BLDC-Based Cordless Power Tools Offer Longer Run Times and a Better User Experience

Integrated motor control simplifies the challenge of driving BLDC motors

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Cordless power tools are becoming increasingly popular in professional and DIY usage due to their ease of use, portability, and increased safety over mains-powered tools. With the inclusion of brushless DC (BLDC) motors, they are now suitable for most tasks.

However, manufacturers are being challenged to reduce the size and weight of tools to enhance ergonomics as well as extending battery life between charges. At the heart of all cordless tools is the motor controller that has a significant influence on allowing designers to meet end-market objectives of more convenient use.

This article discusses the challenges that need to be overcome to deliver state-of-the-art power tools and also considers how highly integrated motor controllers play a significant role in meeting contemporary design challenges for this application.

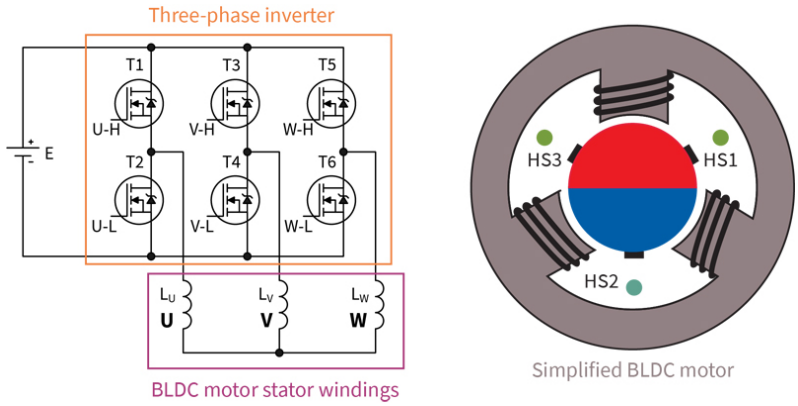


Figure 1: Three-phase BLDC motor drive overview

The world of power tools – today and in the future

Sales of cordless power tools are strong and rising rapidly. A relatively recent report by Future Market Insights estimated that the market was worth around US $27 billion in 2015, rising to over US $45 billion by 2025. Their report calculates a growth rate (CAGR) of 3.7 percent between 2016 and 2020 and, furthermore, shows this rising to an estimated 5.1 percent between 2021 and 2031. Many factors drive this acceleration in growth, and a general improvement in the construction industry worldwide is one of those. With the cost of moving house being high, many homeowners are deciding to improve their current house on a DIY basis rather than move. The recent pandemic has only accelerated things further, as people generally have more time at home and more disposable income to do repairs and upgrades.

In industry, as operational efficiency increases in importance, cordless power tools are increasingly being used on assembly lines to speed up processes.

In the past, Ni-Cd or Ni-MH powered cordless tools with brushed DC motors had some limitations, hence corded tools were preferred for the most demanding tasks. However, with a shift to Li-ion battery power and brushless DC (BLDC) motors, the capability of cordless tools is now on a par with their corded cousins.

Convenience, portability, and safety are the primary factors for professionals and DIY users choosing cordless tools as there are no mains voltages present and no power cord which can be snagged, tripped on, or cut through during use.

Key challenges for designers

The primary challenge for designers of cordless power tools is the need to constantly reduce size and weight while increasing the run-time between charges (or changes of battery). In fact, these goals often conflict as a larger battery increases run-time but also increases size and weight.

The motor is key to solving the challenge, and two main types are in use. Older brushed DC motors have an armature (rotor), commutator, brushes, spindle, and permanent magnets. The more modern BLDC motors operate without brushes, thereby removing a wear-out mechanism and reducing rotational friction, which extends the operating time.

