# 48V Board Net Reduces Vehicle $CO_2$ Emissions and Improves Drivability

## Introduction

Automakers around the world have begun releasing vehicles that include a new 48-volt (48V) power subsystem, also known as board net. The first announcements have come from European OEMs, like Audi, who announced a 48V system with its SQ7 TDI model. The Audi 48V system powers an electric compressor that eliminates turbo lag and an electromechanical active roll stabilization system that improves ride and handling. Other European OEMs have announced they will soon launch 48V mild hybrid systems, such as Mercedes Benz who plans to introduce a 48V subsystem on its S-Class line to improve fuel economy. What began as a German initiative now has a growing list of worldwide automakers also coming on board. Chinese OEMs like Geely and FAW Group announced they will launch 48V mild hybrids in the coming years, and Italian-American OEM Fiat Chrysler has made a similar announcement. Meanwhile, Korean OEMs Hyundai and SsangYong have both demonstrated 48V mild hybrid concepts.

## Legislation Sparks Worldwide Rollouts

While the introduction of 48V subsystems does introduce an incremental vehicle cost, the widespread acceptance shows that automakers acknowledge it as a means to achieve lower $CO_2$ emissions, improved fuel economy, and vehicle drivability enhancements that make driving fun again. A key driver for the adoption of 48V mild hybrid systems is the regulatory requirements placed on automaker fleets concerning $CO_2$ emissions and improved fuel economy. The penalties imposed on OEMs that do not meet these legislated targets are severe. Figure 1 demonstrates the $CO_2$ emission limits enacted worldwide. In the U.S., Europe, China, and Korea, automakers will need to achieve a 22-36% $CO_2$ emissions reduction in their fleets over the next 10 years to comply with the current legislation.

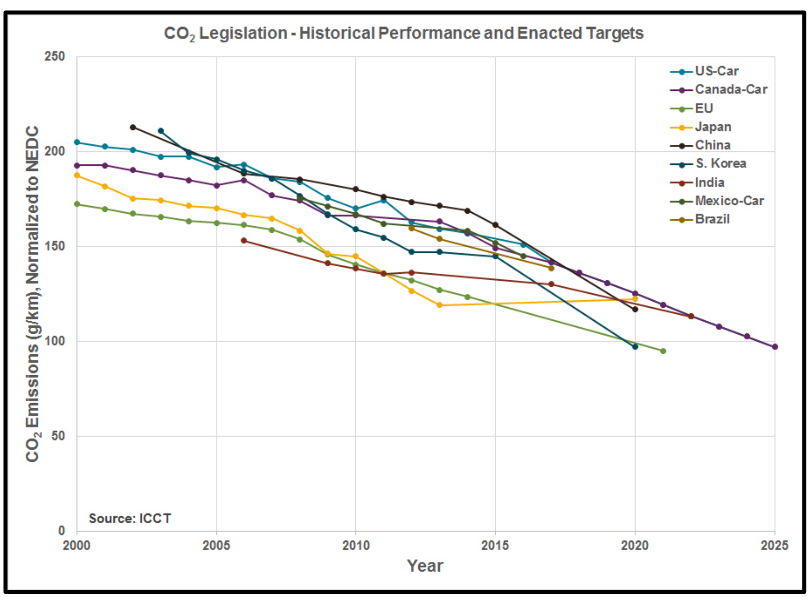


Figure 1. $CO_2$ legislation

Figure 2 shows the fuel economy targets. In order to meet these targets, automakers must improve fuel economy by 24-49% over the same 10-year time period. While the regulations are getting tighter, there is a further push worldwide to make the testing cycles more representative of real-world driving conditions. As test methodologies improve, it is expected that automakers will find it even more difficult to meet the regulation targets.

