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Smart Gate Driver IC Simplifies Motor Drive Design In Battery-Powered Applications

by Peter Green, Infineon Technologies, El Segundo, Calif.

The design of power-dense motor drive inverters is highly challenging, requiring many components to be placed on an often awkwardly shaped board within a confined space. At the same time, many different functions and protection schemes are necessary to produce a robust system. The 6EDL7141, recently introduced by Infineon, is a smart gate driver IC for three-phase, battery-powered BLDC motor drive inverters. The IC can operate over an input voltage range of 5.5 to 60 V. Interfacing with a microcontroller, the gate driver supports single- or three-shunt designs operating with trapezoidal control using Hall sensors or sensorless field-oriented control algorithms.

Many key system functions are integrated into a single package, including configurable gate drivers able to operate up to 100% duty cycle, buck regulator, linear regulator, current-sense amplifiers and protection circuitry. This enables designers to significantly reduce component count, reduce PCB area and routing, which helps to meet the challenges of housing motor drives in small and awkwardly shaped cavities.

Such applications include cordless power tools like drills, screwdrivers or circular saws, which operate from battery packs in the 12-V to 48-V range. In these products, space is very limited and the PCB shape is usually not ideal for ease of layout. For example, the PCB could be circular with a hole in the center to enable mounting to the motor. Fig. 1 presents an example of such a motor drive inverter board in a battery-powered tool, which serves to illustrate the PCB design challenges. Alternatively, the PCB may be shaped to fit inside the tool handle.

Fig. 1. A circular BLDC inverter board.

Fig. 1 illustrates how much of the limited PCB area is taken up by the six MOSFETs, for which a variety of SMD power packages are available such as D^2PAK-7P, TOLL, QFN or DirectFET. That does not leave much room for the controller, gate drive and associated functions.

This article discusses how the high level of integration provided by the 6EDL7141 gate driver IC addresses the space limitations encountered in power tools and similar battery-powered applications. It also explains key details of the design process when implementing motor drive inverters using this IC.

Consolidation Of Motor Drive Functions

Fig. 2 depicts how the 6EDL7141 integrates many of the BLDC inverter's essential functions into a 7-mm x 7-mm, thermally enhanced 48-pin VQFN package, which is small enough to fit in the remaining space. Its architecture is based around a digital core with around 50 operating parameters, which can be programmed via an SPI interface using a dedicated GUI tool with a simple dongle connected to a USB port.