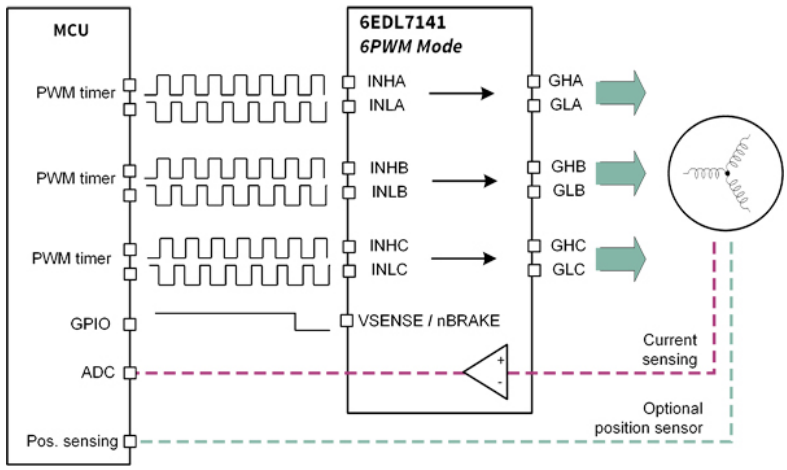


Figure 2a

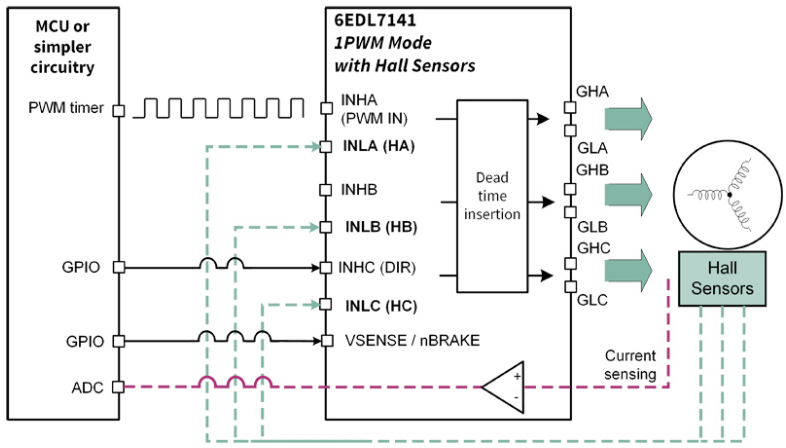
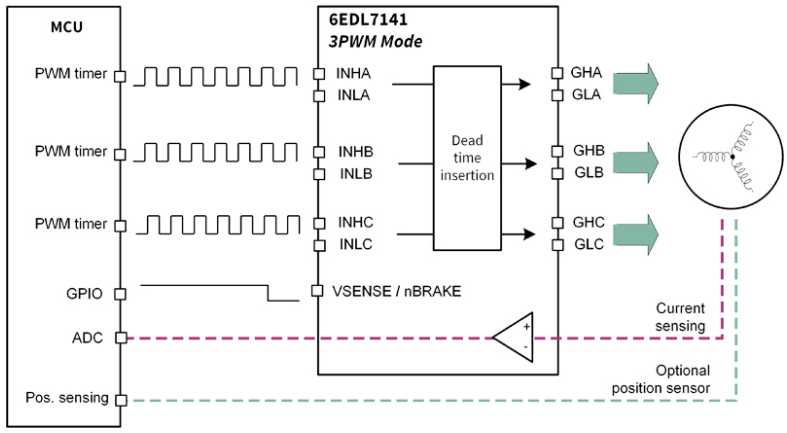


Figure 2b



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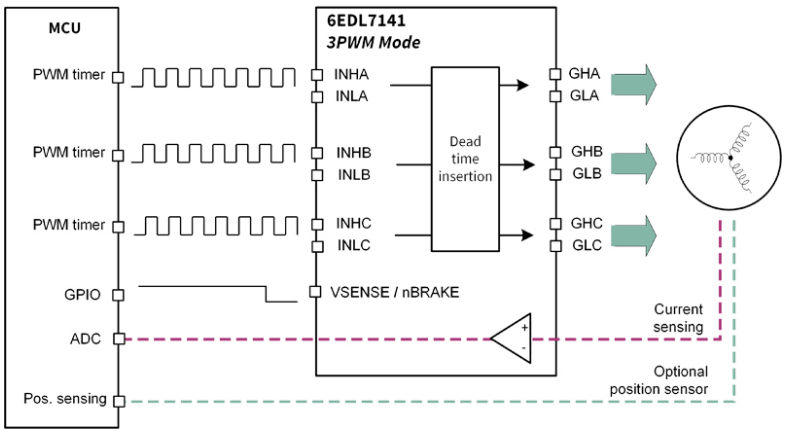

