System Solution Guide

On Board Charger (OBC)

Updated: MAR-2024

Industry	• Automotive – Vehicle Electrification
Applications	• On Board Charger (OBC) is used to charge the high voltage battery pack of Battery Electric Vehicles (BEV) and Plugin Hybrid Electric Vehicles (PHEV). It is integrated directly into the vehicle's design and enables the conversion of AC power from the grid into DC power suitable for the vehicle's battery pack. This technology allows EV owners to conveniently recharge their vehicles at home or at public charging stations. • In China the term New Energy Vehicle (NEV) is used to encompass BEV, PHEV and Fuel Cell Electric Vehicles (FCEV), which use electric motor but rely on hydrogen fuel cells instead of a large battery. FCEV may incorporate a low power OBC, but it is not a standard.

System Purpose

Development and integration of OBC continues to scale up as tougher CO2 emission standards accelerate the development of EVs. Given the charging landscape with an insufficient number of fast Level-3 DC charging stations worldwide, the OBC is not going away any time soon.

The OBC unit enables charging from the AC grid when the vehicle is parked and connected to a supporting Level-1 or Level-2 charging station or connected to a wall outlet using an approved charging cable. Major stream is “Level-2 OBC”, 7KW – 22KW range of charging power.

PHEVs and BEVs are a step up from Mild Hybrid Electric Vehicles (MHEVs). These vehicles require a high voltage battery system as well as the supporting modules to operate it, including OBCs. PHEVs reduce the average CO2 emissions from vehicles while BEVs have no CO2 emissions from the vehicle. Consumer expectations for vehicle performance can be maintained across these vehicle types except for range anxiety for BEVs. Work is ongoing worldwide to address these concerns.

System Implementations

Table 1 : Comparison between PHEV and BEV, the two most common electric vehicles to use an OBC.

Plugin Hybrid Electric Vehicle (PHEV)	Battery Electric Vehicle (BEV)
• OBC is lower power and lower cost due to lower power levels and battery capacity. • 1 phase AC: 3.3kW, 6.6kW or 7.2kW power rating. • Note that in many countries a maximum of 3.7kW – 4.2kW per phase will limit this. • Can be plugged in almost anywhere at lower power levels (1.4kW – 1.8kW). • Increased power levels may be implemented to allow for faster charging. • Reduced emissions based on emission profile.	• Higher cost OBC due to higher power levels and more complexity. • 1 phase AC: 6.6kW or 7.2kW power rating. • 3 phase AC: 11kW up to 22kW for higher end BEVs. Trending towards higher power tiers to reduce charging time. • Higher power tiers may require utility upgrades in certain countries. • Note that in many countries a maximum of 3.7kW – 4.2kW per phase will limit this. • Can be plugged in almost anywhere at lower power levels (1.4kW – 1.8kW), but not preferred. • DC fast charge bypass option. • No emissions.

System Description

PHEVs and BEVs contain a module used for charging the high voltage battery pack known as the **On Board Charger (OBC). The main function of the OBC is to convert an input grid AC voltage to an output DC voltage** with the appropriate output current and voltage level for the battery pack to charge. AC input is usually 1 phase for low power OBC and 3 phase for higher power OBC. Additionally, it must perform this charging function **while implementing Power Factor Correction (PFC)** which aligns the voltage and current phases to minimize impact to the AC grid. FCEVs can have a low power OBC to charge their battery, but it is not a standard.

- It must be considered during the design phase of OBC what is the target power level in kW (peak & continuous), Input voltage range, number of AC phases and overall efficiency.
- For all power stages (PFC, Primary and Secondary DCDC), the correct topology must be considered in terms of efficiency and total cost. Also, for individual stages, the option of analog controller IC or a digital control solution with the appropriate switching frequencies must be selected.
- Since most EVs can be charged **using a DC fast charger, the OBC provides a bypass functionality** to charge DC battery directly as there is no need for AC/DC conversion.

As the name suggests these “On Board” Charger modules are located on the vehicle and due to the power levels will have air or liquid cooling to help with thermal management. Depending on the architecture, the OBC output may need to operate down to less than 250VDC and operate as high as 850VDC when charging the main vehicle battery pack. Space constraints relate to power density targets and necessary isolation at the board level. Isolation could apply to communication, feedback signals and gate drivers.

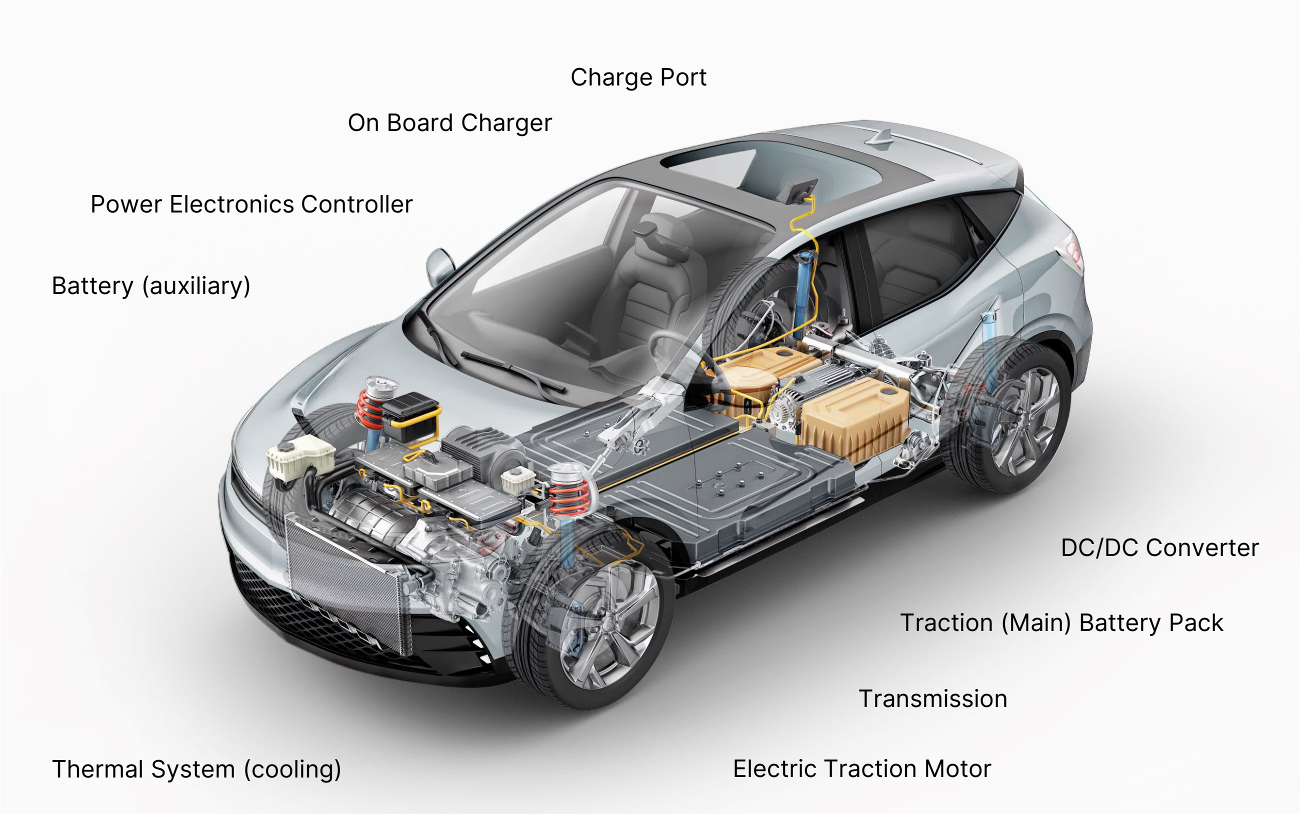


Figure 1: Systems overview of an Electric Vehicle.

Market Information and Trends

OBC is migrating to higher power tiers and higher voltages

OBC designs today support a variety of voltages and power tiers, but the designs are evolving towards higher power tiers and higher voltages, along with the evolution of the electrical power train. A need to support powers of 11kW to 22kW while also supporting higher battery voltages up to 800V is underway.

- **onsemi**, as proven supplier of power modules into high power automotive applications is ready for 800V battery systems transition thanks to its 1200V SiC MOSFETs and APMs. With among the highest power density with the Automotive Power Module (APM) technology, supplying modules to Tier 1 and OEM customers for 10+ years.
- Electrification is spreading to buses, vans, Heavy-Duty & Agriculture vehicles and ships. These **emerging markets** push OBC development into further higher power tiers, typically above 22kW. APM32 SiC modules can provide here an efficient solution.
- **onsemi** gate drivers pair very well with its power stage solutions, exhibiting great noise immunity and efficiency at Miller Plateau. Isolated gate driver portfolio has grown with more options for high power SiC MOSFETs and continuing coverage for Si MOSFETs and IGBTs.

While many OBC implementations are unidirectional (grid to vehicle), **there is a gradual adoption of bidirectional capability, allowing both grid to vehicle and vehicle to grid charging with BEVs**. Topologies of individual power stages must be adapted to allow bidirectional capability. This makes most sense for BEVs where battery energy capacity is much higher than in PHEVs.

The importance of an OBC can be explained by looking at the existing charging infrastructure. There are three classifications or “levels” of chargers for a battery electric vehicles.

- Level 3 DC chargers provide very fast charge times, but it is an expensive solution. Ideal for highway and heavy commercial installations. Far fewer installations exist compared to level 2.
- Level 2 chargers are an interface between a higher power AC source and the EV’s OBC. Very cost-effective solution for light commercial and small business installations. Rapidly growing capacity segment which relies on the cars installed OBC.
- Level 1 chargers are little more than a plug interface between a 15A-20A outlet and the EV’s OBC. Allows charging at home (overnight charging) or from any outlet, but at an impractically slow rate.

Table 2 : The 3 levels of EV charging stations, approximate numbers for US as of 2023.