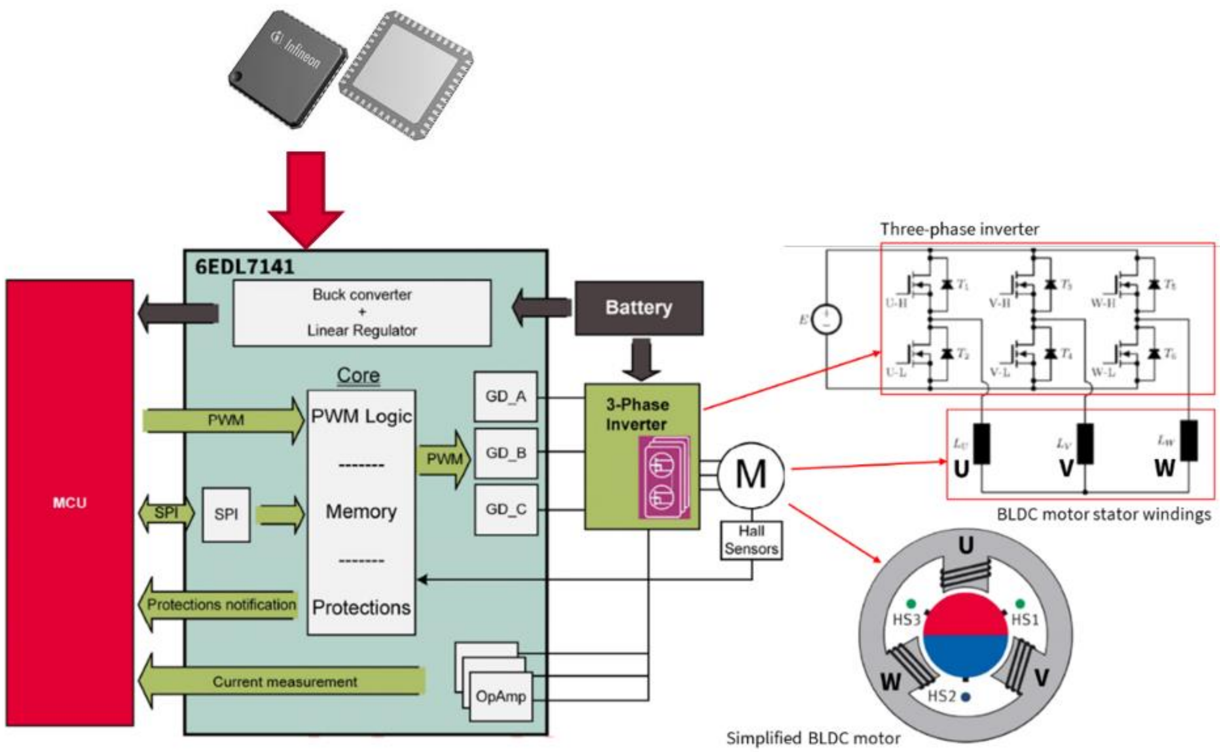

Fig. 2. System block diagram showing key elements of a BLDC motor drive inverter and how many of these functions are integrated within the 6EDL7141 gate driver IC.

These operating parameters include a set of high- and low-side gate drive current and timing settings, which eliminate the need for external resistor and diode gate drive networks. This not only saves on component count and space but also makes the designers' task of optimizing MOSFET switch-on and switch-off quicker and easier. Now instead of soldering different resistors onto the board to test, they simply need to adjust the parameters on a laptop through the GUI.

The design process involves calculating the gate-drive parameters based on MOSFET characteristics found in the datasheet and the desired slew rate (dv/dt). The slew rate is controlled by the gate current during the switching transition period. By adjusting the gate source current during turn-on and sink current during turn-off, the charge and discharge time can be controlled.

The desired slew rate may be fast to minimize switching losses. However, it is also necessary to meet EMI radiated emission standards, which may be exceeded if the slew rate is too fast. The process of determining the fastest possible slew rate while remaining within EMI limits in a test facility is clearly much easier when adjustments can be made without having to change any components. An EMI test-setup for radiated emissions is pictured in Fig. 3.

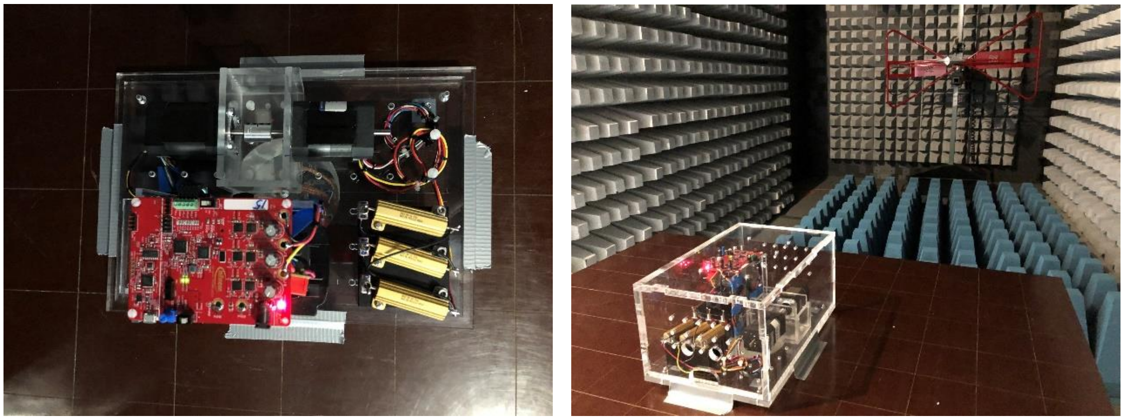

Fig. 3. Radiated emissions testing of a motor drive allowing adjustment of parameters via the GUI.

In addition to replacing three half-bridge gate driver ICs and resistor networks, several more components can be removed due to the integrated power supply architecture. This includes all of the elements of the buck regulator used to supply the inverter circuitry and gate drives, apart from the inductor and output capacitor. The buck output can be 6.5 V, 7 V or 8 V depending on the user-selected gate-drive voltage from the four available values: 7 V, 10 V, 12 V or 15 V.

A very stable low-noise digital supply voltage for the system microcontroller is also provided by means of an integrated low dropout linear regulator fed from the buck regulator output. This digital voltage bus can be user configured to 3.3 V or 5 V.