Figure 2d

Figure 2: There are multiple PWM motor drive schemes available: 6PWM (a), 1PWM with Hall sensors (b), 3PWM (c), and 1PWM without Hall sensors (d)

Generally speaking, BLDC motors are becoming the preferred choice for designers as they are more powerful for a given size and are virtually maintenance-free. However, they are more expensive than the brushed type, and the method of control is somewhat more complex.

Designers pay a lot of attention to ergonomics in modern power tools. As they are used for extended periods – especially by professional users – the shape is important. However, in designing the most comfortable space for the user, the designer often finds challenges in fitting an ideal motor and battery in the housing.

During normal use, all cordless tools will experience both electrical and mechanical stresses and shocks that they must survive. Hence, protection circuitry is an essential element of any design to protect the control electronics and motor.

Typically, power tools need to be reasonably well sealed from the dust, dirt and damp they encounter during use. While this is necessary to prolong life, it hampers cooling, meaning that efficient operation is required, especially if the tool is required to operate in elevated ambient temperatures.

The final point is reliability; especially with professional users, tools that are not reliable and robust will fail prematurely, damaging the manufacturer's reputation in the process through a bad customer experience.

Key elements of a cordless power tool

Within their electrical systems, cordless power tools typically comprise a battery, motor drive circuitry, protection circuitry, the motor, and often a microcontroller (MCU). In most cases, the battery is removable, which means that battery charging circuitry is located in an external charger.

For a BLDC motor, the most common drive topology is a three-phase inverter that is driven by a PWM signal from the MCU. As most BLDC motors have three stator windings, each winding is driven by one phase of the inverter, and sensing is performed by a trio of Hall Effect Sensors.

Each phase of the inverter requires a PWM drive signal that is 120° out of phase with respect to the other PWM drive signals. One approach for this is for the MCU to produce a single-phase PWM signal that is used in conjunction with modulated GPIO lines to control the motor in the desired direction. Another approach is for the MCU to generate all three required phases to drive the inverter directly.

Protection circuitry usually involves operational amplifiers (op-amps) and/or comparators that measure key voltages, temperatures, and currents. While these signals can be used directly to restrict or shut down motor operation, in many cases, they are fed directly to the MCU that takes appropriate action to ensure the safe operation of the tool.

It is possible to design and implement a cordless power tool control system in discrete components, but this can be bulky and take significant time