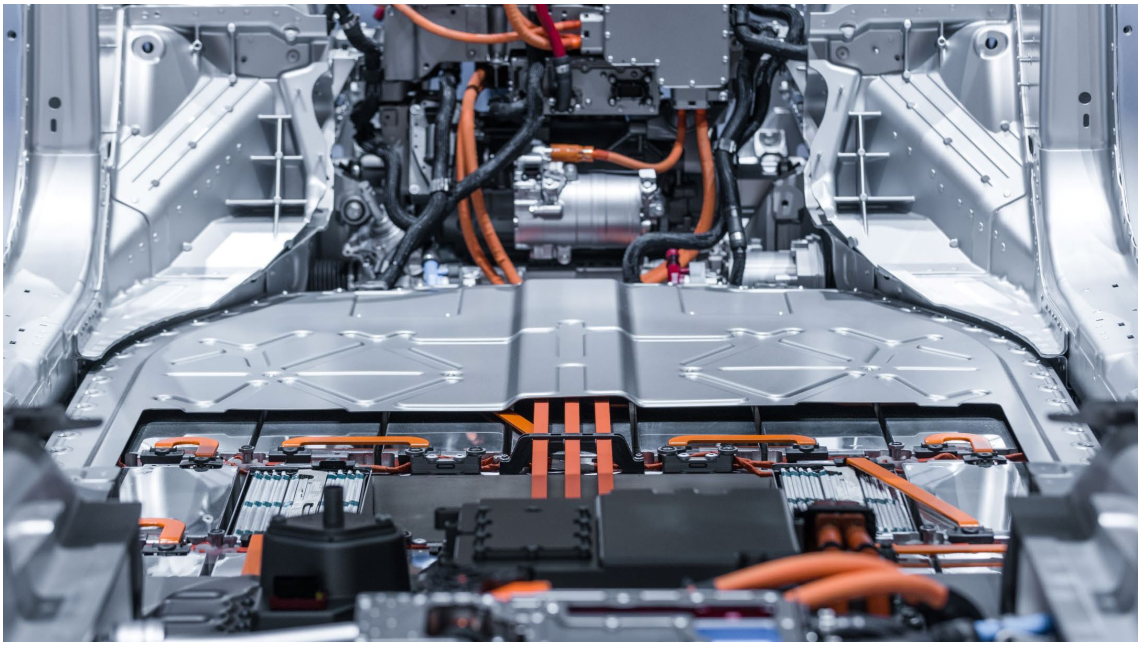
Charger Type	Typical Power	Output	Notes	# in US
Level 1	1.2 kW	AC	• Charges battery via OBC • Charge time limited by wall outlet max power.	1 per BEV
Level 2	3 kW to 19kW	AC	• Charges battery via OBC • Charge time may be limited by charger output or OBC power capacity	>130 000 (rapid growth)
Level 3	50 kW to 350+ kW	DC	• Bypasses OBC and directly charges DC battery • Charge time limited by charger output or battery limitations	>35 000 superchargers

System Description

Standards and compliance

Compliance with ISO26262, an international functional safety standard, is essential for the development of electrical and electronic systems in road vehicles. Its primary goal is to minimize the risk of hazards caused by system failures in vehicles, addressing potential dangers such as software glitches, sensor errors, and hardware malfunctions. It provides an automotive-specific approach for determining risk classes known as ASILs, which can vary based on customers and worldwide regions. (ASIL QM,A,B,C,D) Requirements can go as high as ASIL-D. The standard also defines guidelines to minimize the risk of accidents and ensure that automotive components perform their intended functions.

- **onsemi**, with its long history as a leading provider of automotive products, understands the challenge to reduce costs, combined with increasing demands on performance and safety. Expertise and Implementation of ISO 26262 at onsemi is a key in providing cost effective solutions to customers, without compromising on safety.
- It enables the company to offer optimal architectures and solutions by identifying safety requirements assigned to integrated circuits and other automotive components. Focusing on the important failure modes and their prevention.



- Since the deployment of ISO 26262, **onsemi** has developed and introduced ASICs and standard products with safety requirements ranging from ASIL A to ASIL D.
- **onsemi** is a member of the ISO 26262 workgroup and the semiconductor sub-workgroup.
- All **onsemi** automotive design centers have been trained on Functional Safety (FuSa) and ISO 26262. **onsemi** has integrated the requirements of ISO 26262 into its Quality Management System, and a dedicated organization has been put in place to manage functional safety within the company.

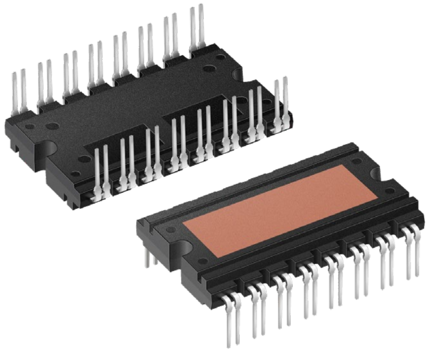
Solution Overview

Automotive Power Modules APM32 for OBC

The **APM32 (Automotive Power Module) family** is equipped to handle 800V battery systems and high power OBC by integrating 1200V Silicon Carbide (SiC) devices. **EliteSiC** is the brand name of onsemi's SiC technology. APM32 offers various solutions for the PFC stage, primary side DC-DC stage, and secondary rectification side.

For the PFC Stage, 3 Phase Bridge modules like NVXK2VR40WXT2, which feature 1200V 40 mΩ SiC MOSFETs are a great option. Full Bridge and Dual Half Bridge modules are also suitable for the DC-DC stage, with 1200V 40 mΩ SiC MOSFETs mounted on different substrates. Introduction to onsemi 1200V SiC MOSFET Modules for OBC Application Note offers detailed information about the modules and their benefits in terms of electrical and thermal performance, as well as power density. APM32 designs can use onsemi isolated gate drivers and current sense amplifiers to complete the OBC power conversion solutions.

- The APM32 module technology offers several advantages over discrete solutions, including a reduced form factor, improved thermal design, lower stray inductance, lower internal bond resistance, increased current capability, improved EMC performance, and increased reliability.
- These power modules comply with IEC-60664-1 and IEC60950-1 for creepage and clearance and are automotive qualified under AEC-Q101 and AQG-324.
- APM packaging technology is designed and manufactured internally, which allows for greater control over thermal optimization. This is in contrast to some competitors who outsource their manufacturing process.



APM32 Package: 44.00 x 28.80 x 5.70 [mm]

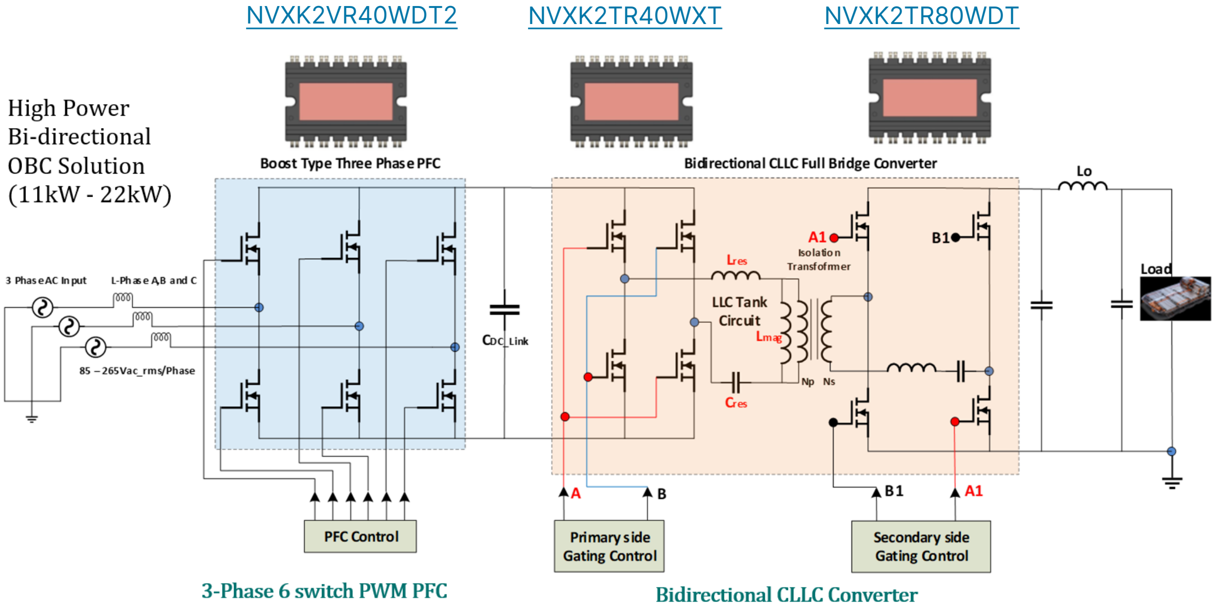


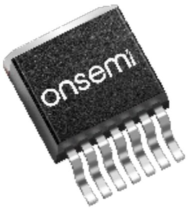
Figure 2: OBC Power Stage design with APM32 1200V EliteSiC power modules.

Solution Overview

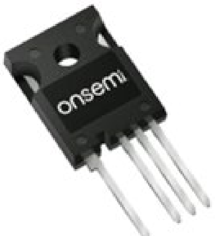
SiC-based OBC design with onsemi's EliteSiC technology

As the trend in electric vehicle OBC design moves rapidly to higher power and higher switching frequency operation, the demand for SiC MOSFETs for this application is also growing. **EliteSiC** is the brand name of onsemi's SiC technology. Designers are adopting the Bridgeless PFC topology using the EliteSiC MOSFET due to its superior switching performance and small reverse recovery characteristics. The 1200V EliteSiC MOSFETs are extensively utilized in 800V battery automotive architecture.

- The planar design ensures no drift in $R_{DS(ON)}$, $V_{GS(TH)}$, or body diode voltage drop over their lifetime, and they can operate with negative gate drive voltages.
- The recommended on−state gate voltage for these MOSFETs is 18 V, but they can still work down to 15 V to remain compatible with gate drive circuitry designed for older generation SiC MOSFETs.



D2PAK-7L



TO-247-4L

The onsemi M3S is the second generation of 1200V EliteSiC MOSFETs. It focuses on improving switching performance while reducing specific resistance R_{SP}. The M3S strikes an excellent balance between conduction and switching losses, making it ideal for hard−switching applications like PFC. Additionally, M3S low $R_{DS(ON)}$ values position them as strong contenders for soft−switching applications (such as LLC, CLLC, Phase Shifted Full Bridge), where switching losses are significantly reduced by virtue of the circuit topology, so that conduction losses become the dominant loss component. In-depth comparison of M1 and M3S SiC MOSFET generations is explored in the AND90204 Application Note. (Requires webpage login to open)

The M3S require less total gate charge $Q_{G(TOT)}$ than the 1st generation named M1, which significantly reduces the amount of sinking and sourcing current from gate drivers, as shown in Figure 3. M3S further reduces FOM (Figure of Merit) factor in $R_{DS(ON)}$ * $Q_{G(TOT)}$ by 44% compared to its older M1 counterpart.

Figure 4. shows the improved switching performance of M3S at the given conditions, with 40% lower E_{OFF}, 20−30% lower E_{ON}, and 34% lower total switching loss than M1. In high switching frequency applications, it will cancel any disadvantage of potentially higher $R_{DS(ON)}$.

