EFFICIENT, FLEXIBLE GATE DRIVE POWER SOLUTIONS FOR IGBTS, SI AND SIC MOSFETS WITH ISOLATED DC/DC CONVERTERS

Optimizing power stage design needs adaptable gate drive solutions for evolving technologies like Si, SiC, and GaN. This paper highlights the benefits of isolated DC/DC converters with programmable outputs for efficient, flexible, and future-proof gate drive power.

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ABSTRACT

As industries transition to higher switching frequencies and voltages to improve performance and minimize overall system size, designers are finding it increasingly challenging to balance cost, efficiency, and reliability. A critical aspect of power stage design optimization is selecting appropriate gate drive solutions that can adapt to the always-changing current and emerging transistor technology requirements — such as silicon (Si), silicon carbide (SiC), and gallium nitride (GaN). This paper explores the challenges associated with standard gate drive designs and highlights the benefits of using isolated DC/DC converters with programmable outputs to achieve efficient, flexible, and future-proof gate drive power for IGBTs, Si, and SiC MOSFETs.

CURRENT CHALLENGES IN POWER STAGE DESIGN

Power conversion system designers face a dilemma when selecting gate drive solutions for their power stages — fixed gate drive voltage solutions, while simple to implement, lack the flexibility to accommodate different transistor technology requirements. For instance, optimal gate voltages for IGBTs, Si and SiC MOSFETs vary, consequently requiring the use of gate drive circuits or a total power stage redesign for newer transistor generations.

IGBTs typically require a positive gate voltage between +15V and +20V to fully turn on. For rapid turn-off and false triggering prevention, IGBTs require a negative gate voltage between -5V and -15V. Si MOSFETs have lower gate voltage requirements in contrast, generally needing between +10V and +15V to turn on and between 0V and -5V to turn off.

SiC MOSFETs, chosen for their high switching speeds and low on-state resistance, have gate voltages close to those of IGBTs — with some devices requiring up to +25V for optimal performance. Using fixed gate drive voltage solutions for multiple transistors can lead to suboptimal performance, increased loss, and failure due to insufficient or excessive gate voltages. Designers may consequently resort to using separate gate drive circuits tailored to each transistor type, which increases not only the overall system complexity, but also cost and board space.

Increasing the switching frequency and voltage to enhance both efficiency and power density introduces certain challenges. Higher frequencies require faster switching transitions, which can result in increased EMI and noise issues. Faster switching edges (high dv/dt and di/dt) can couple noise through the circuit's parasitic capacitances, including the transistor package, PCB traces, and isolation barriers. This noise interferes with the gate drive circuit's proper operation, leading to unintended switching and even increased power loss and device failure.

Using high-performance components to achieve faster switching comes at a premium, as designers must strike a balance between cost and performance based on the application and market requirements. For example, designers may opt for lower-cost Si MOSFETs or IGBTs in cost-sensitive consumer applications. This decision sacrifices efficiency and performance in favor of a cheaper solution. On the other hand, in high-performance industrial or automotive applications, using expensive SiC MOSFETs may be justified to achieve efficiency, reliability, and power density benchmarks.

The need to reduce overall system size is another significant challenge in power stage design. As power density becomes increasingly important, designers must find ways to achieve greater miniaturization and seamlessly integrate gate drive circuitry without compromising performance or reliability. Unfortunately, standard gate drive solutions rely on discrete components and separate power supplies, which can occupy valuable board space and complicate the design. Discrete gate drive circuits consist of the following: a gate drive IC, isolated power supply, passive components such as resistors, capacitors, diodes, and more. Carefully selecting and placing each component on the PCB can only be done after considering factors such as power dissipation, thermal management, and signal integrity. As the number of transistors in a power stage increases, so does gate drive circuitry complexity and size.

ISOLATED DC/DC CONVERTERS FOR IGBTS, SI, AND SIC MOSFETS

Most isolated DC/DC converters available on the market come with fixed output voltages. This lack of flexibility makes it difficult to accommodate the gate voltage requirements of different transistor technologies, including IGBTs, Si, and SiC MOSFETs. As a result, designers may need to use multiple isolated DC/DC converters or resort to additional circuitry to achieve the required gate drive voltages, which increases system complexity, size, and cost.

To address this problem, designers are turning to programmable isolated DC/DC converters as a solution. These converters combine the functionality of an isolated power supply and a gate drive circuit into a single package, while offering the ability to adjust the output voltages to match the needs of the chosen transistor technology. By providing gate drivers with programmable output voltages for each transistor, designers can optimize turn-on and turn-off characteristics of their power stage while simplifying the overall design and reducing system size.

