



# Maximizing Power Density with an Innovative 5MHz LLC Transformer Driver

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## Introduction

As the world strives for carbon neutrality, electric vehicles (EVs) are rapidly taking market share from internal combustion engine vehicles. However, one of the issues with electric vehicles is range anxiety, as customers are unsure of how long they will be able to drive without the car needing to be charged. To combat this, governments around the world are massively investing in charging infrastructure.

## Types of Charging Stations

Several types of charging stations are being used today, from Level 1/Level 2 (L1/L2) charging stations to DC fast-charging (DCFC) stations that can provide up to 400kW of power (see Figure 1).



Figure 1: Electric Car Charging Stations

These charging stations are described in greater detail below.

- **L1/L2:** These stations provide AC power to charge an electrical vehicle, and generally take 8+ hours to fully charge an EV. L1 chargers charge at 3kW or less (meaning a car can be charged to drive 2 to 10 miles per hour of charging), while L2 chargers are rated for 3kW to 19kW (10 to 25 miles of range per hour) of AC power.
- **DCFC:** This charging station can charge an EV battery from 20% to 80% within 40 minutes, depending on the power rating (50kW to 400kW) of the charging station itself and the maximum power that the vehicle can be charged at.

When charging at home or at work, L1/L2 stations are sufficient. However, DCFC and supercharger stations are necessary for people who cannot charge over longer periods of time, such as when a driver is on a longer trip where the battery's full capacity is utilized.

Figure 2 shows the different types of connectors that are used globally for both L1/L2 AC charging and DCFC. While DCFC is convenient and quickly replenishes energy, the high charging rate degrades EV batteries more quickly than AC charging. L1/L2 charging utilizes the on-board charger in an EV to convert the AC power into DC power to charge the battery. On the other hand, DCFC stations house all of the power electronics to convert the AC power from the grid into DC power, which can be used to directly charge a vehicle battery.

Note that Tesla uses a proprietary plug for their superchargers in all markets except for Europe, where Tesla also offers CCS2 connectors.

	China	EU and rest of markets	North America South Korea	Japan	All Markets Tesla in EU uses CCS2
<b>AC</b> L1 (120V) Power:1kW-3kW L2 (208V-240V) Power:3kW-19kW					
<b>DC</b> L3/DC Fast Charger 400V-800V Power: 50kW-400kW					

Figure 2: Global Chargers Connectors

Figure 3 shows a typical DC fast-charging station block diagram to convert a 3-phase AC voltage into a 250V to 800V DC voltage to charge electric vehicles. A DCFC station typically contains several of these subunits, each ranging from 30kW to 75kW. This diagram exhibits many of the solutions that can drive DC fast charging stations, including isolated gate drivers, isolated power modules, transformer driver bias, and digital isolator solutions with an integrated power supply.