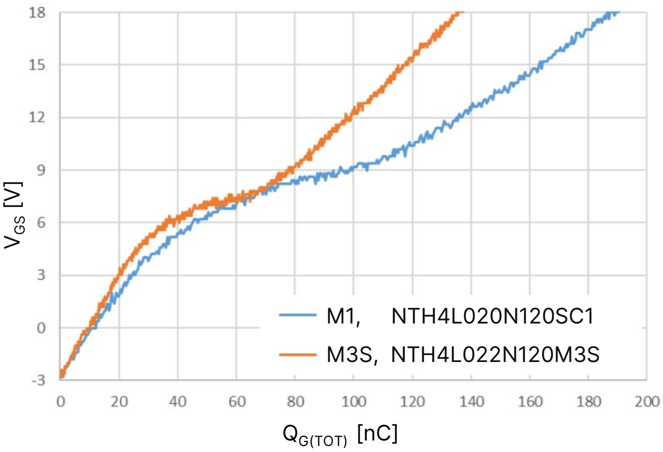


Figure 3: Total Gate Charge $Q_{G(TOT)}$ [nC] @ 800V / 40A, driven by constant 10mA

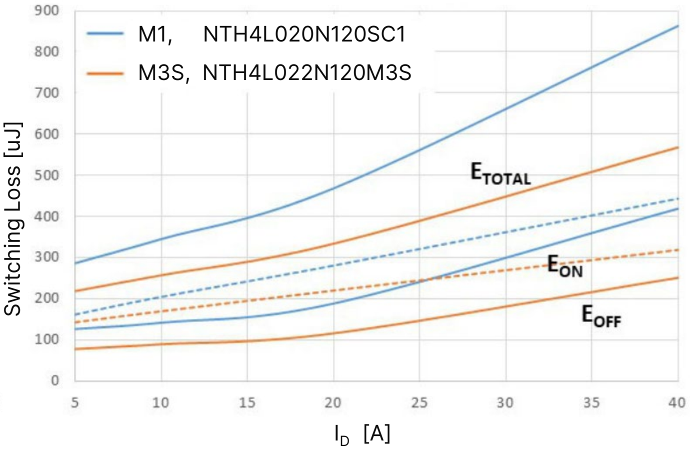


Figure 4: Switching Losses by drain current I_D [A] @ V_{DS} = 800V, V_{GS} = -3V / 18V, R_G = 4.7 mΩ

SiC MOSFETs vs Si SJ MOSFETs vs IGBTs

SiC MOSFETs are recommended for use in PFC, primary side DC-DC, and secondary side rectification (bidirectional) in **800V battery systems** due to their high efficiency and power density compared to IGBTs or Si SJ MOSFETs**.** In some designs, a hybrid solution may be used where some power stages of the OBC utilize IGBTs or Si SJ MOSFETs. Explore the app. note and competitive comparison in EliteSiC M3S Technology for High-Speed Switching Applications [TND6429/D]. **EliteSiC** is the brand name of onsemi's SiC technology.

When designing 400V battery systems, using 650V SiC MOSFETs in traditional boost or interleaved boost topologies can improve efficiency in power density and thermal performance. It is recommended to use SiC MOSFET technology for any battery voltage when utilizing Totem Pole PFC.

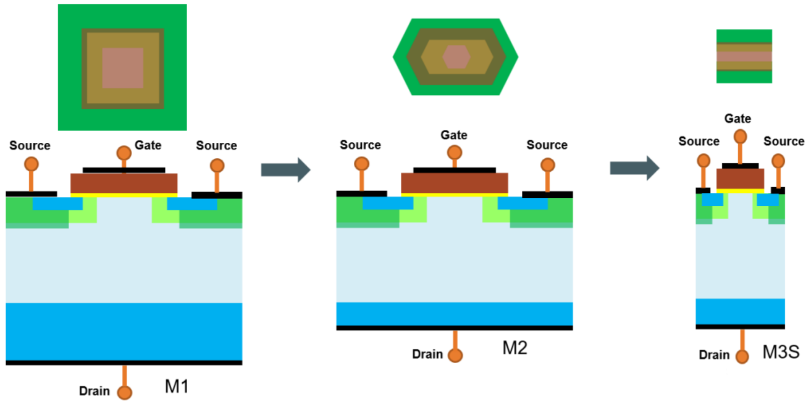


Figure 5: Technology Evolution of onsemi EliteSiC MOSFETs

- **Left – M1 Technology**
  Planar Square Cell
- **Center – M2 Technology**
  Planar Elongated Hex Cell,
  Thin Wafer Technology
- **Right – M3S Technology**
  Planar Stripe Cell,
  Thin Wafer Technology
  Significant unit cell reduction

Si SJ MOSFETs are suitable for use in 400V battery systems for PFC and DC-DC stage. They work well in traditional boost, bridgeless boost, and Vienna rectifier designs for PFC. However, they are not recommended for use in Totem Pole PFC due to the reverse recovery losses of the body diode and the inability to function in Continuous Conduction Mode. Si SJ MOSFETs offer higher efficiency and switching speeds than IGBTs.

IGBTs are suitable for most PFC topologies and DC-DC stage. IGBTs do not have an internal body diode and the packaging must include a diode internally or an external diode must be added in parallel. A hybrid IGBT includes a SiC diode in the package. IGBTs can be used also in the low-speed leg of Totem Pole PFC even when MOSFETs are used for the high-speed leg. IGBTs are suitable for lower power tier designs when component cost is a factor for DC-DC stage. The slower switching speeds and lower efficiencies will have to be considered acceptable for the design when compared to Si SJ MOSFETs or SiC MOSFETs.

Table 3 : onsemi power components suitable for PFC and DC-DC Stage of On Board Charger

800V Battery Architecture		400V Battery Architecture	
Product Family	**Product Example**	**Product Family**	**Product Example**
APM32 SiC Modules	NVXK2VR40WXT2	APM16 Si Modules	FAM65HR51XS1/2
1200V M3S SiC MOSFET	NVBG030N120M3S	650V M2 SiC MOSFET	NVH4L025N065SC1
1200V M1 SiC MOSFET	NVHL040N120SC1	650V Si SJ MOSFET	NVH040N65S3F
1200 V SiC Schottky Diode	NVDSH50120C	650V IGBT	AFGHL75T65SQDC
		650V SiC Schottky Diode	FFSH2065B-F085

Solution Overview

Isolated Gate Drivers for OBC with SiC MOSFETs

As SiC MOSFETs are increasingly used in automotive power electronics applications, it has become necessary to use special drivers. Isolated gate drivers are designed to meet the highest switching speeds and system size constraints required by SiC technologies, by providing reliable control of MOSFETs and also IGBTs. It is critical to optimize the gate drive voltage for speed to minimize switching losses and take full advantage of the power switching devices.

The challenge of SiC MOSFETs compared to Si MOSFETs is the control of the gate threshold voltage. SiC MOSFETs have a greater dependence on the gate voltage at the recommended gate drive voltage than Si devices. SiC MOSFETs require a higher positive gate drive voltage (+20 V) and, depending on the application, a negative OFF gate voltage in the range of −2 V to −6 V, as they exhibit a lower V_{GS} threshold that could lead to unwanted turn−on of the SiC MOSFET. Follow onsemi's guideline for using an isolated gate driver to efficiently drive SiC MOSFETs in **Application Note AND90063/D**.

onsemi has several isolated gate drivers available for SiC MOSFETs and Si Power MOSFETs, as well as IGBT gate drivers. Galvanic isolation component roadmap will further improve propagation delay and higher CMTI with new features. Broad portfolio of gate driver evaluation boards enables rapid prototyping.

NCV51561 and NCV51563 Isolated Dual Channel Gate Drivers

The NCV51561 and NCV51563 are isolated dual channel gate drivers with 4.5A/9A Source/Sink peak current. They are designed to drive Si and SiC power MOSFETs. They offer short and matched propagation delays. Try the NCV51561 Evaluation Board and test your isolated gate driver application.

- NCV51561 or NCV51563 can be used in any possible configurations of two low-side, two high-side switches or a half−bridge driver (Figure 6.) with programmable dead time
- Typical 36 ns propagation delay with 5ns max delay matching , Independent UVLO Protection
- Single or Dual Input Modes via ANB, 5 kV galvanic isolation allows peak voltage of up to 1500 (1850) V_{DC}
- CMTI ≥ 200 kV/µs , SOIC-16WB with 8mm creepage distance

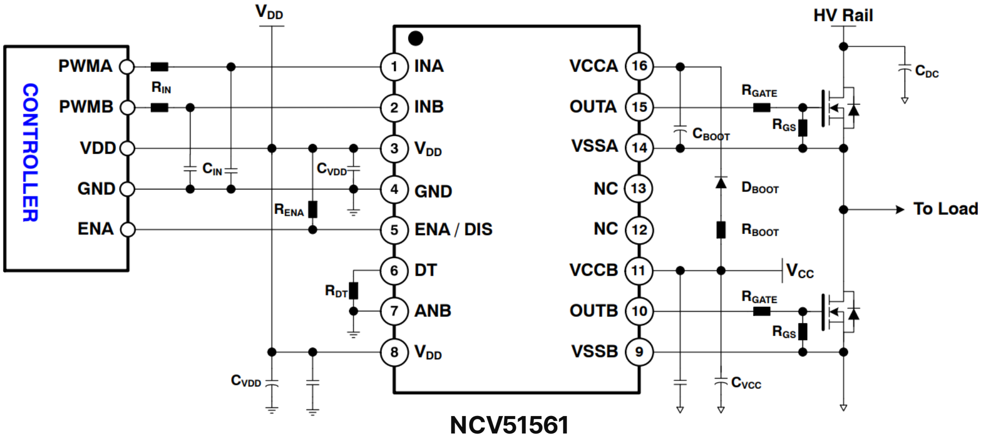
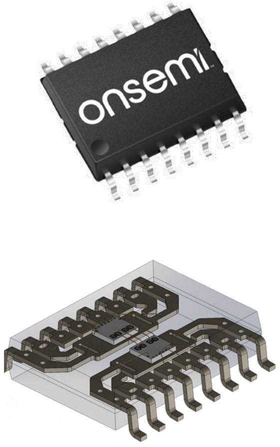


Figure 6: Typical Application Circuit with the NCV51561 or NCV51563.



Look inside the SOIC-16 package of the NCV51561.

Solution Overview

Digital Isolators

Digital isolators are employed in automotive applications thanks to their stability over temperature and time. NCIV9211 , NCIV9311, NCIV9401 are series of high speed, bi-directional ceramic Digital isolators with 2/3/4 channels. They utilize **onsemi's patented galvanic off–chip capacitor isolation technology** and optimized IC design to achieve high 2kV insulation and noise immunity. Off–chip ceramic capacitors serve both as the isolation barrier and as transmission medium for signal switching using On–Off keying (OOK) technique.

