How to Design a Compact Low-voltage BLDC Motor Drive Inverter Using a Monolithic GaN ePower™ Stage

EFFICIENT POWER CONVERSION

Motivation

Brushless DC (BLDC) motors are popular and finding increasing application in robotics, e-mobility, and drones. Such applications have special requirements such as lightweight, small size, low torque ripple, and precision control. To address these needs, inverters powering the motors need to operate at higher frequency, but require advanced techniques to reduce the resultant higher power loss. GaN FETs and IC's offer the ability to operate at much higher frequencies in hard-switching topologies without incurring significant losses. This application note presents the design of a high-frequency and compact BLDC motor drive inverter using the monolithic GaN half-bridge ePower™ Stage IC. It is capable of up to 3 MHz switching and 10 A_{RMS} load current per phase.

Introducing the monolithic GaN ePower™ stage IC

The next evolution for GaN FETs is monolithic integration. The monolithic integration of the power stage not only significantly reduces common source inductance (CSI), power and gate loop inductances that have a great impact on switching performance, but also evens out the power dissipation distribution within the IC. In addition, it reduces component count and simplifies PCB layout.

Figure 1 shows the block diagram of the **EPC2152** GaN ePower™ Stage that integrates two 70 V, 10 mΩ main FETs and a self-contained half bridge gate driver optimized for driving the FETs. It includes input buffers, a logic interface with Power-On-Reset (POR), Undervoltage-Lockout (UVLO) functions a high voltage, high dv/dt capable control signal level-shifter, and a synchronous bootstrap that ensures proper supply voltage for the high side gate driver. The EPC2152 is compatible with both CMOS and TTL logic levels. Figure 2 shows a photo of the **EPC2152** monolithic GaN power stage with pin allocation. It measures only 3.9 mm by 2.6 mm and can carry up to 15 A current.

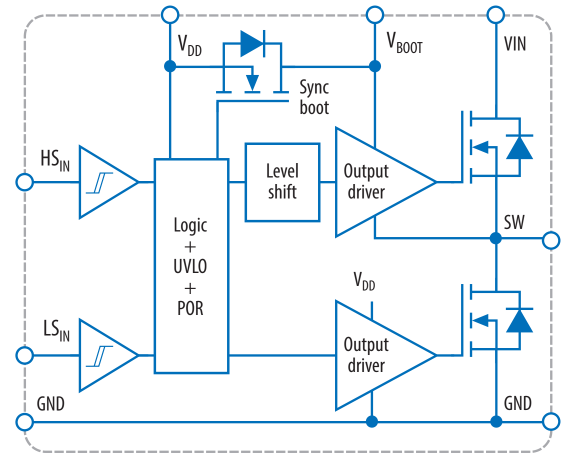

Figure 1. Block diagram of the EPC2152 GaN ePower™ Stage

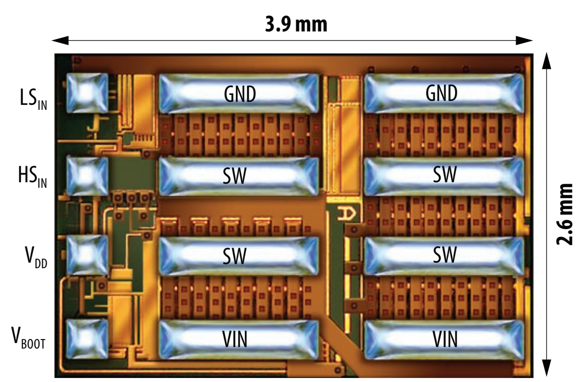

Figure 2. Bump view of the EPC2152 GaN ePower™ Stage

Design of the BLDC motor drive inverter using EPC2152

A practical high-performance motor drive requires at least the following functional elements:

- A 3-phase half-bridge power stage
- Voltage and current sense for at least 2 phases of the motor
- Voltage and current sense for the DC supply to the drive
- Housekeeping power for the various control and auxiliary circuits
- A harmonic filter between the high dv/dt output of the half-bridges and the motor connection
- A controller with adequate processing capability to operate the motor control functions
- Protection features such as over-temperature and over-current monitoring.

