Power Distribution in Domain / Zone Architectures and Intelligent Power Device (IPD) Solution

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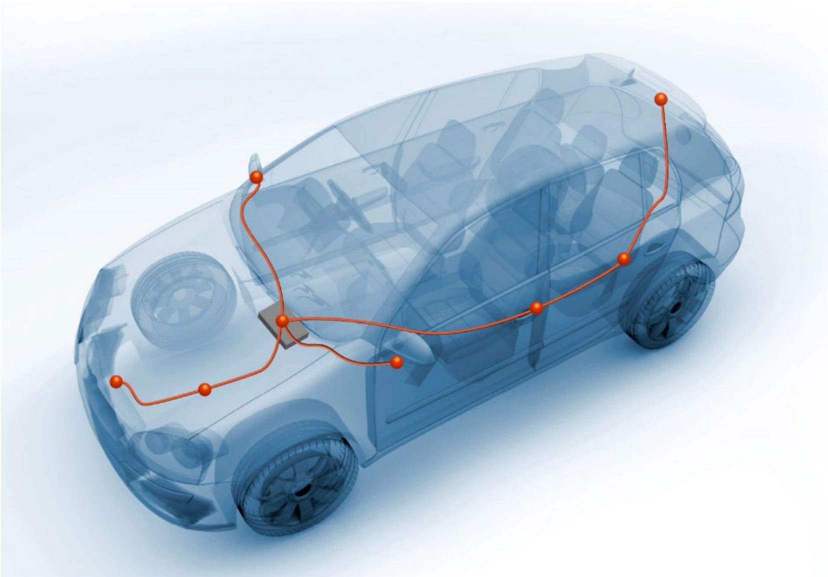


Introduction

The evolution of the in-vehicle electronic and electrical (E/E) architecture and changes in power distribution requires more functionality in the power switch devices. This article presents an overview of E/E architecture with a particular focus on power distribution networks and new features for semiconductor switches required in both modern and future vehicles.

Evolution of E/E Architecture

As automotive architectures continue to evolve, the number of electronic control functions is increasing dramatically which in turn increases the number of ECUs (electronic control units) and complexity of the power distribution, network, communication and processing among ECUs. As ECUs are grouped together, their interconnections are becoming more hierarchical to reduce complexity. Additionally, the performance of microprocessors and microcontrollers has improved significantly, making it possible for a single ECU to handle multiple functions, resulting in lower ECU count and reduced cost.

One way to have a hierarchical structure and optimize the number of ECUs is to group similar functions into functional domains. For example, a powertrain domain controller will control engine ECU, transmission ECU, etc. while the body domain controller handles a variety of body-related functions throughout the vehicle such as wipers, door latches, locks, windows, seats, interior lighting, etc. This is called a domain architecture. The other method is to combine functions physically located close together in the vehicle regardless of function type which is called zone architecture. ***Domain*** architecture has the advantage of easing integration by combining similar functions, as well as localizing communication between close functions inside the domain. However, the wiring between ECUs is not always optimized in a domain architecture and may run back and forth from an ECU in one location to an ECU far away. A ***zone*** architecture controls ECUs that are located close to each other, eliminating the need for wiring to go back and forth – an attractive benefit as it reduces the amount of wiring. However, with zone architecture the communication between ECUs in different locations in the same functional domain increases which means the communication bandwidth of the backbone network connecting the zone controllers increases. In either configuration, the communication networks / wires are hierarchical as shown in Figure 1 as are the power networks / wires. That is, a parent ECU manages the power supply of the child ECUs.