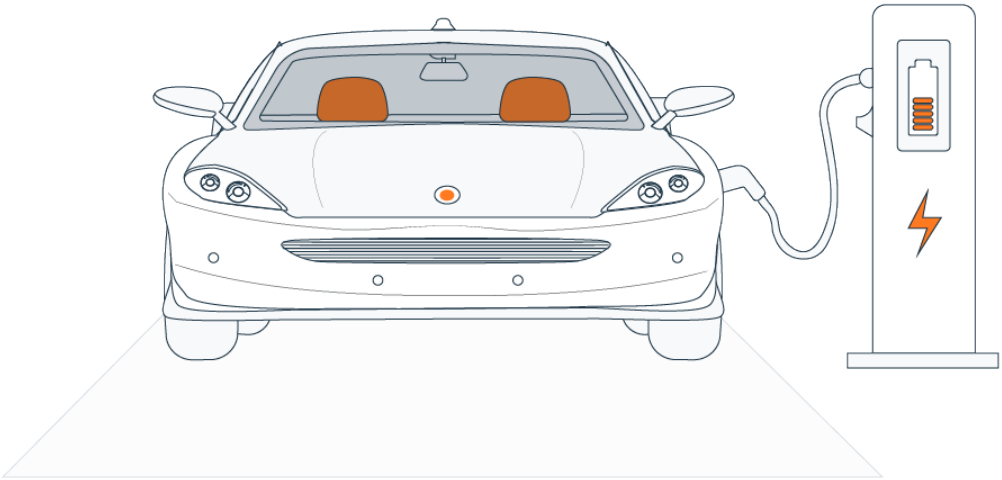
Typical Applications for Isolation: PWM Control, MCU interface, Programmable Logic Control, Data Acquisition System, Voltage Level Translation.

Power Tree

Isolated auxiliary power supply in the form of a flyback DC-DC topology can be used to isolate power planes with the NCV1362 or NCV12711 controllers which can then feed an SBC or discrete LDO power ICs. NCV1362 based flyback application can supply from few watts up to 50W output power.

System-Basis-Chips (SBC) are optimized based on customer requests and can match customer needs for communication, power, specific features etc. Customers can also choose from list of standardized SBC adapted for popular applications. SBC like the NCV7471C or NCV7450 combine the functionalities of system power sequencing, communication bus interface requirements as well as a built-in DC-DC converter supplying the 5V rail.

Additional rails can be generated using LDOs such as the NCV8170 , NCV8164 or NCV59801. For further noise enhancements related to the gate drivers the NCV3064 controller can be used to generate isolated rails for the required switching technology. onsemi offers a wide LDO portfolio with very low RMS noise down to 4.4uVrms, excellent PSRR greater than 90dB, very low Iq and 150°C junction rating. Pin to pin compatible devices. Power Good (PG) pin.



Solution Overview

Analog Signal Chain

NCV21911 or NCV20071 op-amps can be used for voltage measurements while **NCV21xR** current sense amplifiers can be used for low side current sensing in HV applications. For low side sensing applications, the common-mode range of -0.3V to +26V is acceptable. For more tolerance on the negative voltage side of the range the NCV7041 family should be considered with the common-mode input range of -5.0V to +80V (gain options of 14, 20, 50 and 100).

NCV225x comparators along with the NVT211 temperature sensor and NCV431 shunt voltage reference allow for monitoring a variety of system information with high accuracy. Make sure to choose amplifiers with right bandwidth, offset and desired drift.

IVN & CAN ESD Protection

onsemi develops CAN, CAN-FD and LIN devices from day 0 for automotive customers. These products are qualified at all the major automotive OEMs and offering a full portfolio addressing LIN, CAN, CAN-FD and FlexRay.

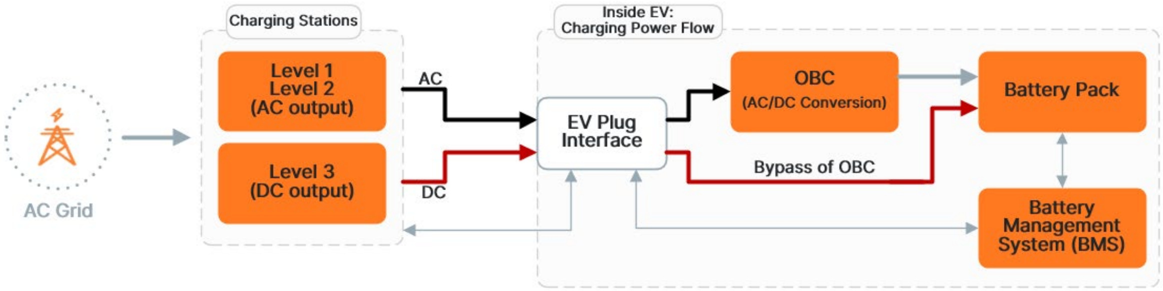
- Options for both **CAN** and **CAN-FD** transceivers like NCV7343 , NCV7446 (NCV734x line) are available along with LIN transceivers like NCV7329 and NCV7422.
- Communication interface lines should have ESD protection from transient events by incorporating devices such as the SZNUP3125 and SZESD8704**.**

Mechanical and Thermal Considerations

Mechanical packaging constraints may affect electrical component choices for height, mass etc. Thermal management should be addressed also on system level whether to use air or liquid cooling. It is important to consider choice of materials and component packaging to assist with thermal management. Learn more about thermal performance and mechanical considerations with SiC APM modules in Application Note AND90017/D.

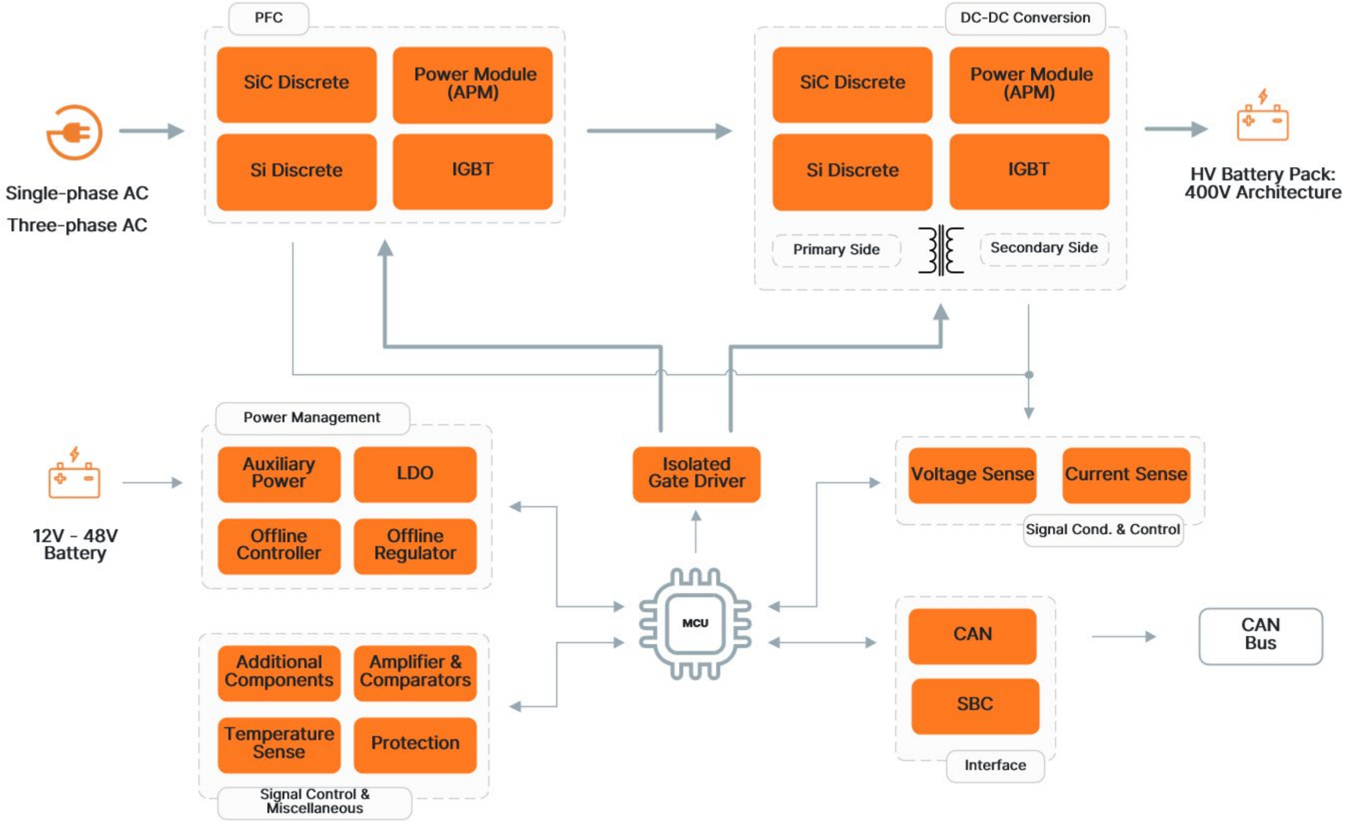
System Level Diagram of EV Charging

There are three classifications or “levels” of charging stations. Level 1 & 2 chargers deliver AC power to the vehicle’s OBC which then charges the DC battery with appropriate output current and voltage. Level 3 chargers are the “off-board” DC charging stations which bypass the vehicle’s OBC and supply high-voltage DC current up to 400A directly to the vehicle’s battery.



Solution Overview

Block Diagram of On Board Charger, power stage and interface components



On Board Charger power stage (PFC, DC-DC) uses different power components depending on the voltage of the EV battery pack. The diagram above is for a 400V EV battery architecture, which requires power switching devices rated up to 650V. Voltage margin is necessary for the high currents and voltage transients.

Interactive block diagram on onsemi.com also includes a block diagram variant for 800V EV battery architecture, with power discrete devices and automotive power modules rated up to 1200V.

The block diagram also includes **isolated gate drivers**, **auxiliary power supplies** and various controllers. Signal measurement and conditioning can be achieved with **OpAmps**, **CSA**, and temperature sensing. **CAN and LIN transceivers** ensure fast and reliable communication within the automotive network. To support MCU operation, **ESD protection devices** with fast transient clamping capability and low capacitances protect the integrity of critical signals.