A 60 V, 3-phase BLDC motor drive inverter is designed using the **EPC2152** ePower Stage. Figure 3 shows its block diagram featuring all of the essential elements listed. Each phase uses one **EPC2152** ePower Stage that requires only a few support capacitors. Due to the high dv/dt's generated by the GaN FETs, an optional LC- filter that comprises a line inductor and shunt capacitor is included. It can be configured as either a harmonic filter or EMI filter. When configured as an EMI filter, a resistor is placed in series with the capacitor. The housekeeping power supply generates two main voltage levels, 12 V and 3.3 V, for the gate drive and control stages. The controller reads the sensed motor drive phase currents and voltages, the supply voltage, and the temperature, and sends PWM control signals back to the power stage inputs.

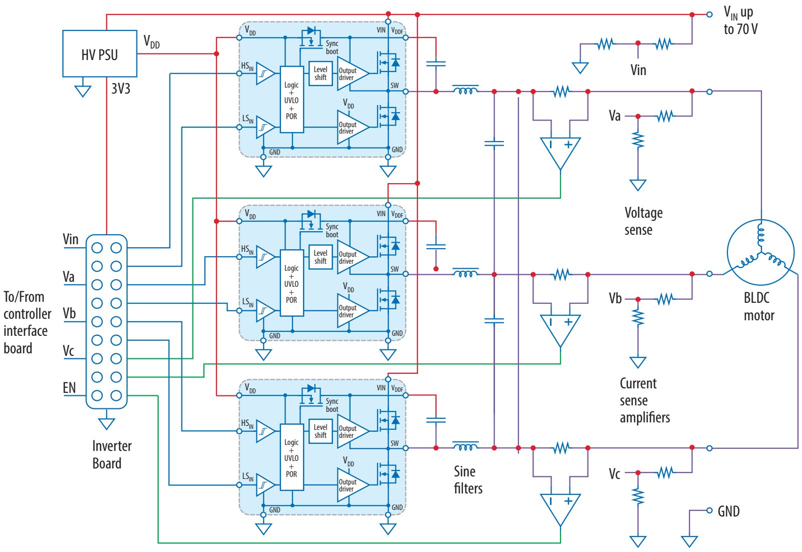

Figure 3. Block diagram of the BLDC motor driver inverter

Figure 4 shows the BLDC motor drive inverter board. Also included in the design are threaded mounting posts for attaching a heatsink to increase the power throughput. Detailed steps to attaching a heatsink are explained in [1]. The drive is designed to operate from 15 V through 60 V DC input and power a 400 W NEMA 34 size BLDC motor. It can operate from 20 kHz through 1 MHz switching frequency and deliver a peak current of 15 A into each phase of the motor when a heatsink is attached. The board measures just 45 mm x 55 mm.

Design validation

The motor drive inverter was operated from a 48 V DC supply voltage while switching at 100 kHz to power a 400 W NEMA 34 motor with sinusoidal modulation frequency of 20 Hz. The dead-times for the half-bridges were set to 10 ns for both the rising and falling edges and are very short when compared to MOSFETs that start at 50 ns.

Figure 5 shows the switch-node voltage (V_{SwN}) and phase current (I_{phase}) measured in the modulation frequency timescale for one phase leg when the motor drive delivered 10 A_{RMS} per phase into the motor. This was captured without the optional L-C output filter. Figure 6 shows the switched-node voltage measured in the switching frequency timescale at both positive and negative phase current. It is seen to be free from excessive ringing and overshoot. Further zooming in the waveforms in the transient timescale, Figure 7 shows that the hard-switching transients and the self-commutated transients are extremely fast with minimum ringing before reaching steady state.

Due to the lack of a dynamometer, the power loss of the inverter was measured when driving the motor at no load condition. The measured power loss as a function of one phase RMS motor current is shown in Figure 8. If one extrapolates to 400 W motor power, the expected efficiency for the inverter, including the controller at 184 mW, will exceed 98.4%.

The inverter was operated without a heatsink attached and with 400 LFM forced air. Figure 9 shows the ePower stage device temperatures at thermal steady-state when operating at 9 A_{RMS}.

