Electronic Design

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Add Wireless Connectivity to Next-Gen Power Tools while Cutting Cost, Size

As power tools add capabilities like Bluetooth connectivity, it's crucial to integrate the required features into fewer devices. As such, one reference design demonstrates a single-MCU BLE solution.

Adding increased functionality to successive generations of devices isn't just a characteristic of fast-moving markets like smartphones. It's becoming commonplace in the more traditional power-tool market, which includes handheld devices such as drills, circular saws, and sanders; lawn and garden equipment; and vacuum cleaners.

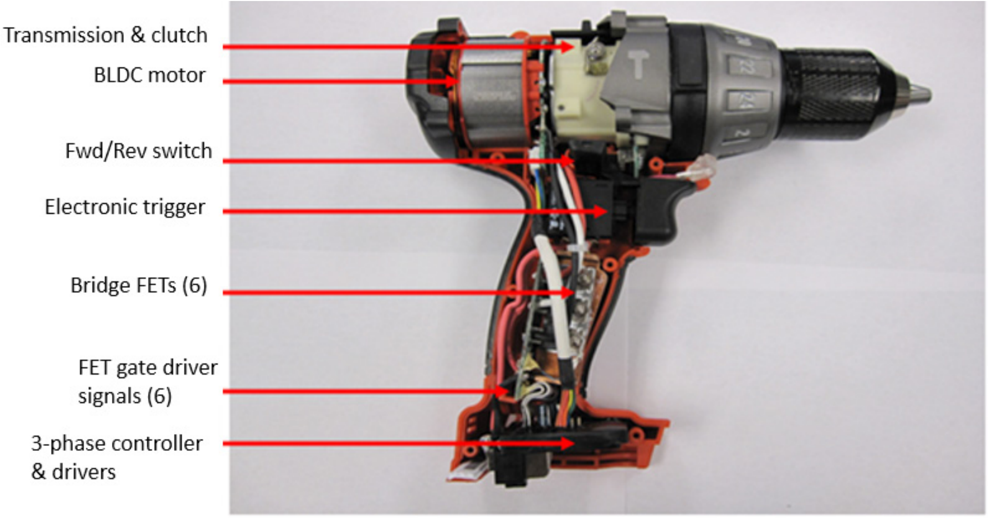
Just like their colleagues in the consumer space, power-tool designers are continually charged with cramming more electronics into the same or smaller spaces. First came the move to cut the cord by moving to battery-powered devices. The need to conserve battery power led to a switch from brushed to more-efficient brushless DC (BLDC) motors with their more complex control schemes, sensors, and power drivers.

A current-generation handheld tool with a BLDC drive is a packaging marvel *(Fig. 1)*, with every nook and cranny occupied. But the latest power tools are raising the bar yet again. They're adding wireless connectivity as an available feature, beginning with the professional market and migrating to home and hobby products.

WHY WIRELESS?

For the construction professional, wireless connectivity offers features such as authentication, tracking, intelligent inventory management, fault reporting, and information about battery condition or total operating time. If the tool goes out of range and leaves the job site, the battery can shut down.

The home user will benefit from features such as a "lending button" to allow for the sharing of battery-powered equipment. When a neighbor borrows a cordless lawnmower,



1. A handheld power tool leaves little room for the BLDC controller (it's in the handle), even before adding BLE functionality. (Source: TI blog: "Demand for higher power density drives innovative power tool solution," Fig. 2)

2. Although the new wireless connection did help track down his missing lawnmower, Walter realized that his addition of a flare gun was not an improvement. (Source: Flickr)

A wireless microcontroller needs features such an RF front end, a high-frequency reference clock, a digital phase-locked loop (PLL), and DSP modem capability.

The BLDC section also deals with high-voltage, high-current switching signals with fast rise and fall times. These can generate high levels of electromagnetic interference (EMI) and cause problems for the sensitive analog circuitry of the RF front end. With separate MCUs, it becomes easier to lay out the printed circuit board (PCB) to separate high-current and low-current ground paths and keep switching noise off the RF power rails.

So far, so good. However, each successive design must not only achieve higher performance, but cost less and occupy less space. What steps can the designer take to meet these goals?

say, the owner can select an amount of time for it to be lent out. When time expires, the battery shuts down and the owner receives an alert. Preferably on their smartphone and not the approach used in *Figure 2*.

The most common method for adding wireless connectivity is via a Bluetooth Low Energy (BLE) module, either inside the existing case or attached externally as a separate unit.

The traditional block diagram of a connected power tool includes two microcontrollers (MCUs): one for BLDC motor control, and the other for Bluetooth wireless connectivity.