Find Interactive Block Diagram on the Web

Recommended Products

Suggested Block	Part Number (PN)	PN Description, Comments
Power Stage - 800V EV Battery Architecture		
Automotive Power Integrated Modules **SiC - APM32** PFC Stage DC-DC Stage	NVXK2TR40WXT NVXK2TR80WDT	EliteSiC Dual Half-Bridge modules, 1200V, 27A (20A), Typ. 40 mΩ (80 mΩ) Thermal Resistance Junction−to−Case $R_{\theta JC}$ = 0.37 (1.41) °C/W.
	NVXK2PR80WXT2	EliteSiC Full-Bridge, 1200V, 31A, Typical 80 mΩ, $R_{\theta JC}$ = 0.56 °C/W.
	NVXK2VR40WDT2	EliteSiC 3-Phase Bridge, 1200V, 31A, Typical 40 mΩ, $R_{\theta JC}$ = 1.13 °C/W.
	NVXK2VR80WDT2	EliteSiC 3-Phase Bridge, 1200V, 20A, Typical 80 mΩ, $R_{\theta JC}$ = 1.41 °C/W
	NVXK2VR40WXT2	EliteSiC 3-Phase Bridge, 1200V, 55A, Typical 40 mΩ, $R_{\theta JC}$ = 0.37 °C/W
	NVXK2VR80WXT2	EliteSiC 3-Phase Bridge, 1200V, 31A, Typical 80 mΩ, $R_{\theta JC}$ = 0.56 °C/W
	onsemi's automotive power modules are optimized for OBC design. The SiC MOSFET modules enable higher efficiency, superior switching performance and improving thermal performance. Showing typical values for R_{DSON} & $R_{\theta JC}$. All modules are Auto qualified per AEC-Q101 and AQG324.	
	APM32 Power Integrated Modules optimized for OBC.	
SiC MOSFETs (M3S family)	NVH4L022N120M3S	EliteSiC MOSFET, 1200V, 22 mΩ, 89 A, TO247−4L
	NVBG030N120M3S	EliteSiC MOSFET, 1200V, 29 mΩ, 77 A, D2PAK−7L $R_{\theta JC}$ = 0.43 °C/W , $Q_{G(TOT)}$ = 107 nC , C_{OSS} = 106 pF
	NVH4L040N120M3S	EliteSiC MOSFET, 1200V, 40 mΩ, 54 A, TO247−4L
	NVBG070N120M3S	EliteSiC MOSFET, 1200V, 70 mΩ, 36 A, D2PAK−7L
	Application recommended SiC M3S MOSFETs	
	M3S SiC MOSFETs family uses a new technology optimized for low switching losses, further reducing gate charge $Q_{G(TOT)}$ and capacitance C_{OSS} while maintaining low $R_{DS(ON)}$	
SiC MOSFETs **(**M1 family**)**	NVH4L020N120SC1	EliteSiC MOSFET, 1200V, 20 mΩ, 102 A, TO247−4L
	NVBG080N120SC1	EliteSiC MOSFET, 1200V, 80 mΩ, 30 A, D2PAK−7L
	NVHL040N120SC1	EliteSiC MOSFET, 1200V, 40 mΩ, 60 A, TO247−3L
	Application recommended SiC M1 MOSFETs	
SiC MOSFETs (1700V , M1)	NVBG1000N170M1	EliteSiC MOSFET, 1700V, 960 mΩ, 4.3 A, D2PAK−7L
	NVHL1000N170M1	EliteSiC MOSFET, 1700V, 960 mΩ, 4.2 A, TO247−3L
SiC Schottky Diode (D1, D3 family)	FFSB10120A-F085	EliteSiC Diode 1200V, 10A , D1, D2PAK (single diode)
	FFSH20120A-F085	EliteSiC Diode 1200V, 20A , D1, TO-247-2L (single diode)
	NVDSH50120C	EliteSiC Diode 1200V, 50A , D3, TO-247-2L (single diode)
	Application recommended SiC D1, D3 diodes	
EliteSiC	*EliteSiC is the brand name of onsemi's silicon carbide (SiC) technology, which is used in its APMs, MOSFETs and diodes.*	

Recommended Products

Suggested Block	Part Number (PN)	PN Description, Comments
Power Stage - 400V EV Battery Architecture		
Automotive Power Integrated Modules **APM16** PFC Stage DC-DC Stage	FAM65CR51DZx FAM65CR51XZx FAM65CR51ADZx	Integrated Si 650V MOSFETs and Si 600V (SiC 650V) Diodes. 33A, 41A, 64A, Typical $R_{DS(ON)}$ = 40Ω at V_{GS} = 10V, I_D = 20A Boost Converter Stage modules for Multiphase and Semi-Bridgeless PFC.
	FAM65HR51DS1/2 FAM65HR51XS1/2 NXV65HR51DZ2 NXV65HR82DZ1/Z2	Integrated Si 650V MOSFETs , Typical $R_{DS(ON)}$ 44 – 73 mΩ per FET Half-Bridge modules for LLC and PSFB DC-DC Converter. I_D = 26 – 64 A variants, Optional snubber capacitor for improved EMI.
	Application recommended Si 650V APM16 Modules	
SiC MOSFETs (M2 family)	NVH4L095N065SC1	EliteSiC MOSFET, 70 mΩ, 650V, 31A, TO247−4L
	NVBG060N065SC1	EliteSiC MOSFET, 44 mΩ, 650 V, 46A, D2PAK−7L
	NVH4L025N065SC1	EliteSiC MOSFET, 21mΩ, 650V, 96A, TO247−4L
	Application recommended SiC M2 MOSFETs	
Si MOSFETs (SUPERFET III family**)**	NVB125N65S3	Si MOSFET 650 V, 24 A, 125 mΩ, D2−PAK
	NVHL082N65S3HF	Si MOSFET 650 V , 40 A, 82 mΩ, TO-247 fast recovery
	NVH040N65S3F	Si MOSFET 650 V , 65 A, 40 mΩ, TO-247
	Application recommended Si Super-Junction (SJ) MOSFETs	
IGBT with co-packed diode (FS4 family)	AFGB30T65SQDN	IGBT 650V, 30A, Si diode, D2PAK
	AFGHL50T65SQD	IGBT, 650V, 50A, Si diode, TO-247-3LD
	AFGHL75T65SQDC	Hybrid IGBT, 650V, 75A, SiC diode, TO-247-3LD
	Application recommended IGBTs	
SiC Schottky Diode (D2 family)	FFSD0865B-F085	650V , 8A , DPAK (single diode)
	FFSH2065B-F085	650V , 20A , TO-247-2L (single diode)
	FFSP4065BDN-F085	650V , 40A , TO-220-3L (2diodes in 1 package), 20A per leg.
	Application recommended SiC D2 diodes	
Si Diode	Application recommended Si diodes	
Power Management : Protection		
eFuse	NIV6150 NIV6350	Resettable fuse 200 mΩ (85 mΩ) $R_{DS(ON)}$ Reverse current protection. Fast response Overvoltage clamp and undervoltage lockout.
	NIV3071	eFuse 4 channels. Vin 8V - 60V, Ideal for 48V applications, 10A when channels are parallel (2.5A continuous current per channel)
Protected power switches	FPF2895V	28 V, 5 A Power switch, Features OCP, OVP, Reverse current protection
	NCV47722 NCV47822	40V, 350mA, High Side Switch : Single / Dual version, Adjustable Limit
	Application recommended Protected Power Switches	

Recommended Products

Suggested Block	Part Number (PN)	PN Description, Comments
Power Stage - Gate Drivers		
Gate Drivers for Power Si & SiC MOSFETs	NCV51561 NCV51563	Dual Channel Gate Driver, 5 kVrms Isolation, 4.5/9 A Source/Sink, UVLO Protection, 6.5V to 30V Output , Short Propagation Delay
	NCV51152 NCV51752	Single Channel 3.75 kVrms Driver, 4.5/9 A Source/Sink , UVLO Protection Small 4mm SOIC-8 pckg, 6.5V to 30V Output , (negative bias control)
	NCV51705	Low-Side Single 6A Driver for SiC MOSFETs. High-Speed.
	Application recommended gate drivers for SiC MOSFETs.	
	Onsemi isolated gate drivers are designed for fast switching to drive power MOSFETs and SiC MOSFET power switches. Providing short and matched propagation delays and high reliability.	
Protected MOSFETs and Si MOSFET Drivers	NCV8406	Self-Protected Low-side 65V Smart FET, Temperature and Current Limit
	NCV8415	Self-Protected Low-side 42V Smart FET, In-Rush Current Management
	NCV5106	600V Gate Driver IC, 250/500 mA , 2 Channel Output, dV/dt 50V/ns
	FAD7191	600V Gate Driver IC, 4.5/4.5 A, SOIC-8, High & Low-Side Gate Drive
	NCV7520	FLEXMOS Six-Channel programmable Low-side MOSFET Pre-driver. For driving logic-level MOSFETs in automotive power management.
	Application recommended gate drivers for Si MOSFETs.	
Gate Drivers for IGBTs	NCV57090 NCV57000 NCV57001	Single-Channel IGBT Gate Driver for OBC and high power applications. 5 kVrms Isolation, Active Miller Clamp (DESAT protection) 4.0-6.5/6.5 A Output, Short Propagation Delays and protection features.
	NCV57252 NCV57255xx	Dual-Channel IGBT Driver, 2.5 or 5 kVrms Isolation, 6.5/3.5 A Output Configurable as Low/High-Side or Half-Bridge driver.
	NCV57200 NCV57201	Half-Bridge IGBT Driver with Isolated High-Side & Non-Isolated Low-Side. 1.9/2.3 A Output, Deadtime & interlocks protection. Small SOIC-8 pckg.
	Application recommended gate drivers for IGBTs.	
Gate Driving Buffer BJT	NSV60600MZ4	Low VCE Buffer BJT, PNP, 60V, 12A
	NSV60601MZ4	Low VCE Buffer BJT, NPN, 60V, 12A
Digital Isolation		
Digital Isolation	NCIV9210 NCIV9211 NCIV9311 NCIV9401 NCIV9411	Galvanically isolated 2kV, high speed, bidirectional 2/3/4 Channels Digital Isolators. Allows Isolated PWM control, Communication / Diagnostics. Utilizing onsemi patented galvanic off–chip capacitor isolation technology and optimized IC design for high insulation and noise immunity.
	Application Recommended Digital Isolators	

Recommended Products

Suggested Block	Part Number (PN)	PN Description, Comments
DC-DC Controllers & Auxiliary Power Supplies		
DC-DC : Controllers Converters Switching regulator	NCV898031	Non-Synchronous SEPIC / Boost Controller, 2 MHz. Rich Features. Optimized for pre-regulation (3.2-40 Vin DC) Adjustable output.
	NCV12711	Peak current-mode PWM controller: 4-45 Vin DC. Rich features. Great for 12 V & 24 V Automotive Auxiliary Power Supplies.
	NCV3064	Buck/Boost/Inverting Switching Regulator. 1.5 A DC Adjustable output, precise reference, multi-purpose.
	NCV6323F-xx	Buck converter, Synchronous, PWM. Up to 1.6 A DC. DC-DC converter. Various Fixed Output Voltages. Optimized to supply sub-systems.
	Automotive Step-Down DC-DC Conversion IC (Buck Converters)	
	Automotive Step-Up DC-DC Conversion IC (Boost, Buck-Boost Converters)	
Offline Regulators	NCV1076 NCV1060 NCV1063	Automotive High-Voltage Switching Regulator. Integrated Current mode controller with 670V MOSFET. Provided with different features and packages.
Offline controllers: PWM control LLC control	NCV3843B	Current Mode PWM Controller, suited for driving power MOSFETs Designed for DC-DC converter applications.
	NCV4390	Secondary side PFM controller for LLC resonant converters with synchronous rectifier control.
	NCV1362	Primary side Flyback Controller. Integrated features for easy control of high−performance off−line power supplies
	NCV1397xx	Resonant Mode Controller with Integrated HV Drivers. Can be utilized in half bridge resonant topologies like LLC resonant converters.
	Automotive Power Conversion IC (PWM, LLC, Resonant Controllers)	
LDO		
LDO Regulator	NCV8163	250mA, High PSRR, Very Low Noise, 1uF COUT, TSOP-5 & XDFN4
	NCV8164 NCV8189 NCV59801	300mA, 500mA, 1A Version, High PSRR, Very Low Noise, Power Good, Fixed & Adjustable output options, WDFNW6 & DFNW8 packages
	NCV8718	300mA, 24 Vin max, 4uA Iq, Fixed & Adjustable Vout options WDFN6 package
	NCV1117	1A, High PSRR, (up to 20 Vin), Adjustable and fixed output options.
	NCV8730	150mA, Low Iq 1uA (2.7-38 Vin range) Adjustable and fixed output options, PG ideal for power sequencing.
	Application recommended Post-Regulation LDOs.	

