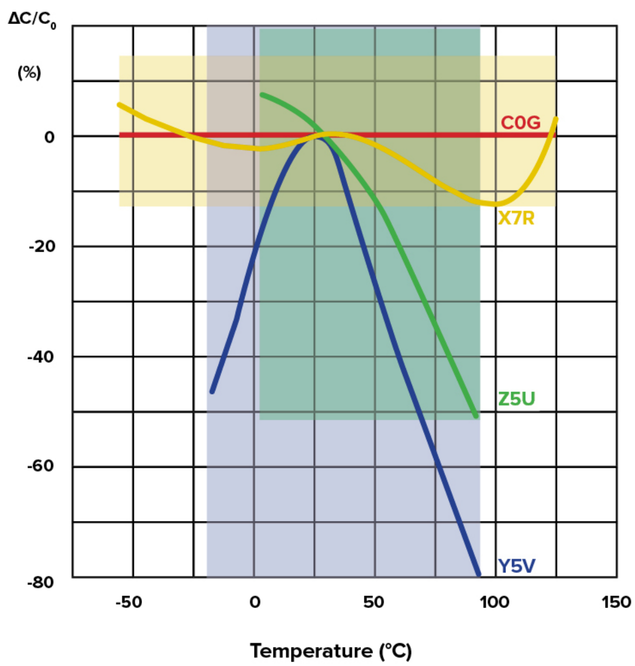

Figure 5 A comparison of temperature stability for a variety of dielectrics.

To further address challenges with heat dissipation that can cause issues with reliability in resonant capacitors, our engineers have developed a strong understanding of the effects of case sizing when considering the AC current that flows through the capacitor, causing it to warm up. Larger case sizes radiate more heat, resulting in better cooling and reduced chance of overheating. Power dissipation can be calculated using the equation $P = I^2R$ and we can select the proper case sizing for optimal power/heat dissipation. Another way we inherently address power dissipation and resulting stability issues is by manufacturing our materials in house, which means we clearly know the ESR of our dielectrics. We are also proficient in using the following techniques when necessary to further reduce the ESR of our MLCCs:

- Using electrodes with small resistivity
- Correctly sizing the metal electrode
- Increasing the number of layers

We have also improved some of the mechanical aspects of our MLCC design to further ensure reliability. With FlexiCap™, our proprietary flexible silver-loaded epoxy polymer that can be applied with the C0G dielectric, we can reduce the mechanical stress exerted on the capacitor by absorbing mechanical strain between the PCB and the ceramic component (Figure 6). A 1,000-cycle temperature test from -55°C to 125°C has shown that MLCCs terminated with FlexiCap can absorb some of the strain created during repeated rapid temperature changes.

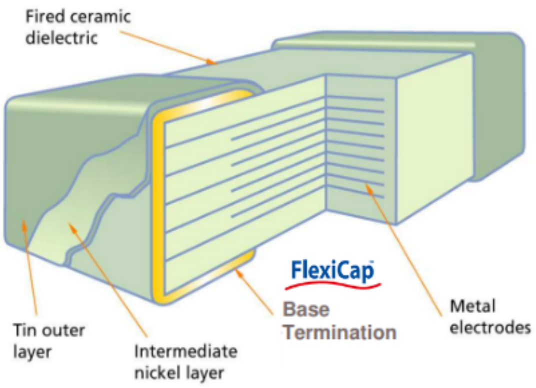

Figure 6 A diagram representing the construction of one of our MLCCs using a FlexiCap termination.

Working with Knowles Precision Devices to Select the Right Components for Wireless Charging

When working with Knowles Precision Devices to select the best option for your wireless charger's resonant capacitor, there are a variety of paths you can take to help you navigate what can sometimes be a complex evaluation process. First, we have a variety of high-performance off-the-shelf MLCC options you can use in the LC compensation network and for other important or specialty capacitors in the nearby circuits. This includes a variety of FlexiCap C0G MLCCs as well as newly developed AEC-Q200-certified MLCCs that can achieve rated voltages of up to 6kV. We also offer MLCC options that have capacitance for high-power devices from >10pF up to ~ 100nF.

Another option is to leverage the expertise of our engineers to perform an evaluation of your full charging solution and develop a best-fit resonant capacitor option. Since we are a leading supplier of EV components and are working in many cutting-edge wireless charging applications already, we have the experience to examine your wireless charging solution as a whole. Taking this approach means we can work together to identify any potential issues that may occur in other parts of your charging application based on the specifications you are looking at for the LC compensation network. Once we evaluate your charging solution wholistically, we can then use our expertise to help you spec and design a unique capacitor that will best meet your application needs.

For example, we can build custom large capacitor assemblies as shown in Figure 7 that utilize the vertical space above the circuit board to offer high capacitance and high voltage in a smaller area.

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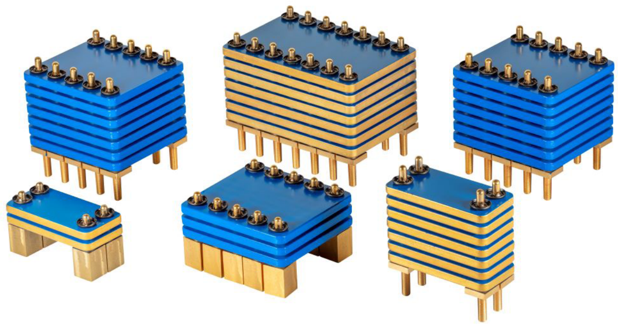

Figure 7 Our large capacitor assemblies are highly customizable both in height and shape and are built with reliability in mind.

Our new large cap assembly design provides all the benefits of using a ceramic capacitor while removing the need to strategically design multiple capacitors in series or in parallel to achieve higher capacitance. Additional benefits of our new cutting-edge large cap assemblies include the following:

- High capacitance ranges of 10nF to 3.9uF, D.F <0.0015, low inductance
- Mechanically decoupled from ceramic elements which provides the ability to withstand severe shock and vibration
- Extremely resilient against temperature variation
- Tested to meet AEC-Q200 requirements including those for bump and vibration
- Customizable in shape and height up to seven layers

At Knowles Precision Devices, we are just starting to scratch the surface of ways to optimize your wireless charging applications for EVs. In the near future, we expect to provide even higher-powered resonant circuit options and we are also working to advance active cooling technology.

Getting started with a wireless charger design for EVs? **Contact us today** to discuss how we can work together to bring stability and reliability to your charging application from the very beginning.