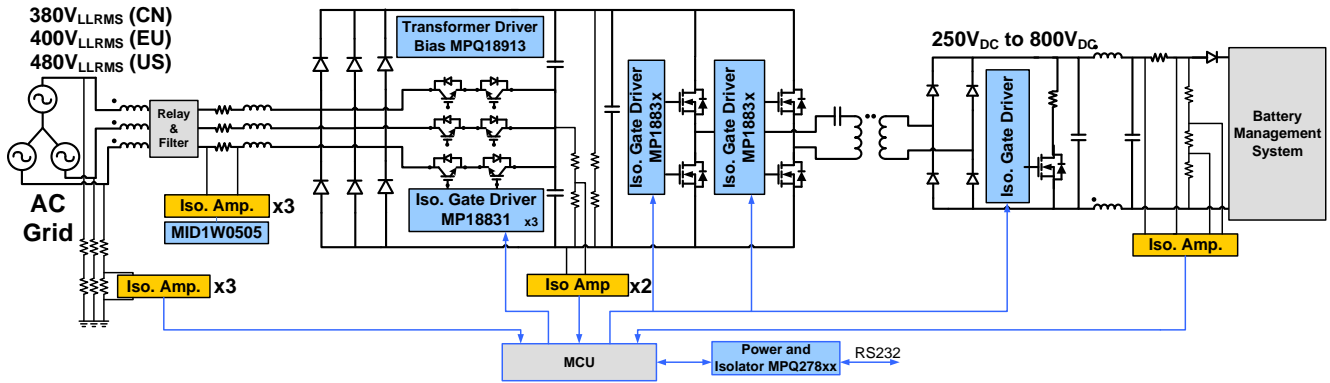


Figure 3: Block Diagram of a DCFC Subunit

Figure 3 shows that the DCFC system is generally comprised of two conversion stages. The first stage is a power factor correction (PFC) stage, which converts the AC voltage from the power grid into an intermediate DC voltage bus between 800V and 1300V. Three-phase, 3-level rectifier/inverter topology is commonly used for the PFC stage. This particular topology refers to a three-level converter that can interface with a 3-phase power grid.

At the second stage (also called the DC/DC stage), an isolated DC/DC converter converts the intermediate DC voltage to the target voltage that is specific to the battery being charged. LLC and phase-shift full-bridge converters are common topology choices for the DC/DC stage.

Some of the challenges for designing high-power charging stations are maximizing power density, reducing cost, and reducing size. One industry-wide method to increase efficiency is to replace

semiconductor MOSFETs/IGBTs with silicon carbide (SiC) FETs. This is particularly important since DCFC stations have increased in power from 50kW to more than 400kW.

Due to the high-voltage and high-power nature of DCFC systems, isolated devices are required to protect users and low-voltage control circuitry from the potential hazards and disturbances that could originate from the high-voltage power conversion circuits. Additional components can be implemented to reduce the risk of hazards:

- Isolated gate drivers for SiC MOSFETs and IGBTs, such as the [MP18831](#) and [MP18851](#)
- Digital signal isolators, such as the [MPQ27811](#) and [MP27631](#)
- Isolated current-sensing and voltage-sensing devices, such as the [MCS1806](#) and [MCS1803](#)

Note that isolated gate drivers require an isolated bias supply for power, and that the gate drive power supplies must be able to withstand high isolation voltages. At minimum, the gate driver power supplies must be able to withstand the intermediate DC bus voltage, and must offer low isolation capacitance to minimize disturbances from the high-voltage side to the low-voltage side.

### Designing an Isolated Power Supply for Gate Drivers

The [MPQ18913](#) is a transformer driver for isolated bias supplies. This device can work with SiC FETs as an isolated bias for SiC gate drivers. Flyback topology is often used for isolated power supplies to provide an isolated 18V/-4V output that drives the SiC FET. Figure 4 shows a typical application circuit implemented with the MPQ18913 to achieve a 18V/-4V output. The number of outputs can be configured based on the transformer used and the output voltage can be altered via the turns ratio.

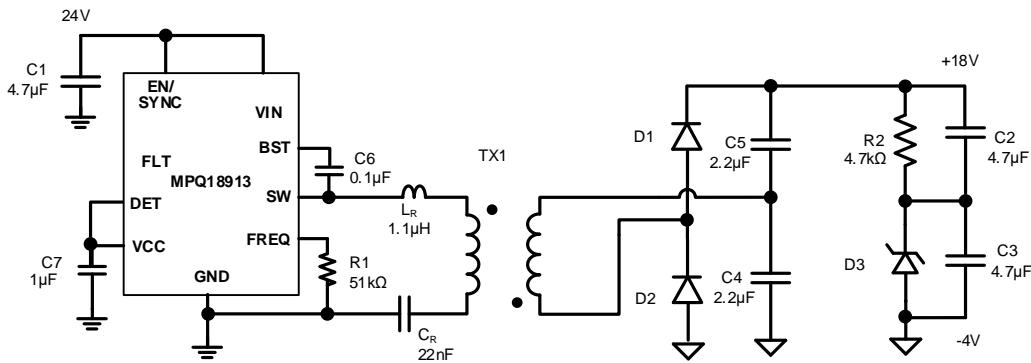


Figure 4: MPQ18913 Application Circuit

The [MPQ18913](#) can be used as an LLC converter, which is the most efficient topology for isolated gate drive power supplies (see Figure 5). These converters use a resonant LLC tank, which has a magnetizing inductor for energy transfer, as well as an additional capacitor and inductor that make the tank resonate at a certain frequency. The converter uses this resonance to achieve soft switching and ensure highly efficient power conversion. The main benefit of LLC converters is that the leakage inductance created by the transformer can be used as the resonant inductor in the tank. This eliminates the voltage spike induced by the leakage inductance, and improves efficiency compared to flyback topologies.