Recommended Products

Suggested Block	Part Number (PN)	PN Description, Comments
In Vehicle Networking (CAN, LIN) , System Basis Chip (SBC)		
CAN, LIN (CAN-FD) Transceivers	NCV7343	Low Power & High-Speed, INH, Wake-up, Error Detection.
	NCV7342 NCV7344 NCV7349	Low Power & High-Speed Transceivers Various packages, features and pin functions.
	NCV7446	Dual Transceiver, Low Power & High Speed . Wake-up
	Application recommended CAN Transceivers for In Vehicle networking.	
	Application recommended LIN Transceivers for In Vehicle networking.	
CAN, LIN Protection, ESD Protection	SZNUP3125 SZNUP2125	Protects CAN, LIN transceivers from ESD and other harmful surge events. Bidirectional protection for each data line.
	SZESD8704	Unidirectional High Speed Data Line Protection.
	Recommended ESD and surge protection for CAN, LIN bus	
System Basis Chip (SBC)	NCV7450	SBC with CAN FD transceiver, LDO (5V/250mA) & HS Driver
	NCV7451	SBC with CAN FD transceiver, LDO (5V/250mA) & Wake Function
	NCV7471C	SBC with CAN/CAN-FD + 2 LIN transceivers, Boost-Buck DC-DC (5V/500mA) and LDO (5V/50mA)
Analog Signal Chain		
Low Power & Precision **Operational Amplifier**	NCV21874	Zero-Drift OpAmp, 45 µV Offset, 0.4 µV/°C
	NCV21911xx	Precision OpAmp 36V, 2 MHz GBW, Low Noise, Zero-Drift, 25 µV Offset
	NCV2007x	OpAmp 36V, 480uA supply, 3MHz, 4mV offset, Rail-to-rail output
	NCV20231xx	36V, 3 MHz GBW, 0.95 mV Input Offset. Wide supply range 2.7 V to 36 V.
	NCV333xx NCV2333 , NCV4333	Low Power Zero-Drift Op-Amp, 10 µV (30 µV) Offset, 0.07 µV/°C low offset drift, space saving packages. Single, Dual and Quad channel configuration.
	Application recommended automotive Low Power & Precision Op-amps.	
Low Voltage Comparator	NCV2250 NCV2252	High Speed, 50 ns propagation delay, Rail to Rail, Push-Pull or Open Drain variant.
	NCV2901 NCV2903	36V, Low Offset Current +/- 5.0 nA, Single or Split Supply, Input Common Mode Voltage to GND level
Current Sense Amplifier (CSA)	NCV7041 NCV7030	CSA, V_{CM} 80V, Bi- or Uni-directional. BW 100kHz, Gains : 14, 20, 50, 100 V/V Gain Options: 14, 20, 50, 100 V/V, (0.3 % gain error)
	NCV21674	V_{CM} 40V, Uni-directional, Low Offset Voltage 100µV and Drift 1µV/C
	NCV210, NCV211 NCV213, NCV214	Low offset & zero drift architecture. Bidirectional. For both Low-side and High-side sensing. Multiple Gain Options: 50, 100, 200, 500 V/V
	Application recommended automotive CSA	
Temperature Sensing	NVT211CMxx	Digital Temperature monitor ±1°C with series resistance cancelation. Under/Over-temperature alarm. Serial Interface (i2c, SMBus)

Recommended Products

Suggested Block	Part Number (PN)	PN Description, Comments
Miscellaneous components		
Voltage Level Translator	MC14504B	Hex non-inverting level shifter, CMOS/TTL to CMOS. Shifting any supply between 5 and 15 V.
	NLVSX5004	Level Translator, 4-Bit, 100 Mbps
Automotive EEPROM	NV24C64xx	64-Kb I2C
	CAV24C512xx	512-Kb I2C
	NV25320xx	32-Kb SPI
	Automotive Recommended EEPROM	
Voltage Reference and Supervisors	SC432BVSNT1G NCV431	Programmable Voltage Reference, Temperature compensated Low Cathode Current, Shunt Regulator
	NCV308	Voltage Supervisor with programable delay and reset
	NCV33161	Universal automotive Voltage Monitor , up to 40V

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Technical Documents

Note that reference designs may contain non-automotive parts to support functionality.

Type	Description and Link
Reference Design (Evaluation Board)	6.6kW Totem Pole PFC Eval Board for OBC
Reference Design (Evaluation Board)	11kW 3 Phase OBC Eval Board (PFC & LLC Platform)
Reference Design (Evaluation Board)	6.6kW OBC Using SiC devices (PFC & LLC application)
Reference Design (Evaluation Board)	Dual-channel isolated SiC gate drivers NCV51561 for OBC
Reference Design (Evaluation Board)	Isolated Supply for SiC Gate Driver with NCV3064 Controller
Reference Design (Evaluation Board)	40W SiC Auxiliary Power Supply (NCV1362 Controller) for HEV & BEV applications
Reference Design (Evaluation Board)	Reference design (kit) of CLLC bidirectional DC-DC stage for 6.6kW OBC
Video	OBC Short Walkthrough
Webinar	Adopting SiC for OBC and DC/DC Power Conversion
Application Note	OBC 3 Phase PFC Converter [AND9957/D]
Application Note	Electric Vehicle OBC System Design & Simulation Using Power Modules [AND9813/D]
Application Note (Needs Web Login)	EliteSiC M3S MOSFET Technology for High-Speed Switching Applications [TND6429/D]
Application Note (Needs Web Login)	EliteSiC Gen 2 1200V SiC MOSFET M3S Series [AND90204/D]
Application Note (Needs Web Login)	Practical Design Guidelines on the Usage of an Isolated Gate Driver [AND90180/D]
Ref Design Note	6.6kW OBC Reference Design [TND6320/D]
Ref Design Note	LLC Converter in OBC Applications [TND6318/D]
Design Note	3.3kW OBC Reference Design [DN05107/D]

Solution Overview – Topologies

Table 4 : Overview of topologies and component choice in OBC power stage.

PFC Stage Topologies (Traditional Boost 1 or 2 channel interleaved, totem-pole)	Primary Side DCDC Topologies & Technologies	Secondary Side Rectification & Technologies
Unidirectional 1 Phase traditional boost, 2 channel interleaved traditional boost or Totem Pole. Vienna rectifier with 3 or 4 leg bridge for 3 Phase designs.	**Unidirectional** LLC is the mainstream solution. Alternative uses Phase Shifted Full Bridge (PSFB)	**Unidirectional** Si or SiC diode bridge. (only low power/cost tier) MOSFET full bridge.
Bidirectional Totem Pole designs for 1 phase AC. Totem Pole (3 or 4 leg bridge) for 3 phase AC designs. (most common solution) There is a modified Vienna rectifier that allow bidirectional operation, but rarely used. • **Si SJ MOSFETs** are used for boost and bridgeless boost at <7.2kW power tiers. At 11kW and 22kW Vienna design is recommended. • **IGBTs** can be used for all topologies but higher losses at 11kW and 22kW make their use less likely. Possible use in higher power tiers for the low-speed leg of totem pole PFC. • **SiC MOSFETs** can be used at all power tiers and topologies. They have the best performance at the higher power tiers. They may also be used in lower power tiers to improve efficiency. • **SiC diodes** can be used in all power tiers and topologies that require SiC diodes to gain the efficiency benefit of no reverse recovery losses. • **Si diodes** can be used in all power tiers, but losses are more noticeable at higher power tiers.	**Bidirectional** CLLC is the mainstream solution. • **Si SJ MOSFETs** can be used for 400V systems at the lower power tiers (<7.2kW) • **IGBTs** are typically only used for PSFB. For lower power tiers and lower cost designs, customer may still use IGBTs. IGBTs are not recommended for 11kW and 22kW designs due to losses. • **SiC MOSFETs** can be used in all power tiers for both 400V and 800V battery systems. SiC is the recommended solution for 800V systems, which brings the best performance and energy efficiency.	**Bidirectional** MOSFET full bridge. • **Si SJ MOSFETs** can be used for 400V battery systems, but at higher power tiers the losses become more significant. It may have low efficiency in low Vout condition. • **IGBTs** are not a recommended solution in 800V battery system. Customers may still prefer IGBTs in low power and low cost designs. • **SiC MOSFETs** are dominant in the higher power tiers and may be used also in the lower power tiers to improve efficiency

Solution Overview – Topologies

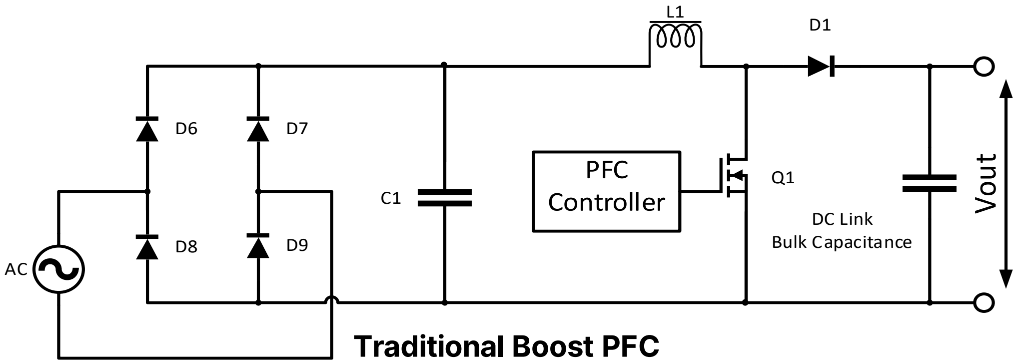
Power Factor Correction (PFC) Topologies

Typical PFC solutions for OBC will vary based on the number of input AC phases from the grid and output power level [kW] of the OBC unit. There are many different solutions for PFC in OBC and we list most common examples.