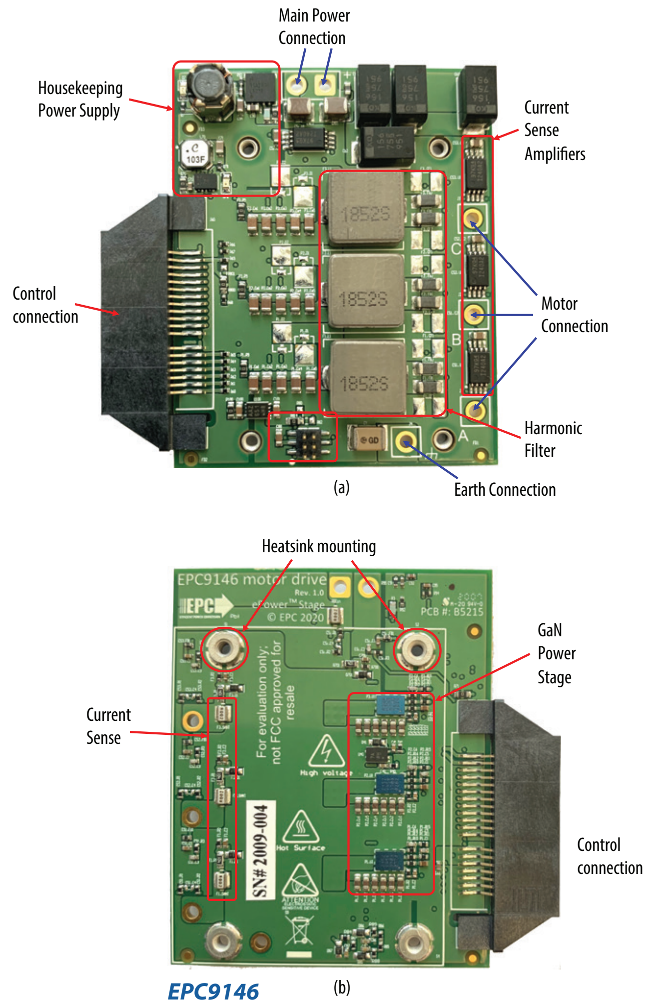

Figure 4. Photo of the 3-phase experimental BLDC motor drive. (a) top side. (b) bottom side

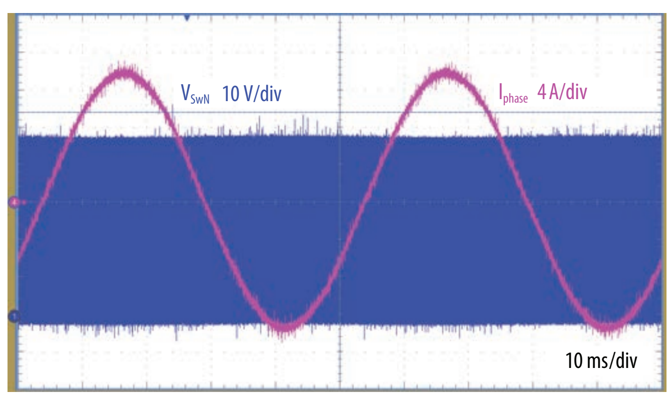

Figure 5. Switch-node and phase current waveforms of the motor drive measured in the modulation frequency timescale when operating from a 48 V DC supply and delivering 10 A_{RMS} per phase into the motor

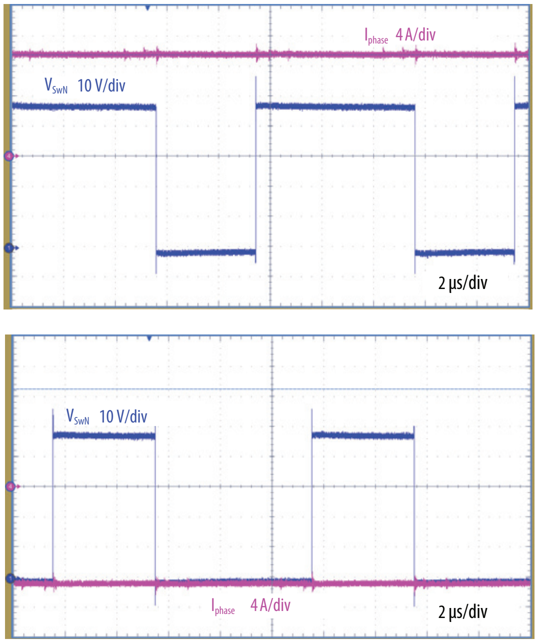

Figure 6. Switch-node and phase current waveforms of the motor drive measured in the switching frequency timescale when operating from a 48 V DC supply and delivering 10 A_{RMS} per phase into the motor. Top: current flowing out of the switch node. Bottom: current flowing into the switch node.