Using programmable isolated DC/DC converters offers the ability to independently control the positive (Vpos) and negative (Vneg) gate voltages for individual transistors. This flexibility allows designers to fine-tune gate drive voltages, ensuring full enhancement and rapid discharge of the transistor while minimizing switching losses and improving efficiency. By selecting specific Vpos and Vneg values, gate voltages can be kept within a transistor's safe limits while maximizing the performance. For example, in an IGBT-based power stage, a programmable isolated DC/DC converter can be set to provide a Vpos of +15V and a Vneg of -8V, ensuring full enhancement during turn-on and rapid gate capacitance discharge during turn-off. Similarly, in a SiC MOSFET design, the converter can be configured to offer a Vpos of +20V and a Vneg of -5V, optimizing the gate drive voltages for the specific requirements of the SiC device.

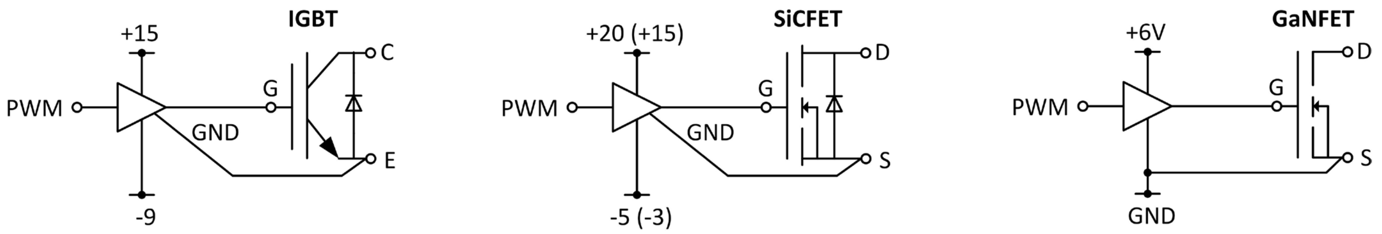

Figure 1: Typical gate voltage requirements for IGBT, SiC FET, and GaN FET

Providing a stable, well-regulated gate voltage supply, independent of the main power supply, is another benefit of isolated DC/DC converters. In typical gate drive circuits, the primary supply derives the gate voltage using a linear regulator or a bootstrap circuit. Linear regulators, while simple to implement, tend to have poor efficiency and greater power dissipation when there is a large difference between input and output voltages. Excessive power dissipation can lead to thermal management issues and may require additional heat sinks or cooling solutions. Bootstrap circuits, on the other hand, rely on a charge pump mechanism to provide the high-side transistor's gate voltage in a half-bridge configuration. As such, carefully size the bootstrap capacitor to ensure an available sufficient charge to drive the transistor's gate over the entire on-time. The duty cycle and switching frequency can affect the circuit's performance, leading to voltage droop and instability.

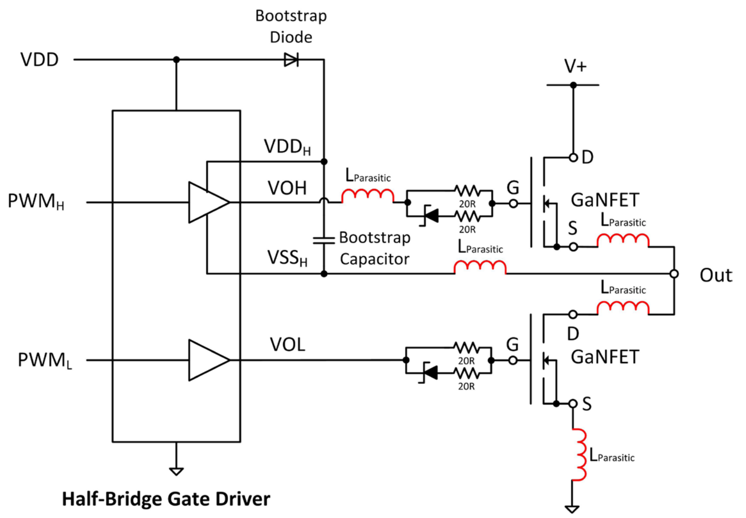

Figure 2: Typical high-side bootstrap supply circuit showing unwanted parasitic inductances that can negatively impact gate drive performance