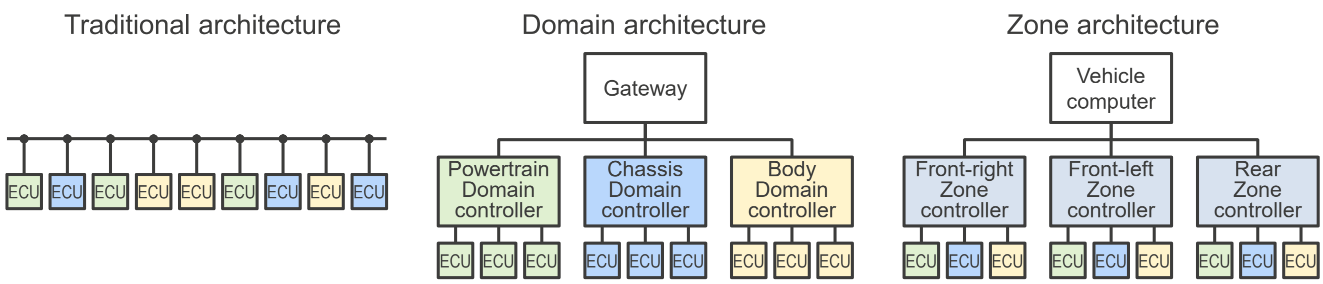


Figure 1: E/E Architecture

Replacement of mechanical relay and fuse

In a classic flat power supply distribution network, relays that control the power to each ECU and fuses that protect the power supply network from overcurrent fault conditions are centrally located in one place. This power distribution center is typically called a relay box, fuse box or junction box, which is in an easily accessible location. The reason for making this module accessible to the end user is to replace relays – which are known for having a finite life – and to replace blown fuses either from wearing out or an issue in the power distribution network. However, with a power distribution network that is hierarchical such as in domain or zone architectures, it becomes necessary to provide more distributed power management functionality to the domain or zone. If the control module used relays or fuses, it would be challenging for the end user to replace them should they wear out due to the locations and potential lack of physical access to the modules. It is more beneficial to replace these mechanical devices with solid-state switches as shown in Figure 2. Solid-state switches have resettable overcurrent and overtemperature protection, are much smaller than relay and fuse combinations and do not require maintenance as they do not have mechanical contacts. These features make them a perfect match for the power distribution switches in domain and zone control units.

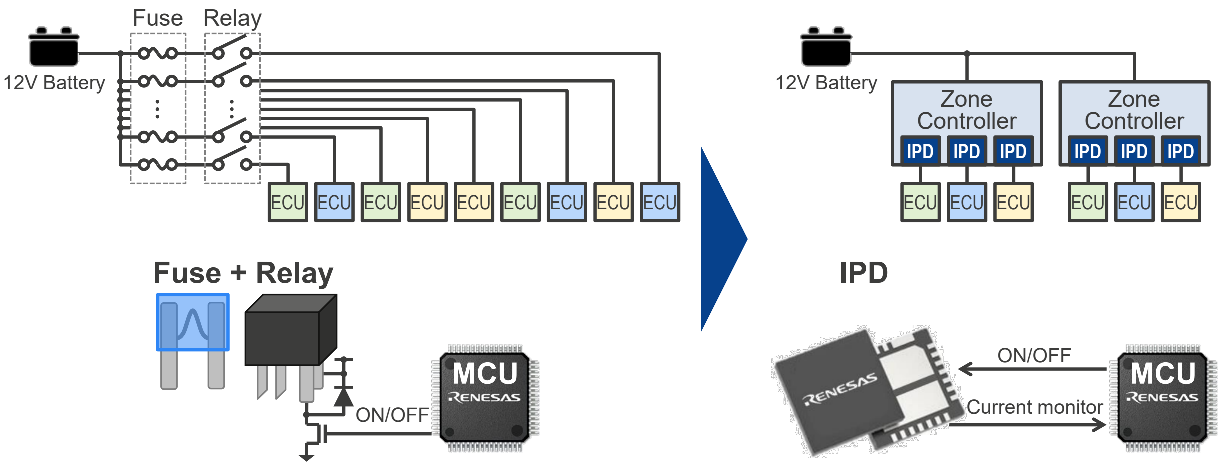
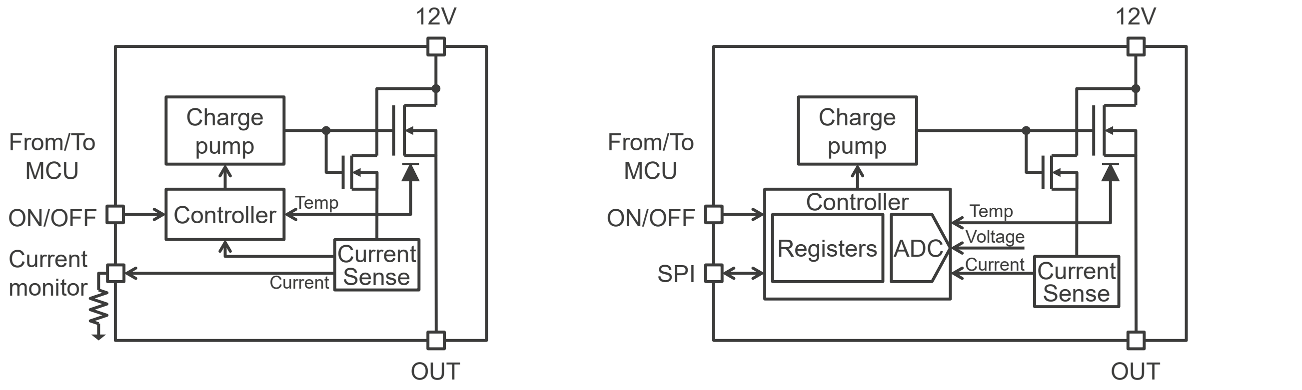