The microcontroller interfaces with the 6EDL7141 through its PWM outputs, which can be configured in several different ways. In some cases, the microcontroller may provide all of the gate-drive signals individually with the dead time determined in the firmware, or alternatively a simplified PWM input signal to the 6EDL7141 can be decoded by the device's internal logic where the dead time is inserted according to a user-defined value.

Feedback information from the current-sense amplifiers and fault detection circuitry is also an essential part of this microcontroller-gate driver interface. To minimize trace lengths and avoid noise pickup, the microcontroller should be placed near the 6EDL7141 on the PCB.

Determining Parameters For Gate-Drive Optimization

The gate drives often require higher voltages than the buck regulator output. These voltages are derived from charge pumps also integrated in the 6EDL7141 that support high-side gate-drive pulses up to 100% duty cycle requiring only external SMD ceramic capacitors. The gate drivers provide controlled sink and source currents during the switch-on and switch-off operations, each of which are divided into three stages.

For switch-on, the time periods for the first two stages are selectable from a range of available values as well as the source currents. During the first stage the gate is charged to a point just before switching begins, this should be above the threshold voltage $V_{GS(TH)}$ and below the gate plateau voltage. During the second stage the hard-switching transition occurs as the gate voltage plateau is traversed. Finally, the gate voltage is raised to its full voltage, which is chosen by the user based on the MOSFET $R_{DS(ON)}$ versus V_{GS} voltage characteristics (Fig. 4).

For switch-off, the sequence is reversed so that in the first stage the gate voltage is discharged from the full drive voltage to the plateau voltage, the second stage traverses the plateau during the switch-off transition and the final stage discharges the gate voltage to zero. In this case, the 6EDL7141 provides selectable currents and time intervals for the first two stages.

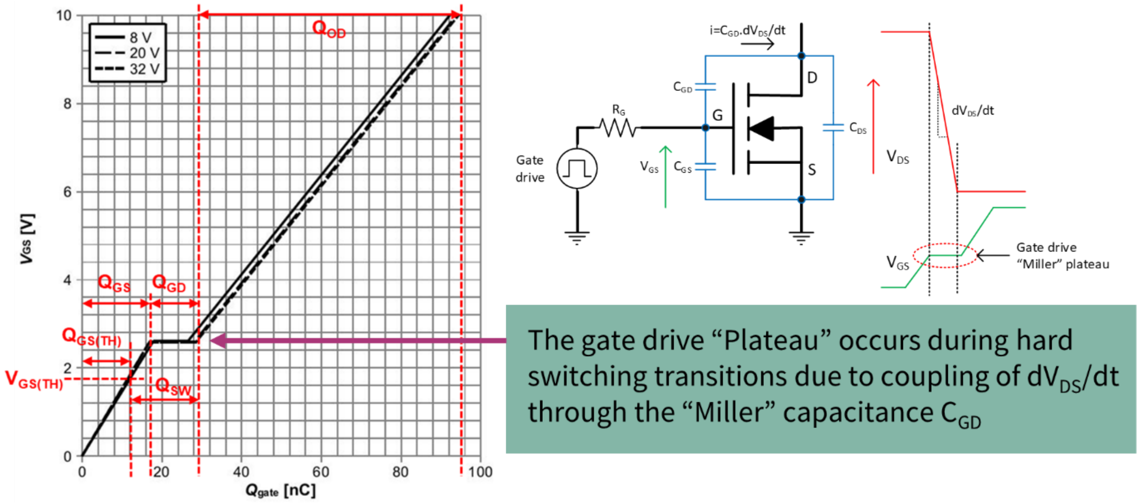

Fig. 4. Gate charge during switch-on and switch-off.

Calculating the gate drive values is fairly straightforward based on gate charge parameters provided in the MOSFET datasheet. A simple tool is available from Infineon to perform these calculations (Fig. 5).

The system parameters used in the following example are based on a power tool application operating from an 18-V battery pack, which is the most widely used. The maximum power rating was selected as 500 W, to reflect a typical motor size used in a drill. The design is based on 40-V best-in-class MOSFETs in a QFN 5x6 SMD package. The MOSFET parameters required for the gate drive calculations, which are entered here, are taken from the datasheet.