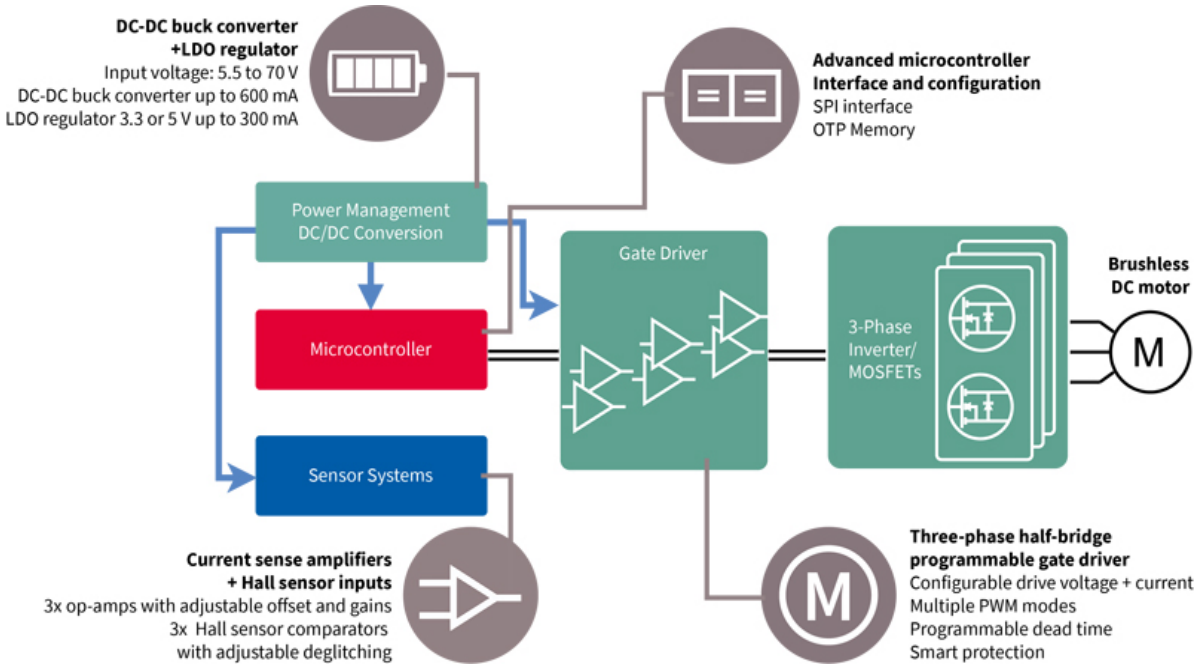

Figure 3: Overview of the 6EDL7141 smart three-phase motor gate driver

due to the relative complexity of driving BLDC motors. Consequently, many designers prefer to use integrated drivers.

Infineon's cutting-edge hardware/technology enables overcoming the challenges

One of the latest devices to become available for use as a three-phase smart motor driver in cordless tools (and other applications) is the 6EDL7141 from Infineon. This highly integrated device contains all of the key elements required to provide the compact solution that is needed for a successful cordless tool design.

At the heart of the device is the programmable three-phase half-bridge gate driver that allows designers to configure the gate drive voltage and current. Compatible with several PWM modes (1PWM, 3PWM, and 6PWM), the half-bridge also offers a programmable dead time and configurable turn-on/off profiles. Additionally, three motor braking modes (high side, low side, and alternate) are offered.

Allowing designs to be completed without compromise, the circuit can be configured for a variety of MOSFETs – and there is no need for a gate drive diode or resistor, reducing external component count.

A trio of Hall sensor comparators (with de-glitching) are built-in, as are three operational amplifiers with adjustable gain and offset that can be used for protection to enhance system reliability.

Inbuilt power management and DC-DC conversion permit a wide input voltage range (5.5 V to 70 V) with DC-DC conversion and LDO regulators providing the voltages required by the system. The power section also includes high- and low-side gate driver charge pumps.

While EMI performance is good with the integrated design, a particularly useful feature is the ability to software configure the gate drive slew rate to reduce EMI, thereby allowing a marginal design to gain approvals.

The MOSFET technology of choice for cordless power tools – OptiMOS™ 6

While the 6EDL7141 can be configured to use a variety of external MOSFETs to suit a

Figure 4: Infineon's BSC007N04LS6 OptiMOS™ MOSFETs are ideally suited to cordless power tools

wide variety of applications, the Infineon BSC007N04LS6 is particularly well-suited to many applications. Part of the OptiMOS™ 6 40 V power MOSFET family, the devices offer best-in-class $R_{DS(on)}$ of 0.7 mΩ and superior switching performance due to low gate charge (Q_g). Capable of handling over 180 W of power and operating at temperatures up to +175°C, the MOSFETs can perform in challenging cordless power tool applications.

Infineon's OptiMOS™ 6 technology ensures that the MOSFETs have excellent figures-of-merit with Q_g x $R_{DS(on)}$ improved by 29 percent over previous devices and Q_{gd} x $R_{DS(on)}$ improved by 46 percent, allowing designers to achieve the necessary performance.