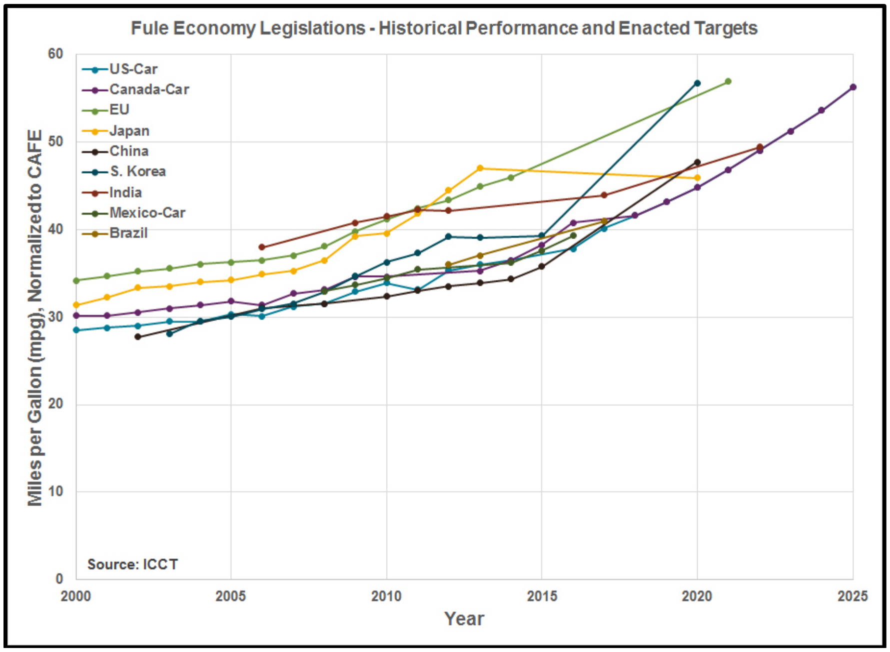


Figure 2. Fuel economy legislation targets

According to FleetEurope, a change in European testing cycles from the New European Driving Cycle (NEDC) to the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) will increase the $CO_2$ emissions test result by an average of 10% for all OEMs. The WLTP driving cycle significantly reduces the fraction of time during the test that the vehicle is at rest and increases the fraction of time spent decelerating (as well as accelerating). These changes will cause the test result to show higher $CO_2$ emissions, and highlight that traditional start-stop systems may not have provided as much benefit as the old test results implied. The WLTP test now accurately reflects the benefit of systems that offer efficient regenerative braking. OEMs that do not meet the mandated $CO_2$ emissions or fuel economy standards are subject to financial penalties.

By 2019 in Europe, the excess emissions premium will rise to 95 Euro for every gram of $CO_2$ that the OEM exceeds for its fleet limit, and for each vehicle registered. The National Highway Traffic Safety Administration (NHTSA) announced in July 2016 that it would increase the U.S. penalty from $55 to $140 for every one mpg under the Corporate Average Fuel Economy (CAFE) standard, per vehicle. In light of the increasingly stringent regulations and higher penalties for non-compliance, vehicle manufacturers are highly motivated to develop technologies that will help them reduce $CO_2$ emissions and improve fuel economy. Not surprisingly, they are rapidly adopting 48V mild hybrid systems because they reduce emissions by 10-15% in small vehicles and 15-20% in larger models, and at a relatively low incremental cost.

## Key Elements of a 48V System

The 48V system typically consists of several core elements as shown in Figure 3. There is a 48V battery, a 48V starter/generator, and a 12-48V DC-to-DC converter. Typically, a 48V Lithium-ion (Li-ion) battery provides the energy storage for this board net. Li-ion is the battery technology of choice because of its high-energy stored-to-weight ratio (energy density) and its ability to accept energy quickly, enabling efficient regenerative braking systems. The 48V starter/generator replaces both the 12V alternator and 12V starter. It starts the engine and then acts as a dynamo, translating the rotational energy of the combustion engine into electrical power. During periods of braking, the kinetic energy of the vehicle turns the dynamo and therefore produces power, typically 12-15kW, while slowing the vehicle. Depending on the way the starter/generator is integrated into the powertrain, it may also be capable of providing a boost or torque assist during periods of acceleration. Finally, a 12V/48V bidirectional DC/DC converter is used to link the existing 12V board net to the new 48V board net. The 12V/48V DC/DC typically supplies power up to 3.5kW from the 48V system to the 12V net to power the existing vehicle electronics. In some situations, the 12V board net must supply the 48V electronics through the 12V/48V DC/DC as well, therefore requiring bidirectional power transfer. Beyond these three common elements of the 48V subsystem, other components that are sometimes added include an electric compressor, electromechanical roll stabilization, electric screen clear, and various motors to support functions such as water pumps, cooling fans, etc.