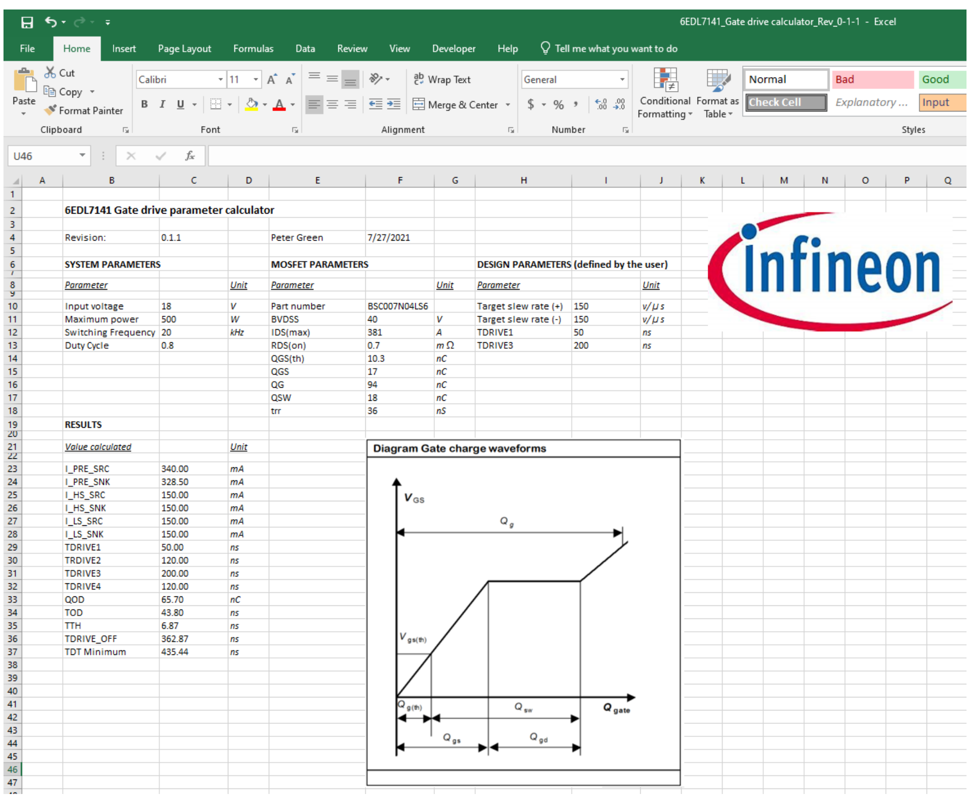

Fig. 5. Gate-drive parameter calculation tool.

Current Sensing Features

A typical motor drive inverter includes one, two or three current shunts depending on whether trapezoidal or sensorless field-oriented control (SL-FOC) is used. Some FOC algorithms are able to operate from sensing current in only two phases whereas others sense all three. It is also possible to eliminate the shunts by using $R_{DS(ON)}$ sensing to detect the low-side MOSFET on-state voltages as an alternative current-sensing method. However this is a less accurate method due to $R_{DS(ON)}$ tolerance and temperature coefficient, but possibly sufficient for cost-sensitive designs.

To implement $R_{DS(ON)}$ sensing, the 6EDL7141 has the ability to sense the drain voltages when low-side MOSFETs are switched on while providing high-voltage blocking when they are not. Clearly such a scheme would be inconvenient to implement externally and would require several additional components. The 6EDL7141 current-sensing mode can be selected by the user.

To minimize power dissipation at high motor-phase currents, the shunt resistances or on-resistances are in the range of a few milliohms. The voltages produced therefore require precision amplifiers to increase these signals to a range where they are able to be received and digitized by the microcontroller. Integration of three current-sense amplifiers within the 6EDL7141 again saves PCB area by eliminating external ICs and surrounding components. This also makes configuration of gains and offsets possible through the GUI tool while minimizing noise.

Switch-on transients commonly appear on current-sense signals, which are difficult to filter out using RC networks since these introduce delay. Leading-edge blanking synchronized to the gate drive is a widely used technique built into many ICs to overcome this. The 6EDL7141 includes such functionality with user-selectable blanking time settings eliminating the need for any external filtering.

Fault Protection—Integrated And Configurable

Fault detection and protection modes are another very important aspect of system design. Fault conditions may include overcurrent, overtemperature or a locked rotor, often caused by a damaged motor or jammed mechanism. In such situations the inverter needs to shut down before any electronic components fail.

Again, external current and temperature sensing would require a significant number of components such as comparators, voltage references and temperature sensors, all taking up board area. The 6EDL7141 eliminates these components by including three comparators with internal voltage references, which can also be programmed by the user to provide positive and negative voltage thresholds for fault detection.