Figure 2: Traditional and Modern Power Distributions

Renesas provides functional solid-stated switches, called intelligent power devices or IPDs for this purpose. The block diagrams for IPDs are shown in Figure 3. These products have the following basic functions in common:

1) **High-side switch with a built-in gate driver** – With an integrated charge pump, it can drive the high side without any external components. The charge pump is designed to function even at very low supply voltages, even taking cold crank into account. ON/OFF commands are given by logic signals from a microcontroller. This replaces a relay and the peripheral components for driving it (MOSFET, freewheeling diode, etc.). It is smaller than a relay, requires less power to drive it and has no contact lifespan so it is maintenance-free.
2) **Overcurrent and overtemperature protection** – Integrated current and temperature sensing circuits provide self-protection for the switch. A fuse melts and is blown when an overcurrent event occurs and once blown it must be replaced to restore functionality. IPDs with overcurrent protection perform self-protection before any damage occurs, so no components are destroyed. Resetting the IPD from the error state by control signals restores functionality. Therefore, replacement is not required, making it maintenance-free.
3) **Current monitor output** – IPDs have an internal current sensing circuit that is used not only for overcurrent protection but also to inform the MCU of the magnitude of the current flowing. There are two ways to provide this data to the MCU, either an analog output representing current flow or communicating via SPI.

In addition to these features, some products have more advanced functionality, which we will explain in the next section.



High-side switch IPD with I/O control, gate drive charge pump and protection circuitry.

Increased functionality IPD with monitoring and programmability via SPI to support functional safety and eFuse.

Figure 3: Internal Block Diagram of IPD

Advanced Features Required for Modern Vehicles

Functional safety and digital communication interface

Functional safety is one of the key common topics in automotive electronics design. Considering that traditional relays and fuses cannot provide any failure detection features, designs are shifting to IPDs which can provide error detection and output to an MCU, along with a current monitoring function that can be accessed by the MCU. Furthermore, IPDs and/or power distribution networks in modern vehicles require ASIL B to meet system-level safety goals. In these products, more error detection and status monitoring mechanisms are implemented to meet ASIL requirements. To set these error thresholds and read the current, temperature, and error status, high-performance IPDs that support ASIL tend to be equipped with an SPI interface. Renesas is designing IPDs that support ASIL B.

eFuse for capacitive load and wire guard

In the legacy E/E architectures, IPDs used as replacements for relays have mainly been used to drive inductive and resistive loads such as light bulbs, heaters, etc. For these applications, a simple overcurrent detection comparator could satisfy the requirements. When IPDs are used to drive an ECU power supply, it will drive a capacitive load especially during startup because ECUs have input bulk capacitance. Capacitive loads induce a large inrush current which was not a problem with classic fuses. The fuses shut down the circuit by melting due to Joule heating caused by an excess current, so there is a certain amount of time before heat builds up. That is, fuses will tolerate short-term overcurrent but will shut off if the overcurrent is continuous. The simple overcurrent comparator in legacy IPDs will shut off the circuit even in response to a short-term inrush current. If the overcurrent detection threshold is increased, continuous overcurrent will be permitted but this increases the risk of damage to the wiring harness.