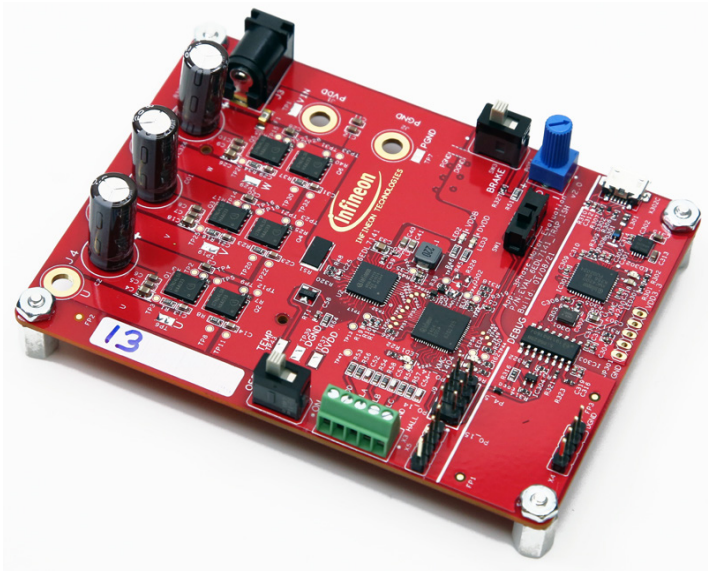

Figure 5: Infineon's advanced motor drive evaluation board

The BSC007N04LS6 devices are housed in surface-mount, 8-pin, SuperSO8 5x6 packages that are compact and easily mounted inside compact cordless power tool designs.

Design support tools – making configuration easy

The 6EDL7141 is easily configured and adapted using freely available GUI software from Infineon as part of its toolbox. The intuitive software allows system parameters to be selected from drop-down menus and configurations to be saved to a file. The GUI also incorporates motor drive firmware which can be downloaded to the MCU via an integrated SPI interface.

The GUI is also capable of monitoring the status of the 6EDL7141 device and its registers during operation, as well as controlling the motor, making it incredibly useful for development and debugging.

Soon available to support designers will be Infineon's motor drive evaluation board (EVAL_6EDL7141_TRAP_1SH). The board is optimized for 18 V battery-powered tools operating with trapezoidal control. You may check back with our support on the release of the board.

The board includes six

BSC007N04LS6 MOSFETs, and a detachable heatsink can be mounted to the underside of the board to improve thermal management and increase power handling for larger applications.

Based upon Infineon's XMC1400 microcontroller, the board includes a debugger that can be directly connected to a PC via USB. Source code for the XMC™ microcontroller is implemented using the Eclipse-based IDE, DAVE™.

Using the evaluation board, users can assess the 6EDL7141-based motor drive system and the control capabilities of the XMC1400, along with the control algorithm that includes features that have been specifically customized for cordless power tool applications.

Summary

Cordless power tools are becoming the preferred option for many users due to their convenience, portability, and safety. As they migrate to Li-Ion batteries and BLDC motors, performance is now very comparable with corded mains-powered tools.

Designers face a number of challenges to be able to deliver tools that are ergonomic, small, light, powerful, and able to run for long periods between charges or battery swaps. Also, BLDC motors, while lighter and more powerful, are somewhat more complex to control. Key to meeting these challenges is efficient operation and compactness, which generally leads to an integrated solution.

Infineon's newly released 6EDL7141 three-phase smart motor gate driver provides a highly integrated solution that includes most of the system elements required for a cordless power tool design. Conveniently, the MOSFETs are external, allowing designers to select the most suitable device from Infineon's market-leading and highly efficient OptiMOS™ family.

The 6EDL7141 is supported by Infineon's XMC™ series microcontrollers which allow the use of the DAVE™ IDE for development. Additionally, a GUI-based application is available for convenient configuring and debugging of driver and motor parameters.

The cordless power tool market is significant and growing, and, as a result, Infineon is continuing to invest in integrated solutions for this market. Forthcoming motor drive products are likely to include higher levels of integration and the ability to operate with more battery voltages.

Browse Infineon's offering for cordless power tools here.

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