As shown in Figure 2, parasitic inductances can negatively impact gate drive performance. These inductances arise from the circuit's physical layout and component interconnections. For example, the bootstrap diode's leads and package introduce a small inductance amount in series with the diode. Similarly, traces and interconnections between the bootstrap capacitor and the gate driver IC contribute to the parasitic inductance. The path from the gate driver IC to the gate of the high-side transistor — including the package lead and PCB traces — can also add inductance to the gate drive loop. The high-current path from the high-side transistor's source to the low-side transistor's drain, and back to the DC link capacitor, forms a loop having parasitic inductances from the PCB traces and component packages. These inductances interact with the circuit's fast-switching transients, causing voltage spikes and ringing on the gate drive signal. The resulting oscillations can cause false triggering and increased switching losses.

While isolated DC/DC converters do not directly eliminate the parasitic inductances in the gate driver and MOSFET circuit, they provide a well-regulated gate voltage supply independent of the main power supply which avoids the need for a bootstrap circuit and its associated limitations, including voltage droop and instability.

RXXC2TXX SERIES: RELIABLE PERFORMANCE FOR HIGH-POWER APPLICATIONS

Figure 3: The Isolated RxxC2T25 DC/DC converter with programmable asymmetric regulated outputs in a SOIC package

As an industry-leading power conversion solutions provider, we have developed our RxxC2Txx series isolated DC/DC converters to address the demand for efficient, flexible, and reliable gate drive power in high-powered applications.

The R24C2T25, a key product within this series, offers a range of features and benefits that make it suitable for powering IGBTs, Si MOSFETs, and SiC MOSFETs. Measuring just 7.5 x 12.83mm and packaged in a surface-mount SSOP-36 package with an integrated isolation transformer, RECOM's RxxC2Txx series is suitable for designers looking to minimize their gate drive circuitry's footprint. The RxxC2Txx series' compact size and SMT compatibility is suitable for space-constrained applications and facilitates easy integration into existing designs. The SSOP-36 package also provides excellent thermal performance, with an exposed pad on the bottom of the package that allows for heat dissipation.

The R24C2T25 offers continuous 2W output power, ensuring ample power delivery to the gate drive circuitry. This high output-power capability enables the converter to drive larger transistors or multiple transistors in parallel, suitable for high-current applications including industrial motor drives, solar inverters, and electric vehicle traction inverters. With a 3kVAC/1 min isolation rating, the product offers robust isolation between the input and output stages. The R24C2T25 achieves high isolation voltage through proprietary transformer design and advanced insulation materials for reliable operation even in harsh environments. Moreover, the R24C2T25 features a high common-mode transient immunity (CMTI) rating of 150kV/µs. CMTI is a critical parameter in isolated gate drive applications that represents the converter's ability to withstand rapid changes in common-mode voltage without causing signal corruption or damage to the device. In high-power systems, fast-switching transistors generate considerable common-mode transients, which can couple through the isolation barrier and disrupt gate drive signals. A high rating CMTI ensures that a converter maintains signal integrity and reliable operation even in the presence of these transients.

The R24C2T25 also features an ultra-low isolation capacitance of less than 3.5pF, crucial for minimizing common-mode noise and reducing the impact of high dv/dt transients on the gate drive signals. In high-power applications, the switching transistors can generate large voltage and current transients during turn-on and turn-off events. These transients tend to couple through the gate drive circuit's isolation capacitance, causing false triggering, excessive ringing, and greater EMI. By minimizing the isolation capacitance, the R24C2T25 effectively reduces transient coupling, improving the gate drive circuit's overall signal integrity and reliability. This low isolation capacitance enables faster switching speeds and higher frequency operation, as it reduces common-mode noise impact.