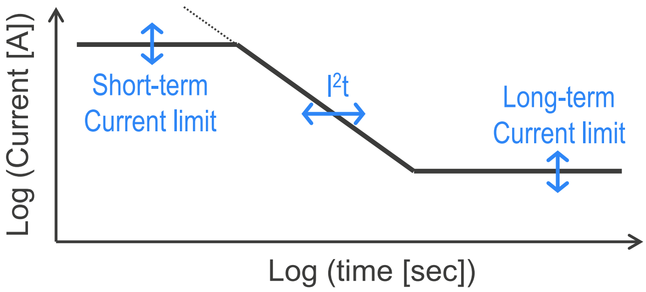


Figure 4: eFuse Shutdown Characteristics

eFuses (electronic fuses) can emulate the behavior of the classic fuse with an electronic control circuit. The Joule heating is proportional to the square of the current and the temperature rise is proportional to its accumulation over time, so it is represented as I^2t.

Joule Heating:

$$P = I^2R$$

P = Power dissipated (Joule heating)
I = Current through the conductor
R = Resistance of the conductor

Thermal Energy Accumulation:

$$E = \int P\,dt = \int I^2R\,dt = R\int I^2dt$$

E = Thermal energy accumulated
Assume:
Resistance (R) remains constant during the time interval
Current (I) is relatively constant or can be approximated

This integral gives us the total thermal energy accumulated over a specific time interval. When current is constant, the equation simplifies to:

$$E = R \times I^2 \times t$$

Or more commonly expressed where the R term is dropped to provide a more device-independent metric for comparing thermal energy capabilities:

$$\Delta T \propto E \propto I^2t$$

ΔT = Temperature rise
I = Current through the fuse
t = Time duration of current flow

Figure 4 shows an example of relationship between current magnitude and time to shutdown. The eFuse controller circuit monitors load current and calculates the I^2t. The overcurrent protection works based on the calculated I^2t value, not the instantaneous current value. The overcurrent and I^2t error threshold curve can be programmed by register settings via SPI. This allows for better compatibility with capacitive loads. Damage to wire harnesses due to overcurrent is also calculated based on I^2t. If the overcurrent threshold is raised to allow for inrush currents in a legacy IPD that provides overcurrent protection based on instantaneous currents, it could allow continuous overcurrent. Ultimately this could result in damaged wires or automotive OEMs needing to use thicker wires to protect against damage. This is similar to what is done today when using fuses and leads to heavier wire harnesses and higher cost. To protect thinner and lower-cost wires while still allowing inrush current, eFuses which provide overcurrent protection based on I^2t are a superior choice. Renesas is developing these eFuse solutions within our IPD product family.

Step charging for capacitive loads

Capacitive charging is critical to eFuses as they can either drive capacitive loads or can be connected to ECUs with inherent capacitance. An eFuse may see an inrush current when turned on that exceeds the limits of the device if it is connected to a large uncharged capacitance. Capacitive charging capabilities are needed for these scenarios to safely handle large current spikes while allowing the capacitor to charge. Renesas eFuse solutions support capacitive charging through a time-based current limitation feature that allows the load current to rise to a threshold below the device overcurrent setting for a short period of time. The voltage will increase with each current pulse while the capacitor charges as seen in Figure 5. The device will either automatically transition out of capacitive charging mode once the capacitor is charged or it will show a fault if the capacitor is not charged within the set timeframe. This functionality is fully integrated and programmable within the Renesas devices.