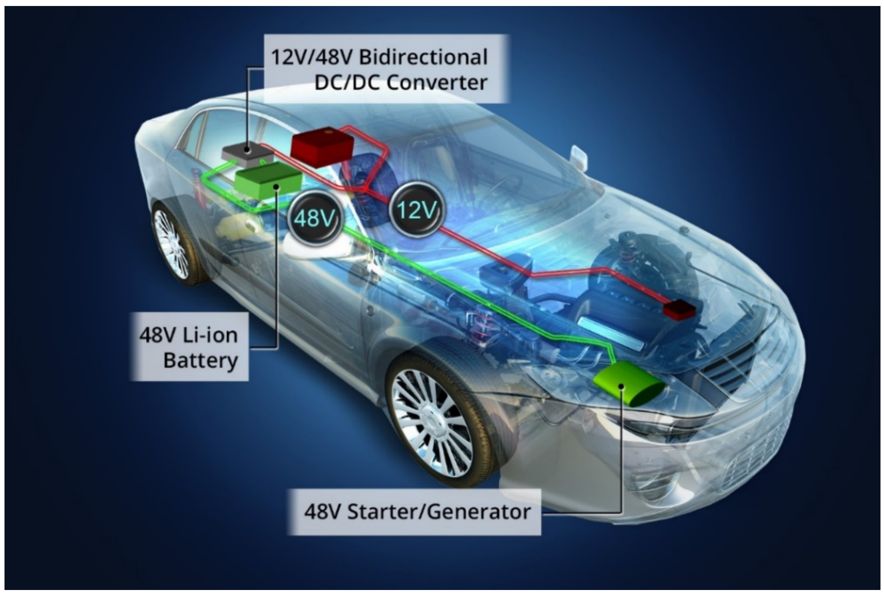


Figure 3. Key components of the 48V board net

## Reduce $CO_2$ Emissions, Improve Fuel Economy

As previously stated, one of the principal benefits that automakers can realize with the addition of the 48V board net is a reduction in $CO_2$ emissions and improved fuel economy. Contributing factors include the addition of the 48V starter/generator, which significantly improves the start-stop system over the standard 12V implementation. The 48V starter reduces engine start time to just a couple hundred milliseconds from as much as 1 to 2 seconds in the traditional 12V system. This allows the engine to stop in cases where the need for quick acceleration or immediate restart would have required the 12V start-stop system to leave the engine running. The added capacity of the 48V battery also allows the engine to be stopped for longer durations while still maintaining functions such as climate control and infotainment. In addition, the 48V starter can provide a boost or torque assist that reduces load on the combustion engine to improve efficiency under acceleration. The 12-15kW starter/generator is able to capture more of the kinetic energy of the vehicle during braking than is possible with a typical 2kW alternator and the Li-ion battery is better able to quickly store the recovered energy, significantly improving the effectiveness of regenerative braking.

## Engine Downsizing Improves Drivability

Automakers also realize another significant improvement, without affecting vehicle drivability, by downsizing the combustion engine and adding a 48V supercharger to provide additional power boost for better acceleration. Standard 12V turbo-charged vehicles also make use of engine downsizing to improve efficiency, but the turbo-lag associated with a mechanically driven system and the lack of available boost at low engine RPMs results in a less than satisfactory driving experience. Using a 48V supercharge provides near instantaneous boost at any engine RPM, eliminating the negative impact on drivability. And there are additional benefits from weight reduction when 12V systems are converted to 48V. Typically, the wiring harness supplying power can achieve a 4x reduction in current required to supply the same power, and motors running off 48V are significantly lighter than with the traditional 12V system. There is a small negative impact due to the added weight of the new 48V systems (where they do not replace an existing 12V device); however, this impact does not diminish the overall improvements.

While the 48V system will reduce $CO_2$ emissions and improve fuel economy, automakers are also banking that consumers will value the improvements in drivability it offers. Audi has demonstrated that when using a 48V electric compressor, they are able to increase off-the-line acceleration. The electric compressor spins up to 70,000 RPM in 250ms, providing torque-boost almost instantaneously, even at low engine rpms. With a 48V starter-generator, the engine starts in less time and with less vibration than with a conventional 12V starter. A start-stop system using 48V also addresses the perception that these systems are irritating and don't allow the driver to make necessary split-second decisions, such as entering into high-speed traffic. The 48V system's lack of vibration and improved responsiveness allow the start-stop system to fade from the driver's consciousness. Beyond these improvements, 48V systems allow other advances, including an electrically heated windshield and electrically powered climate control, enabling the vehicle to prepare the cabin for comfortable driving as the driver approaches, all without starting the engine. With improved drivability, automakers hope that consumers will value the 48V system beyond its 'green' benefits.