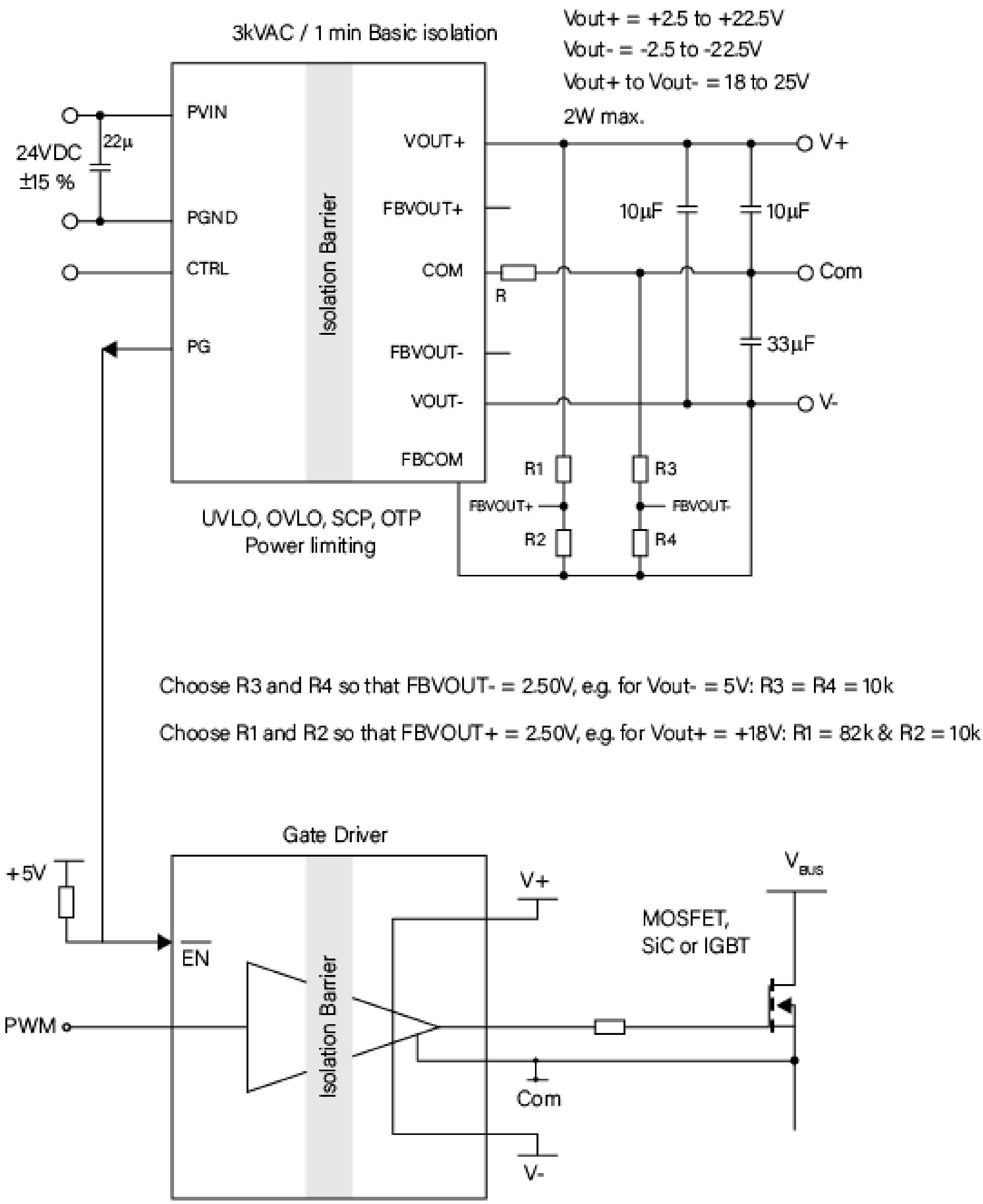

Figure 4: Isolated gate driver solution using the RxxC2T25. R1-R4 set the output voltages

RECOM's R24C2T25 programmable outputs provide flexibility in setting the gate drive voltages with a positive output range of +2.5 to +22.5V and a negative output range of -2.5V to -22.5V. RECOM accomplishes this feat by changing the feedback divider circuit's resistor values — meaning that one power supply solution can provide +15/-9, +20/-5, +18/-4, +15/-3 or any other combination, as long as the combined output lies in the range of 18 to 25V. This programmability simplifies the design process with a single, optimized solution for current and future transistor generations, avoiding the need for multiple gate drive circuits or costly redesigns.