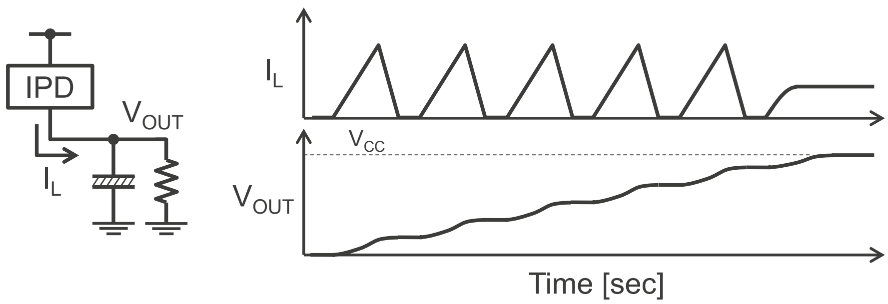


Figure 5: Step Charging for Capacitive Load

Programmability for SDV

SDV (Software Defined Vehicle), in which functions can be added or changed via software, is an ongoing trend in automobile development. Although the functions performed by domain controllers and zone controllers are somewhat invisible compared to infotainment, it is possible that functions may be modified or updated, or that some functions may be activated through subscription services. For domain or zone controllers supporting SDV, the IPD error thresholds may be changed and the information that the MCU wants to monitor may change. By being able to rewrite various settings via SPI and monitor various conditions, it meets the flexibility and functional expansion required for SDV.

Low standby power

Some ECUs continue to operate even when the ignition switch is off (i.e., the vehicle's power switch is off). The IPD controlling the power supply to those ECUs must always be in an ON-state and continue to operate. During this time the IPD power consumption must be very low, otherwise the battery will drain while parked. Renesas IPDs provide idle and sleep modes, which consume low tens of microamps and a single digit microamp-level current.

48V power network

As the number of in-vehicle electrical devices increase and AD/ADAS (Autonomous Driving / Advanced Driver-Assistance Systems) functions become more sophisticated, the power consumption of in-vehicle electric / electronic devices is steadily increasing. xEVs are equipped with a DC/DC converter that converts voltage from the high-voltage battery for traction system to the 12V for ECU power. The limit of this 12V output is generally said to be around 3kW because the DC/DC output current becomes too large. In modern and future automobiles equipped with many high-performance electronic devices, 3kW may no longer be enough. Supplying power to the ECU from 48V makes it possible to reduce the output current of the DC/DC converter, thus making it possible to overcome the 3kW barrier. The 48V system has already been introduced in production vehicles and will be in more vehicles in the future. Some power-hungry systems (such as EPS, pumps, heaters, etc.) or systems that can be run more efficiently at higher voltages (such as audio amplifiers) are driven directly at 48V while other ECUs that are more conveniently powered by 12V are powered after local 48V/12V converters. In such systems, the main backbone power network will be 48V, so 48V IPDs will also be required. Renesas is developing 48V IPDs, including high-side switches and eFuses to support future in-vehicle power networks.