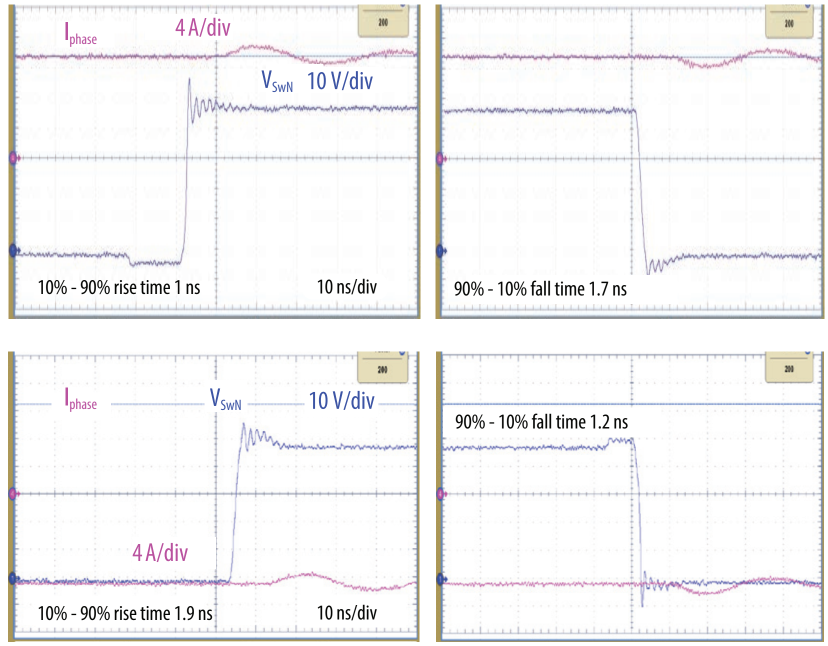

Figure 7. Switch-node and phase current waveforms of the motor drive measured in the switching transient timescale when operating from a 48 V DC supply and delivering 10 A_{RMS} per phase into the motor. Top: current flowing out of the switch node. Bottom: current flowing into the switch node.

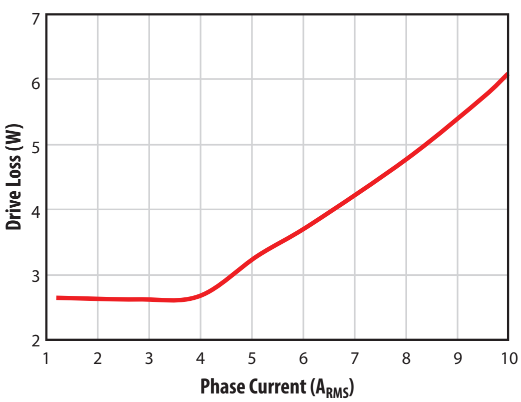

Figure 8. Measured motor drive power loss as a function of phase current into the motor

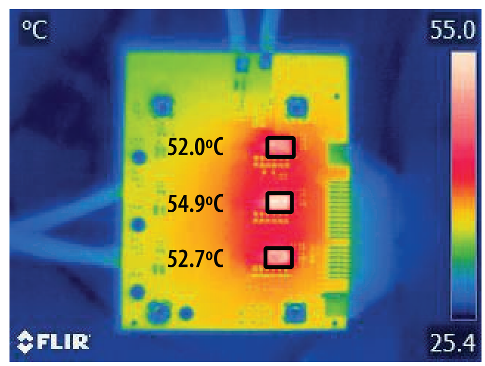

Figure 9. Thermal image of motor drive taken at 48 V input voltage and 9 A_{RMS} phase current with 400 LFM forced air

Conclusion

A 60 V, 3-phase BLDC motor drive inverter designed with EPC2152 GaN ePower stage was demonstrated. The monolithic integration of the FETs and the gate driver ensures not only small size, but also low switching losses even at high switching frequency for the drive. The result is a compact drive solution that can easily be integrated with the motor.

References

[1] How to get more power out of a high-density eGaN®-based converter with a heatsink

[2] GaN Transistors for Efficient Power Conversion 3rd Edition Book – A. Lidow, M. de Rooij, J. Strydom, D. Reusch, J. Glaser, GaN Transistors for Efficient Power Conversion. Third Edition, Wiley, ISBN 978-1-119- 59414-7.