In terms of safety, the R24C2T25 incorporates several protective features to ensure robust and reliable operation in demanding environments, including:

- **Short circuit protection:** In the event of an output short circuit, the R24C2T25 will detect the overcurrent condition and shut down the output to prevent damage to the converter and the connected circuitry.
- **Overload protection:** If the output current exceeds the converter's rated current limit, the overload protection circuit will activate, reducing the output voltage to limit the current and protect the converter from damage.
- **Overtemperature protection:** The R24C2T25 includes an internal temperature sensor that monitors the converter's temperature. If the temperature exceeds a safe threshold, the overtemperature protection circuit will trigger, shutting down the output to prevent converter thermal damage.
- **Undervoltage lockout (UVLO):** The R24C2T25 features both input and output UVLO protection. The input UVLO circuit monitors the input voltage and disables the output if the input voltage falls below a preset threshold preventing the converter from operating in an undervoltage condition, which could lead to unstable operation or damage to the connected circuitry. Additionally, the R24C2T25 incorporates an output UVLO circuit that monitors the output voltages. If the output voltages fall below a predetermined threshold, the output UVLO circuit will disable the output, preventing the converter from operating in output undervoltage conditions. This feature ensures that the gate drive circuitry receives a stable and reliable power supply, even if the output voltages deviate from their nominal values due to load variations or other factors.
- **Power Good (PG) function:** The R24C2T25 provides a Power Good output signal that indicates the converter's output voltage status. This signal can be used to enable the gate drive circuit only when the output voltages are within the desired range.

KEY APPLICATIONS

The RxxC2Txx is suitable for a wide range of industries and systems where efficient, reliable, and flexible gate drive power is critical. Some key applications include:

Electric Vehicle (EV) Traction Inverters

In a typical EV traction inverter, high-power IGBTs or SiC MOSFETs convert the battery pack's DC voltage into three-phase AC voltage for the traction motor. Efficiently driving these transistors is necessary to reduce switching losses and maximize the overall system efficiency. RECOM's RxxC2Txx series is suitable for powering these gate drive circuits due to its programmable outputs and high isolation ratings. Designers can optimize the gate drive voltages for their SiC/IGBT power modules to achieve high efficiency and reliable operation under demanding EV application conditions.

The RxxC2Txx's compact size and surface-mount package allows designers to create space-saving gate drive circuits for easy integration into the traction inverter's PCB layout. This is particularly beneficial in EV applications where space is at a premium and minimizing the size and weight of electronic components is vital. High isolation ratings and low isolation capacitance of the RxxC2Txx also provide the necessary isolation and noise immunity. This isolation protects the low-voltage control circuitry from the higher voltages present in the EV inverter, while the low isolation capacitance minimizes high-frequency noise coupling and transients between the power and control circuits.

Industrial Motor Drives

RECOM's RxxC2Txx series offers programmable outputs to fine-tune the gate drive voltages for specific transistors and optimize motor drive switching performance and efficiency for industrial applications. The RxxC2Txx features robust construction and high-quality materials to withstand industrial environment harsh operating conditions, (e.g., higher ambient temperatures, dust, and vibration), ensuring reliable operation and a long service life.

Solar Inverters and Energy Storage Systems

In a solar inverter, the main switching devices are typically high-voltage Si MOSFETs or SiC MOSFETs. These transistors arrange in a full-bridge or half-bridge configuration to create the desired AC output waveform. Efficient and reliable gate drive circuits are critical to ensure the inverter's optimal performance and longevity. Due to the RxxC2Txx's small size, designers can compact gate drive circuits for easy integration into the inverter's PCB layout, reducing the overall system size and cost.

A wide operating temperature range (-40 to +125°C) also ensures reliable operation in harsh environmental conditions — often encountered in solar installations. Solar inverters are typically subjected to high ambient temperatures and temperature cycling, which can stress internal components and lead to premature failure. The RxxC2Txx's robust construction allows these products to withstand challenging conditions, improving the solar inverter's overall reliability and lifetime.

In addition to solar inverters, the RxxC2Txx series is suitable for energy storage applications such as battery management systems (BMS). Each programmable output optimizes the specific transistor's gate drive voltages, facilitating efficient power conversion between the battery pack and the connected loads or grid.

CONCLUSION

Traditional, fixed-voltage gate drive approaches often fall short of accommodating the diverse requirements of transistor technologies and generations, leading to performance issues and costly redesigns. Isolated DC/DC converters with programmable outputs, such as RECOM's RxxC2Txx series, offer several key features to address these challenges. With independently regulated gate voltages and the flexibility to adapt to multiple transistor requirements, these converters allow designers to optimize their power stages for maximum efficiency and create future-proof gate drive circuits for IGBTs, Si MOSFETs, and SiC MOSFETs.

For more information on RECOM's RxxC2Txx series and other power conversion solutions, please visit www.recom-power.com. To find a distributor or sales representative in your area, please visit the "Buy / Sample" section of the website.

For direct technical support and inquiries, please contact RECOM's Tech Support.

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