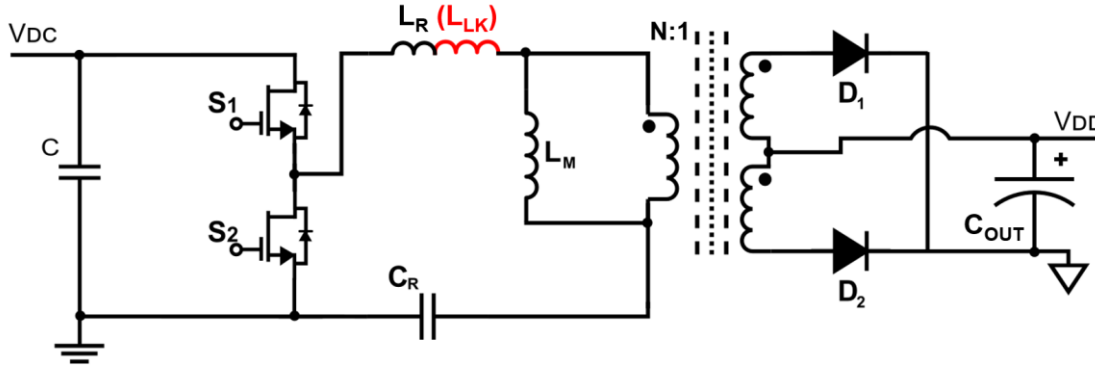


Figure 5: LLC Topology

Using the [MPQ18913](#) as an example, the LLC resonant topology offers several notable advantages compared to a typical PSR flyback topology. One such advantage is that LLC resonant topology reduces the solution size due to the switching frequency ( $f_{sw}$ ), which can reach up to 10MHz, whereas with flyback topology,  $f_{sw}$  stays below 400kHz. This results in a total solution size that is 40% smaller than a flyback application using a similar power level. Another major advantage of LLC resonant topologies is the fact that the isolation voltage can easily reach up to 5kV. Traditional flyback solutions only reach 1.5kV, therefore meeting more stringent isolation voltage requirements.

Table 1 compares LLC resonant topology to flyback topology.

Table 1: LLC Resonant Topology vs. Flyback Topology

Parameter	LLC Resonant Topology	PSR Flyback Topology	Benefit
Switching frequency ( $f_{sw}$ )	High (up to 10MHz)	Low (<400kHz)	High frequency enables much smaller solution size
Transformer size	13 $\mu$ H (11mmx6mm)	30 $\mu$ H (10mmx10mm)	
Leakage inductance	Utilizes leakage inductance as part of the resonant tank	Leakage inductance reduces performance	In LLC, leakage inductance enables higher efficiency and prevents voltage spikes
Isolation voltage	High (up to 5kV)	Low (1.5kV)	LLC enables higher isolation voltage to increase safety
Isolation capacitance	Low (6pF)	High (Up to 25pF)	Up to 40% reduction in solution size and 20% fewer component count
Package size	2mmx2.5mm	4mmx4mm	
Diodes (including Zener diode)	3	6	
Solution size	109mm <sup>2</sup>	180mm <sup>2</sup>	
BOM components	21 components	26 components	

### Conclusion

High-frequency LLC power supplies are typically more difficult to implement and optimize in designs than low-frequency converters, but devices like the [MPQ18913](#) simplify LLC power supplies with features including automatic resonant frequency detection and integrated transistors. In addition, LLC resonant topologies reduce solution size, which increases power density for high-power charging stations such as those used for charging electric vehicles. As electric charging infrastructure continues to improve, look out for the MPQ18913 being used to bias SiC FETs in high-power charging applications, as well as automotive applications such as on-board chargers, traction inverters, and DC/DC converters.