For single phase AC input OBC modules, expect to see traditional boost, bridgeless boost or Totem Pole (all with optional multi-channel interleaved solutions). Most likely interleaved solution is 2 channels. 3 channel interleaving is feasible but the cost vs. benefit may be minimal. If the design is bidirectional then the PFC stage is going to be the Totem Pole topology.

For 3 phase OBC modules, expect to see Vienna Rectifier and 3 or 4 leg bridge PFC (Totem Pole) topologies. 3 leg bridge PFC is for modules that have 3 phase inputs but no neutral, whereas 4 leg bridge PFC has 3 phase inputs (3 fast legs) as well as a neutral (4th "slow" leg). Fast legs and slow leg would switch at different frequencies. If the design is bidirectional then the most cost-effective PFC stage is going to be the 4 leg bridge (Totem Pole) topology.

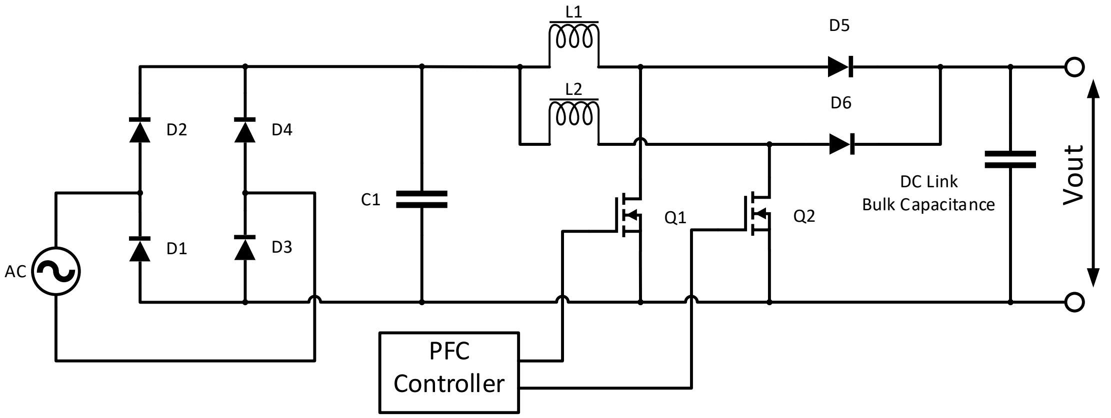
	SiC Diode	SiC MOSFET	IGBT	Si SJ MOSFET
Strengths	• No reverse recovery losses • Higher efficiency than Si diode • Simple solution for 800V systems • Improved power dissipation	• Best power density • Best efficiency in higher power tiers • Improved power dissipation • Higher switching frequencies with low losses • Can be used in nearly every topology for PFC • Best solution for 800V systems	• Mature technology • Lower cost • Can be used in traditional boost, Totem Pole and 3 or 4 leg bridge. • Often used in "slow" leg of Totem Pole PFC with other technologies used in the "fast" leg.	• Mature technology • Higher switching frequencies • Can be used in most topologies for PFC but not preferred for Totem Pole PFC • Good solution for 400V battery systems
Challenges	• Cost vs benefit for 400V battery systems	• Newer technology • Cost vs benefit for 400V battery systems	• Lower switching frequencies	• Body diode reverse recovery in Totem Pole PFC • Not for 800V battery systems



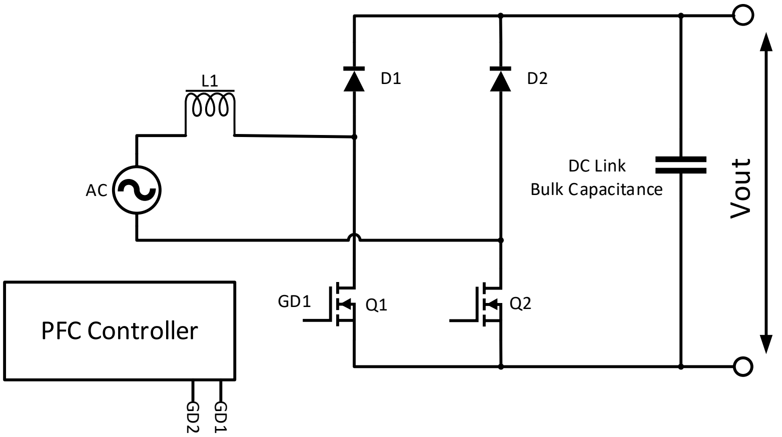
Traditional Boost PFC
**Simplified Schematic*

Solution Overview – Topologies

Power Factor Correction (PFC) Topologies (Continued)



Traditional Boost 2 Channel Interleaved PFC

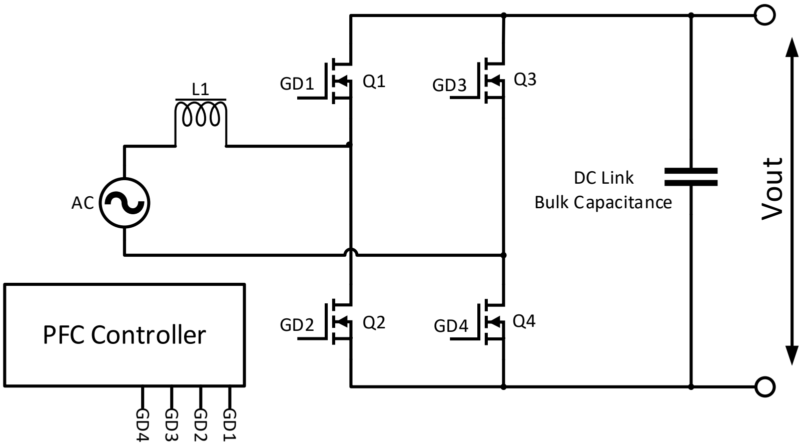


Bridgeless Boost PFC

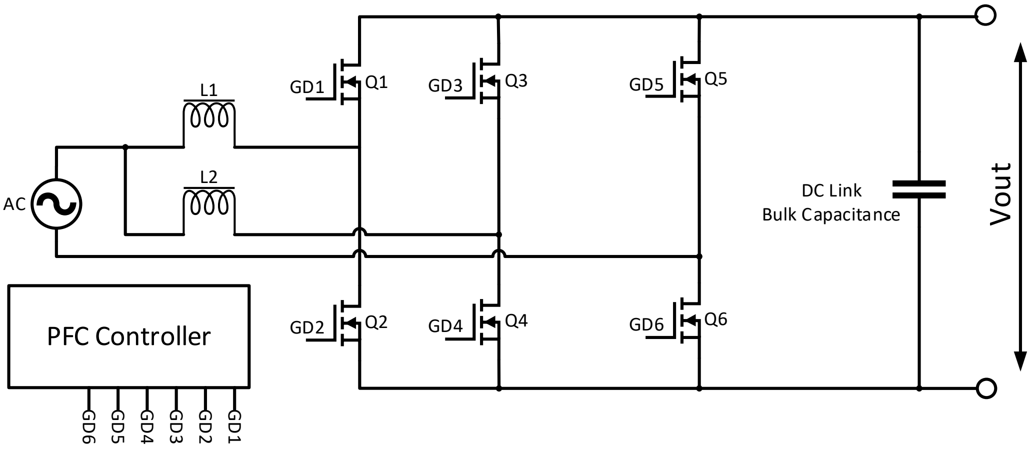
**Simplified Schematics*

Solution Overview – Topologies

Power Factor Correction (PFC) Topologies (Continued)