## Real-World Tests Prove the Value

Automakers and system integrators have been performing real-world tests to confirm vehicles equipped with 48V systems deliver on their $CO_2$ reduction and fuel improvement promises. Recently, the Advanced Diesel Electric Powertrain (ADEPT) project, a partnership between Ford and several suppliers and researchers, demonstrated 10-12% reduction in $CO_2$ emissions on a Ford Focus that was equipped with a 48V mild hybrid system. They announced that the vehicle offers sub-80g/km $CO_2$ emissions with improved responsiveness and acceleration, owing to the higher full-load torque provided by the hybrid system. And in early 2016, a Kia Optima modified to include a 48V mild hybrid system, called the T-Hybrid, was reported to achieve a 16% reduction while improving engine power by 23%.

Automakers have invested in 48V mild hybridization not only because it offers $CO_2$, fuel economy, and drivability benefits, but because it does so at an affordable cost. Most of the benefits described above are offered by full hybrids. In fact, the benefits of full hybrids often outweigh those delivered by mild-hybrids. However, the key differentiator has been cost. A full hybrid requires a very large battery pack capable of storing enough energy to move the vehicle from point A to point B, as well as large electric motors capable of propelling the vehicle. Then add the complexity of re-engineering the vehicle's entire powertrain and the costs become prohibitive. Cost is often cited as one of the key reasons hybrids still make up only a very small fraction of vehicles sold. With mild hybridization, the manufacturer can add incremental elements to the vehicle without making wholesale changes. The mechanical elements can be designed to integrate into the existing vehicle platforms, further eliminating additional manufacturing charges.

On the electrical side, the 48V system was envisioned from the very beginning to be an incremental change. The installed base of 12V electronics is so large and touch so many aspects of the vehicle that it would be extremely cost intensive to try and migrate all of these to operate from 48V. With an incremental approach, new elements like the starter/generator could be engineered to operate from 48V while not changing existing 12V electronics such as interior lighting and the infotainment system.

## Bidirectional DC/DC Controller Enables 12V-48V Systems

With the 12V/48V power-supply system approach, the only additional component needed is a relatively high power, up to 3.5kW, bidirectional DC/DC converter (as shown in Figure 4) that can bridge between the 48V and 12V systems. Initially, the design of such converters in the vehicle did create a challenge because DC/DC converters and the underlying semiconductors are designed for operation in only one direction and they are limited to several hundred watts or less. Fortunately, Intersil's new controller is designed to provide bidirectional dc-to-dc conversion between the 12 and 48V board nets and is scalable for supplying power from under 1kW to over 3.5kW.

