POWER ELECTRONICS

Enhancing Efficiency by Reducing Converter Stages and R_{ON} in Power Management ICs

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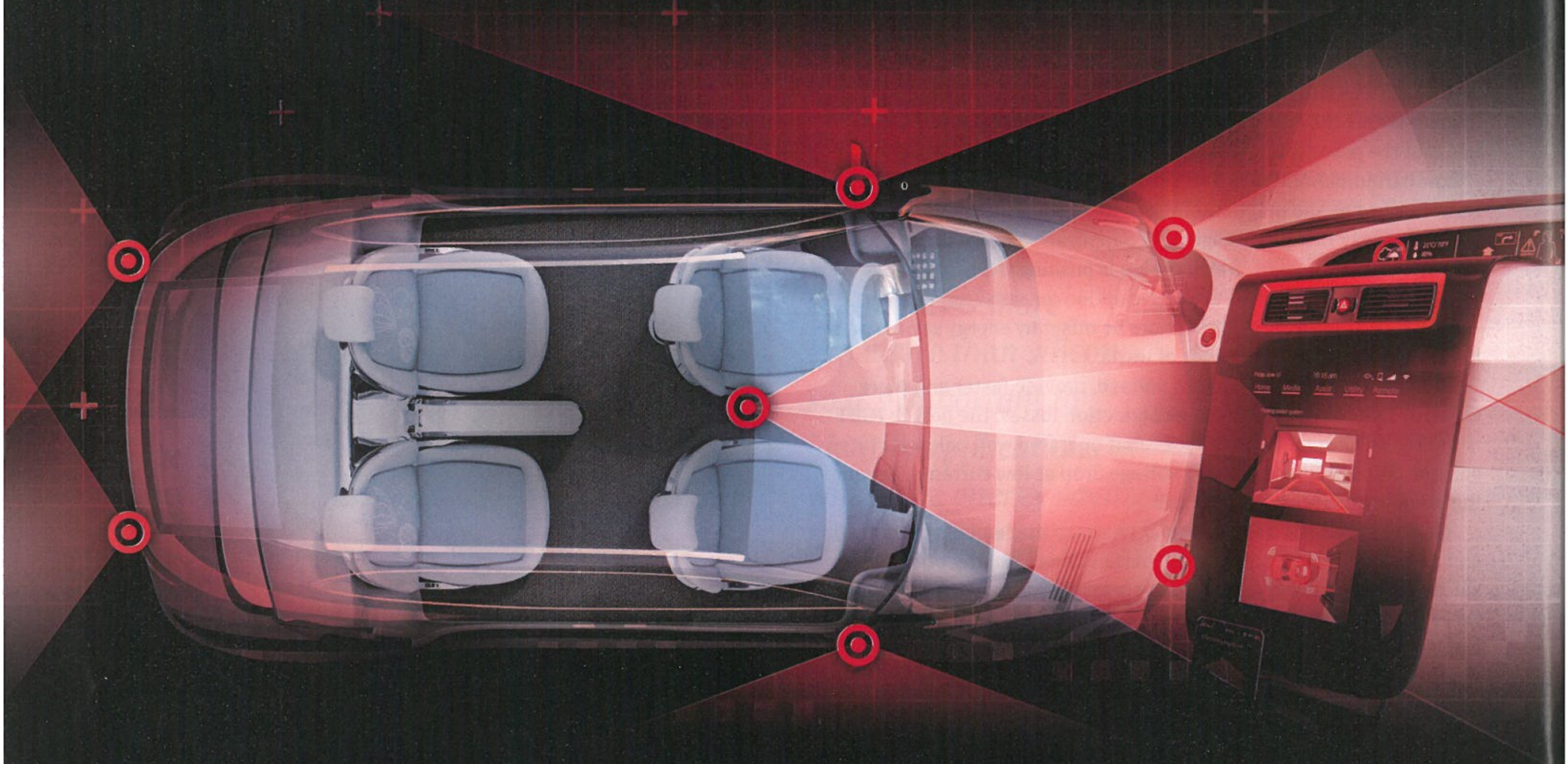
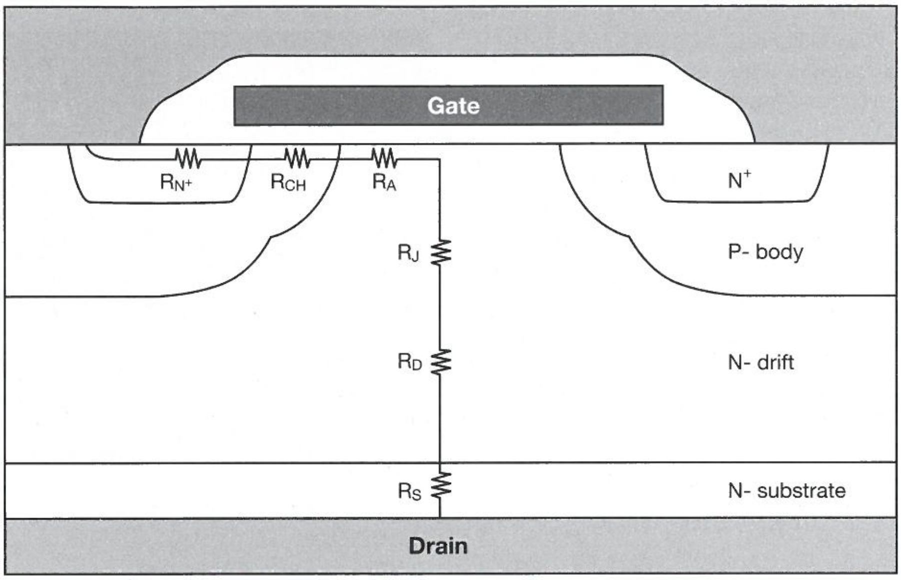