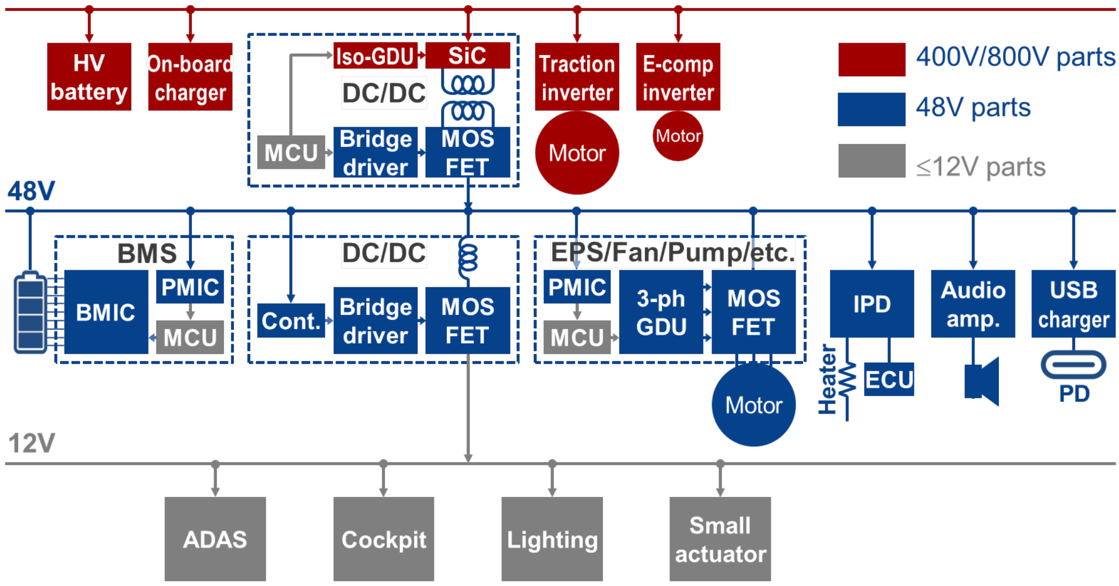


Figure 6: 48V Power Network

Conclusion

The evolution of automotive E/E architecture and the accompanying changes in power network structure were discussed. Devices required for power network management and protection are increasingly being replaced by solid-state switches, replacing traditional relays and fuses. Semiconductor switches have the advantages of being maintenance-free, compact and have the potential to be further improved in functionality in the future. Renesas is developing a new portfolio of both standard IPD and eFuse products to cover these requirements. This portfolio supports ASIL which is essential for modern vehicles, eFuses that are compatible with wire protection and ECU power driving, step charging to drive large capacitive loads and programmability via SPI that is compatible with SDV.

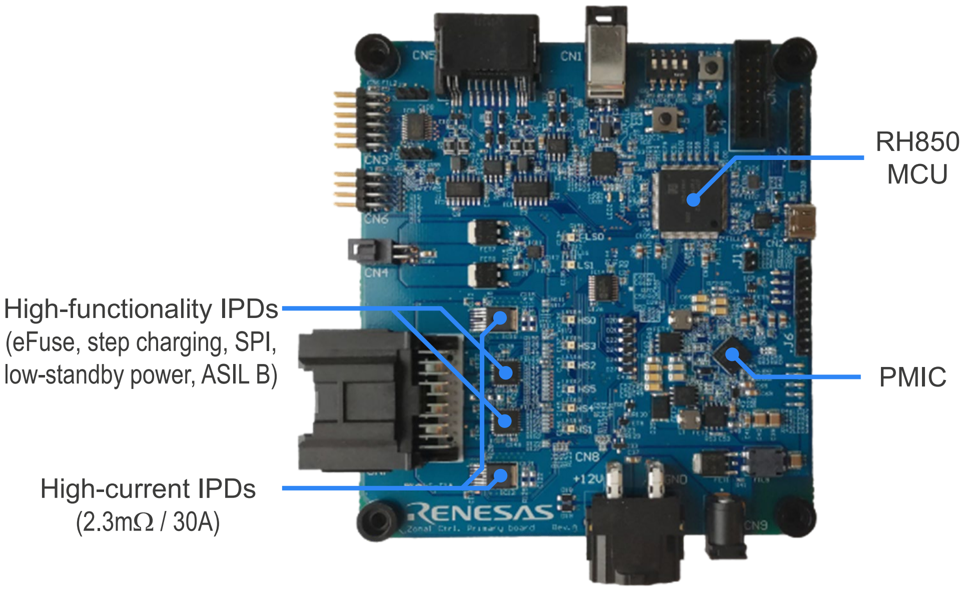


Figure 7: Proof-of-Concept Board

Test chips and a proof-of-concept board shown in Figure 7 have been demonstrated at several exhibition events. 48V in-vehicle power network is also an important technology for future vehicles and Renesas is developing a portfolio of products to address this application space, as well.

For additional information on advanced automotive power solutions, visit the Renesas automotive power management and IPD pages.

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