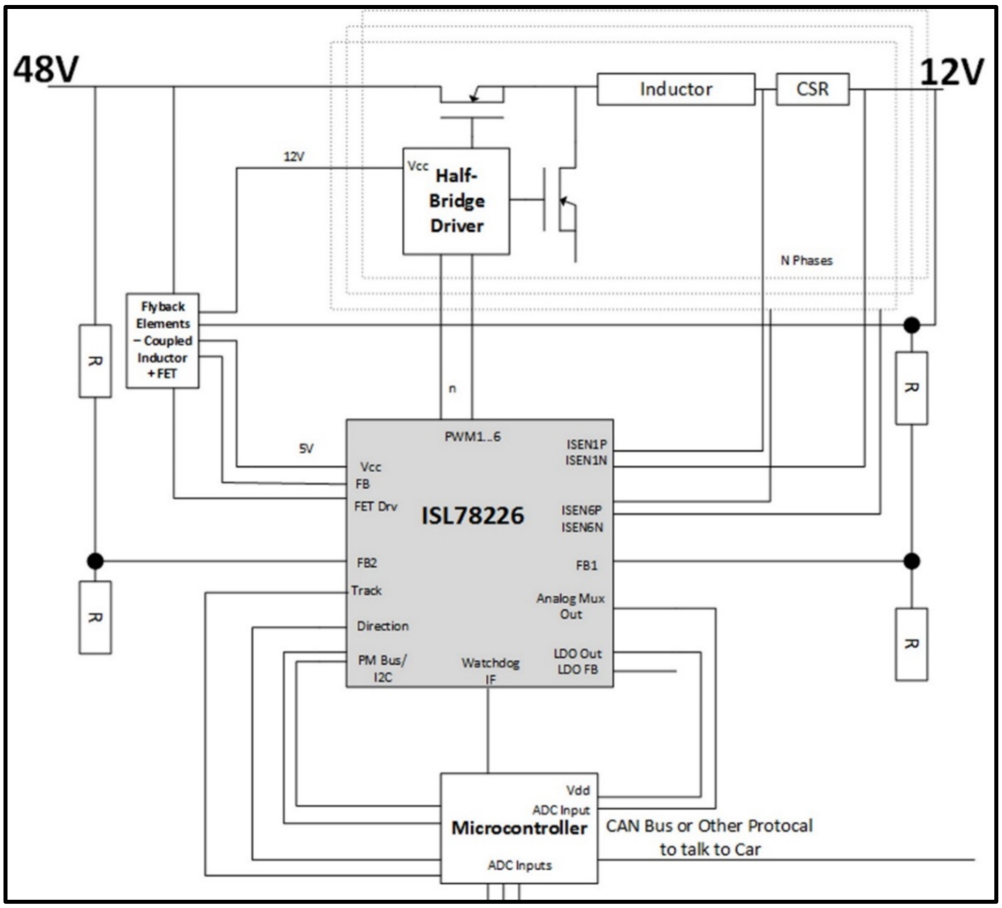


Figure 4. A 3.5kW multiphase 12V/48V system

The ISL78226 is a 6-phase 12V/48V bidirectional synchronous PWM controller developed to solve the challenges associated with implementing a high power bidirectional bridge between the 12V and 48V power systems. To support this new requirement, automotive tier 1s initially had to pull together a system from existing devices intended for other purposes. One way was to use a DSP to implement digital power algorithms that could be used to drive a multiphase half-bridge power conversion stage. This approach was flexible, but required in-depth knowledge of control theory and implied extensive, long-term support of the firmware. Another approach was to combine two unidirectional controllers with multiplexers and a microcontroller to activate the appropriate paths. This approach required redundant components that resulted in a large and complex final solution.

The ISL78226 is a single analog controller that performs bidirectional DC/DC power conversion, eliminating the downsides of alternative methods. It can control up to 6-phases and automatically change the number of active phases to adapt to the load demanded by the output, thereby maximizing the DC/DC conversion efficiency. A single IC typically supports power conversion up to 3.75kW, but multiple ISL78226 ICs can be combined to manage more phases for higher power systems. When used in parallel to make higher power conversions, the ICs coordinate phase-to-phase current balancing and fault response. The controller regulates the output voltage (either 12V in buck mode or 48V in boost mode) and it includes a simple track interface to allow the output voltage to be adjusted via a digital PWM signal or analog reference. And while it is regulating the output voltage, the device actively balances the average current flowing in each power stage phase. This helps equalize losses and prevents hot spots from developing in one of the phases that might otherwise occur when components such as inductors are mismatched.

Additionally, the ISL78226 regulates the maximum average current to limit the power transferred in either direction. This protects the DC/DC converter as well as the vehicle's entire power net. It also allows for constant current charging in applications where either the 12V battery or the 48V battery is connected directly to the output. The controller includes a PMBus digital interface that provides system control and diagnostics, enabling functional safety goals to be achieved with sufficient fault coverage. It also allows the system to take preventative action when conditions exceed warning thresholds, and in the event of a serious fault or failure, the controller can be configured to allow the vehicle to limp-home. The ISL78226 simplifies designing the bidirectional DC/DC converter that makes it possible for 12V and 48V power nets to coexist, while contributing to the cost effectiveness of the 48V board net.

## Conclusion

Automotive OEMs are fully embracing the 48V power subsystem and have signaled their intentions with new car model developments underway. Several automakers have already publically announced 48V mild hybrid vehicles. The impetus for adding another power bus is to improve fuel economy and reduce $CO_2$ emissions through mild hybridization, while at the same time augmenting the drivability of the vehicle. The 48V board net achieves all of the automakers goals at a cost point that has more potential to reach wide-scale adoption than attained by full hybridization.

## Next Steps

- Learn more about the ISL78226
- Download the datasheet
- Watch an overview video

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