This article highlights the need for advanced converter and package technologies. Moreover, it describes which converter design innovations improve efficiency in 48-V systems and reduce on-resistance in power MOSFETs.

Enhancing Efficiency by Reducing Converter Stages and R_{ON} in Power Management ICs

The latest ICs support faster processors, denser memories/storage, and a wealth of features while increasing reliability and proving lower power usage. Moving to lower semiconductor process nodes and relying on lower operating voltages enable these enhancements without dramatically increasing die area, cost, and the need for specialized processes and materials. Conversely, power systems using higher voltages (48 V and up) reduce current consumption and ultimately improve power transfer efficiency. In the case of automotive, industrial (robotics), and data communications systems, this results in a growing voltage difference between power systems and applications in the sensor, processor, storage, and communications fields. Bridging this voltage divide has typically required multiple converter stages and tradeoffs involving higher on-resistance (R_{ON} = conduction losses), which translates to reduced efficiency. Fortunately, advances in converter technology and packaging have been developed to enhance converter efficiency and reduce conduction losses.

This article provides an overview of the industry trends driving the need for advanced converter and packaging technologies to provide greater efficiency in high-power (high-voltage and high-current) solutions.



R_{ON} is a product of the cumulative resistances from the drain to the source of a MOSFET device. (Source: ROHM Semiconductor Europe)

HIGH-VOLTAGE AND CURRENT-EFFICIENCY CHALLENGES

For many applications, including data centers, automotive, robotics, and telecommunications infrastructure, 48 V is commonly used as the highest standard voltage rail in DC systems, as it presents an acceptable tradeoff for both interconnect and system requirements. With higher voltages, the current needed to provide the same power is lower than for a lower-voltage power supply. This enables greater power efficiency, as there are fewer resistive losses throughout the system. Beyond 48 V, however, additional protection, insulation, and a higher class of dielectrics and semiconductor processes may be needed for interconnect and control electronics.

The challenge in using 48 V as a DC power rail: Modern digital electronics (including complex systems-on-chip, multicore processors, and field-programmable gate arrays) use voltages as low as 1.2 V. In order to power these systems, voltage converters that can convert a 48-V rail to 1.2 V are needed. In many applications, these low-voltage power rails also require tens of amps of current, which can lead to very low conversion efficiencies when using multiple voltage-reducing stages. Each converter stage has a typical efficiency of about 90%, and multiple stages compound a reduction in efficiency. At the same time, lower power regulation is typically more efficient. However, in some cases, regulation of as much as 1,000 W is required, leading to substantial design challenges in selecting parts and designing a voltage-regulation solution that overcomes the intrinsic inefficiencies of converter system components.