When a fault is detected there are different options available to determine how the system will react. For example, the fault can be signaled to the microcontroller and/or configured to trigger a braking action directly and independently of the microcontroller. Several different braking modes are possible and these can also be selected in the device configuration via the GUI tool (Fig. 6). It is also possible to limit the phase currents by terminating the PWM gate-drive pulses rapidly if an abnormally high current is detected.

In power tool applications when, for example, a drill is used for an extended period of time, the internal temperature and that of the inverter components may rise to levels that risk damage to the components. This being the case, it is necessary for the system to include thermal protection. The 6EDL7141 includes a temperature sensor operating at the die level, whose value may be read through the SPI interface.

This can be a useful feature during the design phase as the test engineer can check the temperature through the GUI tool. In the system, a warning is signaled to the microcontroller if a temperature exceeding 125°C is detected. Should the temperature rise above 150°C the gate-drive outputs will be switched off to prevent MOSFET thermal failure.

Device Configuration Using The GUI Tool

The GUI tool (pictured in Fig. 6) allows the designer to select the values and options described for the on-board power supplies, gate drive outputs and protection modes previously discussed.

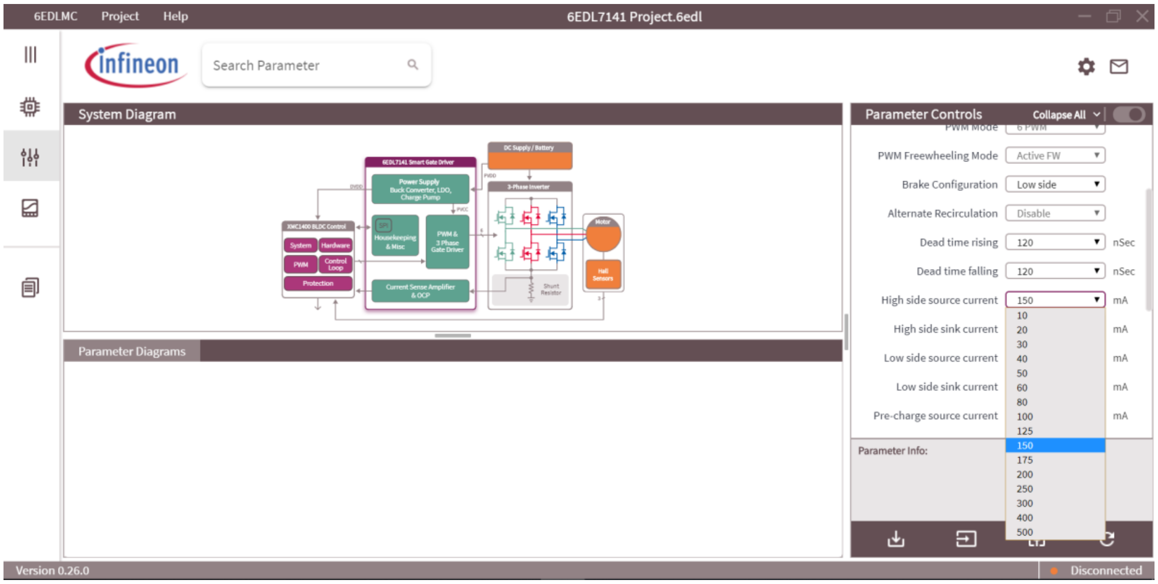

Fig. 6. Entering the parameters and protection modes with the PC-based GUI tool.

Summary

The high level of integration and configurability provided by a smart three-phase gate driver with dedicated functionality for motor drives greatly simplifies PCB layout. It has been shown here that a very significant component count saving can also be achieved to reduce overall area. Apart from enabling space reduction, the task of optimizing the inverter performance and EMI compliance is made less time consuming and more convenient for the engineer through digital configuration of the system parameters by means of a computer-based simple-to-use GUI tool.

References

1. 6EDL7141 datasheet

2. Application Note AN_2104_PL88_024859, EVAL_6EDL7141_TRAP_1SH 18V brushless DC motor drive board, V1.0, June 11, 2021, requestable via link on 6EDL7141 product page.

3. BSC007N04LS6 datasheet

About The Author

Peter Green currently manages a team of applications engineers at Infineon Technologies Americas supporting renewable energy and battery-powered motor-drive applications based in El Segundo, California. He has worked in the power electronics industry for 35 years with 20 years in semiconductor applications engineering at Infineon and International Rectifier.

For more on designing motor drives, see How2Power's Design Guide, locate the Power Supply Function category and click on ”Motor drives”.