Totem Pole PFC

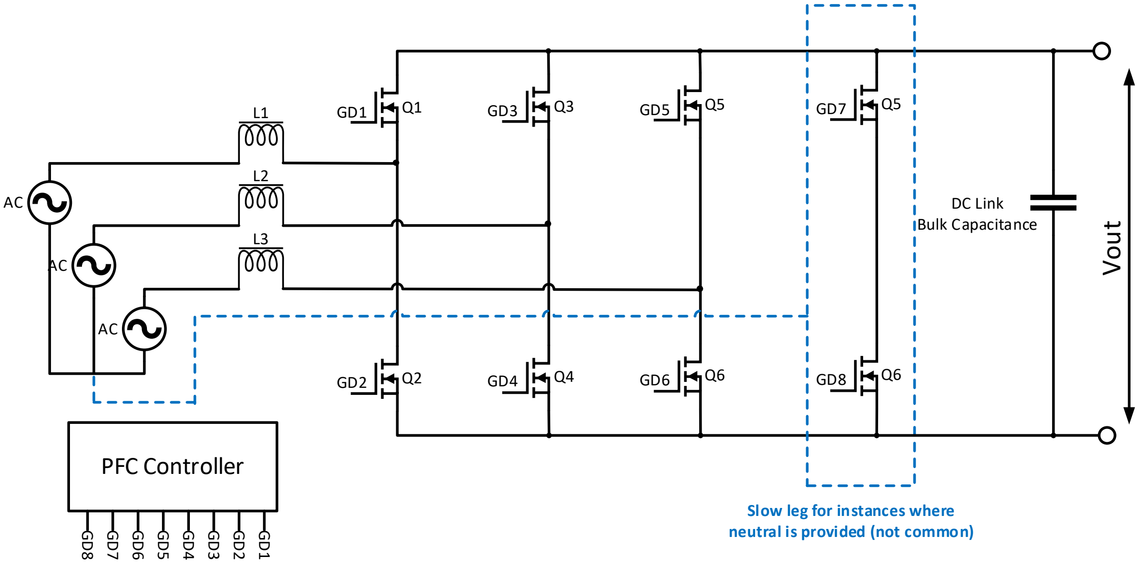


Totem Pole 2 Channel Interleaved PFC

**Simplified Schematics*

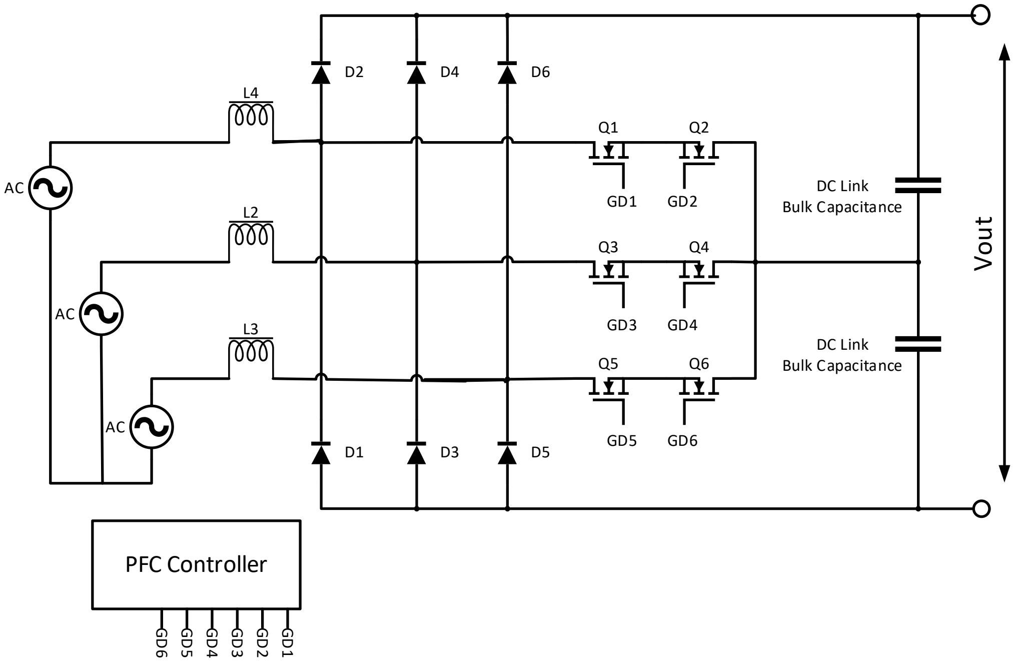
Solution Overview – Topologies

Power Factor Correction (PFC) Topologies (Continued)



Slow leg for instances where neutral is provided (not common)

3 or 4 Leg Bridge, Totem Pole PFC



Vienna Rectifier PFC (Other Variants Possible)

**Simplified Schematics*

Solution Overview – Topologies

Primary Side DCDC Topologies

Primary side DCDC conversion is typically achieved using LLC, CLLC or Phase Shifted Full Bridge (PSFB) topologies. Another term that might come up is Dual Active Bridge (DAB) but this actually includes both the primary and secondary rectification and is used in bidirectional designs. The most common solution for a unidirectional system is LLC and for a bidirectional system is CLLC. Certain bidirectional designs may use PSFB or some other variant. SiC MOSFETs and Si SJ MOSFETs can be used for all the different scenarios in primary side rectification, but IGBTs is only recommended for a PSFB topology. There are cost vs. benefit tradeoffs to consider for each solution, some of which are summarized in the table below.

For 400VDC systems, any 650V technology could be used in the design (Si SJ MOSFET, SiC MOSFET, IGBT). Cost and efficiency targets of the OBC are the main decision-making factors.

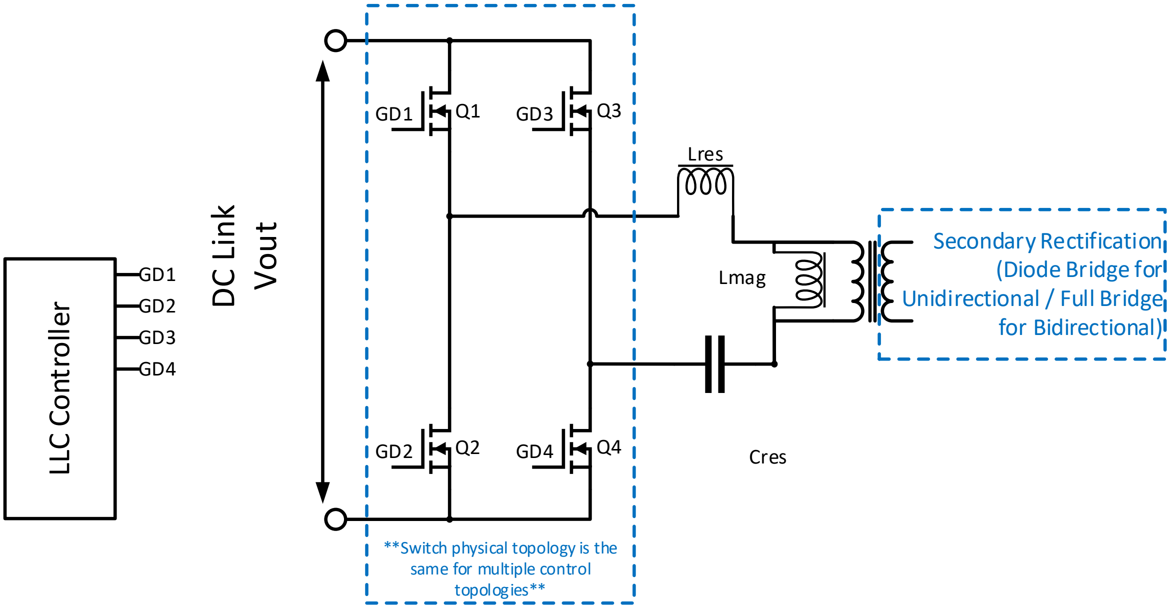
For 800VDC systems, 1200V SiC MOSFETs own the dominant trend although it is possible to use Si SJ MOSFETs if VBUS is a split architecture (400VDC + 400VDC).

Regardless of the methodology used (LLC, CLLC, PSFB, DAB) the primary side rectification is almost always some version of full bridge switching. Therefore, while the components and transformer may have differences, 4 switches is the most common approach for primary side DCDC conversion.

	SiC MOSFET	IGBT	Si MOSFET
Strengths	• Best efficiency in higher power tiers • Improved power dissipation • Higher switching frequencies with low losses • Best solution for 800V systems	• Mature technology • Lower cost	• Mature technology • Higher switching frequencies • Higher efficiency than IGBT • Good solution for 400V battery systems
Challenges	• Newer technology • Cost vs benefit for 400V battery systems	• Lower switching frequencies	• Not recommended for 800V battery systems

Solution Overview – Topologies

Primary Side Rectification Topologies



Primary Side Rectification - Full Bridge LLC

NOTE: Other control topologies exist but the requirement for 4 switches on the primary side is very common.

**Simplified Schematic*

Solution Overview – Topologies

Secondary Side Rectification Topologies

On the secondary side of the transformer the simplest solution is a diode bridge for rectification. This works as long as the design is unidirectional (grid to vehicle only). Depending on desired system efficiency, output voltage and system cost these diodes may be Si or SiC. SiC is the best choice for 800V battery or if the system needs to achieve more efficiency (SiC diodes have no reverse recovery characteristic).

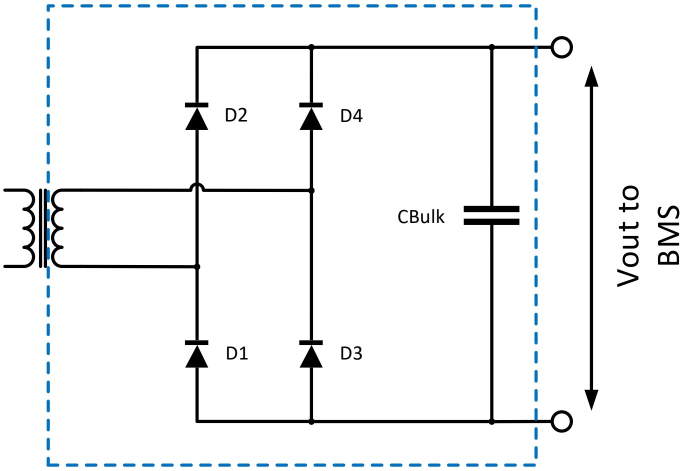
Full bridge solution with Si or SiC MOSFETs could be used to improve system efficiency in unidirectional designs, with higher cost to implement.

For bidirectional OBC designs: Si or SiC MOSFET full bridge is required for bidirectional functionality. IGBT switching losses typically prevent this technology from being used on the secondary (higher power tiers). Si MOSFETs are acceptable for 400V battery systems but will exhibit efficiency drop-off at low load. SiC MOSFETs can provide the highest efficiencies in both 400VDC (650V SiC MOSFETS) and 800VDC (1200V SiC MOSFETs) battery systems, making 1200V SiC MOSFETs the absolute recommendation for 800VDC battery systems.

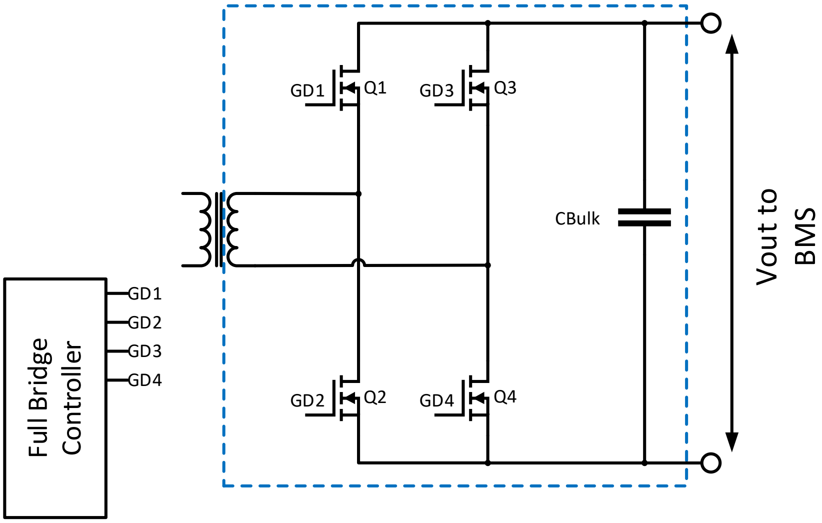
	SiC Diode	SiC MOSFET	IGBT	Si SJ MOSFET
Strengths	• No reverse recovery losses • Higher efficiency than Si diode • Simple solution for 800V systems • Improved power dissipation	• Best power density • Best efficiency in higher power tiers • Improved power dissipation • Higher switching frequencies with low losses • Best solution for 800V systems	• Mature Technology • Lower cost if lower efficiency is acceptable	• Mature technology • Higher switching frequencies • Good solution for 400V battery systems
Challenges	• Cost vs benefit for 400V systems	• Newer technology • Cost vs benefit for 400V systems	• Not common • Lower switching frequencies • Lower efficiency	• Not for 800V battery systems

Solution Overview – Topologies

Secondary Side Rectification Topologies (Continued)



Secondary Rectification Diode Bridge – Unidirectional (Grid to Vehicle) Only



Secondary Rectification 4 Switch Full Bridge– Bidirectional (Grid to Vehicle & Vehicle to Grid)

**Simplified Schematics*

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