For instance, many switching converter topologies use metal oxide semiconductor field-effect transistors (MOSFETs) as switching devices in the power supplies. MOSFETs have a drain-to-source on-resistance ($R_{DS(on)}$, or R_{ON}) that is an intrinsic conduction loss in the device. A lower R_{ON} enables much lower conduction losses in a MOSFET device while also leading to less heat generation and thus easier thermal management. A cooler MOSFET device also translates to lower R_{ON}, as R_{ON} is a function of temperature and rises with increasing device temperatures (positive temperature coefficient).

R_{ON} consists of several resistances that, when in series, are compounded. Factors include the resistance of the diffusion region, channel region, accumulation region, and, most importantly, the drift region. Other factors include the contact resistance between the drain and source metallization, along with the bond wire contact on the die and the package leads. Reducing the conduction losses in each of these, as well as conduction losses through the PCB design, can significantly improve efficiency.

INNOVATIONS IN CONVERTER DESIGN ENHANCE EFFICIENCY IN 48-V (AND HIGHER) SYSTEMS

In the automotive field in particular, regulatory targets have been established in many countries, prompting manufacturers to develop electric vehicles to achieve these limits. As a result, 48-V mild-hybrid vehicles that provide a lower-cost solution while still reducing CO_2 emissions are attracting increased attention.

The major difference between mild-hybrid and standard vehicles is the power supply voltage of the battery. Mild-hybrid systems utilize a 48-V battery, quadrupling the voltage of standard systems (12 V). However, because all other elements remain the same, including ECUs, the input/output voltage difference is significantly increased. In response to these emerging challenges, ROHM innovated a new converter technology, Nano Pulse Control, to enable the conversion of high voltages to low voltages used in modern complex integrated circuits in a single stage. By reducing the switching-on time of the DC/DC converter to several nanoseconds from a typical "on" time of more than 100 ns, Nano Pulse Control devices are able to offer stable control at extremely narrow pulse widths.

One technical hurdle for achieving lower output voltage from a higher input voltage at high frequency is narrowing the switching pulse width. The switching pulse width of a DC/DC converter is a function of the input voltage, output voltage, and switching frequency and is calculated by the following:

$$t_{on} = (V_{OUT} \div V_{IN}) \div f$$

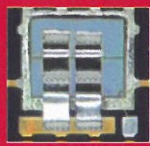
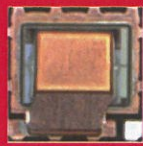
where t_{on} is the switching pulse width, V_{OUT} is the output voltage, V_{IN} is the input voltage, and f is the switching frequency.

As the equation above illustrates, the switching pulse width narrows as the input voltage increases, the output voltage decreases, and the frequency rises. Therefore, a method for reducing the switching pulse width is required for 48-V mild-hybrid systems. But to reduce pulse width, it is first necessary to solve problems related to noise generation during switching.

When this switching noise is introduced into the IC, unstable operation may occur. To prevent this, conventional control methods utilize mask time. Also, an analog circuit is required for operation, which introduces a delay time. These two factors that arise from the increased noise component cause the pulse width to become wider.

An analog control is needed, which leverages high-voltage processes and ultra-fast pulse-control circuitry to detect information before noise is generated and performs appropriate control.

The benefits of copper clip technology range from lower R_{ON} losses to reduced inductive parasitics on the lead lines.

5060 PKG	HSOP8 (Al Ribon) 	5060 PKG (Cu Clip) 
Max Id	≦80A	**≦120A**
Package Ron	0.6mΩ	**0.2mΩ**

A comparison of the R_{ON} and current capability of 5060 power MOSFET packages, one with conventional die bonding and one using copper clip technology. (Source: ROHM Semiconductor Europe)

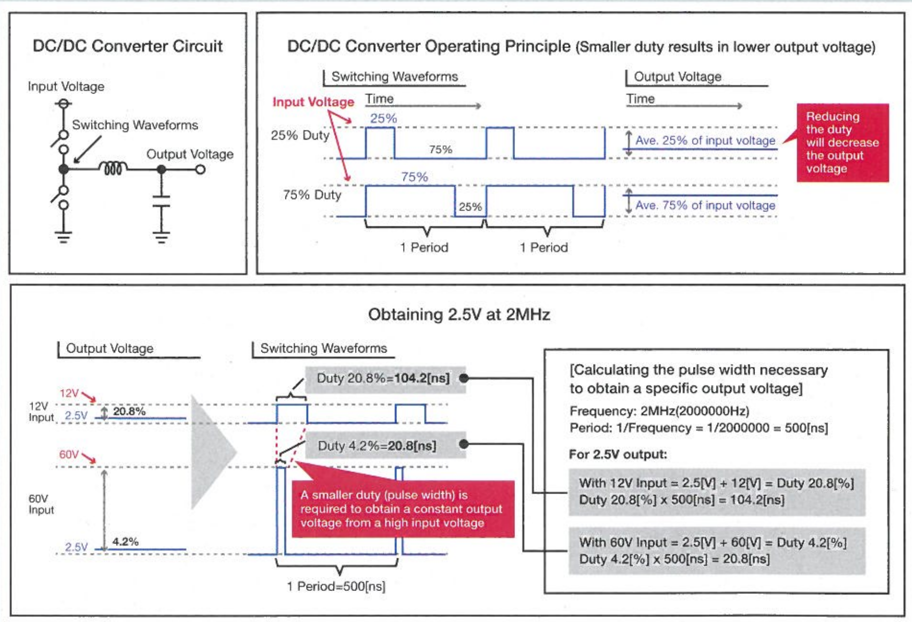
ROHM's vertically integrated production system, together with both proprietary analog design technology and power supply process expertise, has made it possible to achieve such a narrow "on" time. Nano Pulse Control devices are capable of converting voltages as high as 76 V down to 2.5 V in a single stage and, therefore, achieve much higher efficiencies than when using multiple converters to meet very high stepdown ratios. Another benefit of Nano Pulse Control is that the higher-frequency switching circuitry (over 2 MHz) results in smaller component sizes and, consequently, a smaller circuit footprint.

MOSFET POWER SOLUTION ADVANCEMENTS FOR REDUCING R_{ON}

As MOSFET R_{ON} is one of the largest contributors of reducing DC/DC converter efficiency, minimizing R_{ON} is a priority in making the industry's highest single-stage voltage conversion possible.

An enabling technology for reducing R_{ON} for power MOSFETs is the use of copper clip (Cu clip). This technology uses a solid copper bridge between the power device surface and the package leads. The benefits of Cu clip technology range from lower R_{ON} losses to reduced inductive parasitics on the lead lines.

The main reason these benefits can be achieved is that the copper bridge eliminates several long and thin bond wires, along with their respective contact resistances and inductive parasitics. Moreover, Cu clip packaging allows for more effective heatsinking of the device that, when paired with an adequate heatsink, could reduce the device's operating temperature together with R_{ON}. Because the copper forms in the Cu clip package are large and have a high contact area with the die, they are more efficient at conducting thermal energy to a heatsink. This allows for much smaller heatsinks and an overall reduction in circuit board footprint.



The switching pulse width becomes narrower with increasing input voltage, decreasing output voltage, and increasing frequency. (Source: ROHM Semiconductor Europe)

CONCLUSION

As high-voltage power rails become more prevalent and power rails for digital circuits continue to drop, there is a greater need for high-efficiency DC/DC conversion. Reducing the number of conversion stages to a single stage provides a massive boost in efficiency, as does innovative MOSFET power device packaging design that reduces conduction losses. ROHM Semiconductor has been spearheading technological development in these areas and continues to release new DC/DC conversion and MOSFET devices that move away from conventional power electronics limitations and embrace the future. ■

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