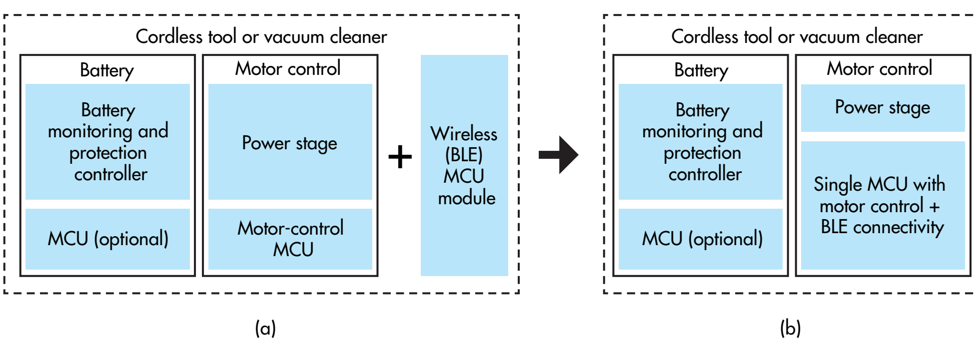
There are good reasons for this segmentation of functions. The wireless and BLDC blocks require very different feature sets. Controlling a BLDC motor calls for high-resolution pulse-width-modulation (PWM) timers, a multichannel analog-to-digital converter (ADC) with the necessary conversion speed, general-purpose input/outputs (GPIOs) with interrupt capability, and wired connectivity options.

COMBINE MCU FUNCTIONS TO SHRINK COST AND SIZE

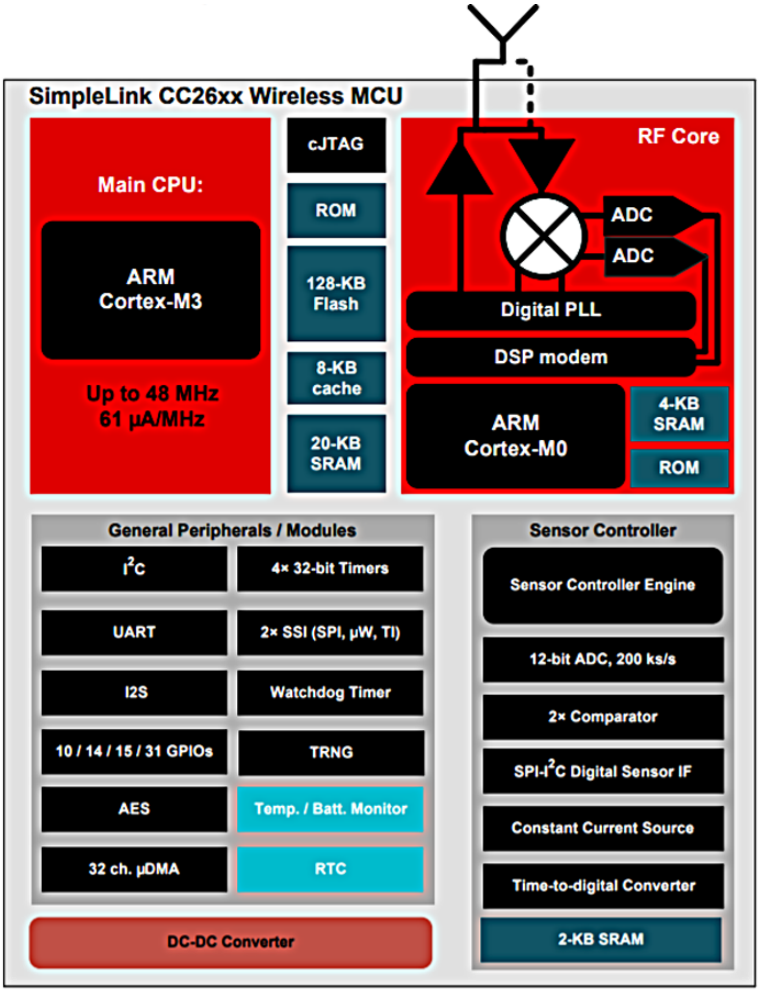
Partitioning the wireless and BLDC functions into separate MCUs is a tried-and-tested option, but it's better to combine the two blocks into a single MCU *(Fig. 3)*. It creates a more compact solution, as well as reduces the power consumption and BOM cost. Of course, the MCU chosen must contain the required peripheral blocks, processing power, and memory to execute both BLDC and wireless functions.

The SimpleLink MCU platform from Texas Instruments combines Arm Cortex-M cores with a range of wired and wireless connectivity options that include Ethernet, CAN, USB, sub-1-GHz, Wi-Fi, Zigbee, and Bluetooth.

The CC2640R2F *(Fig. 4)*, for example, is well-suited to space-constrained power-tool applications that prioritize low power consumption and small size. Its feature set includes:



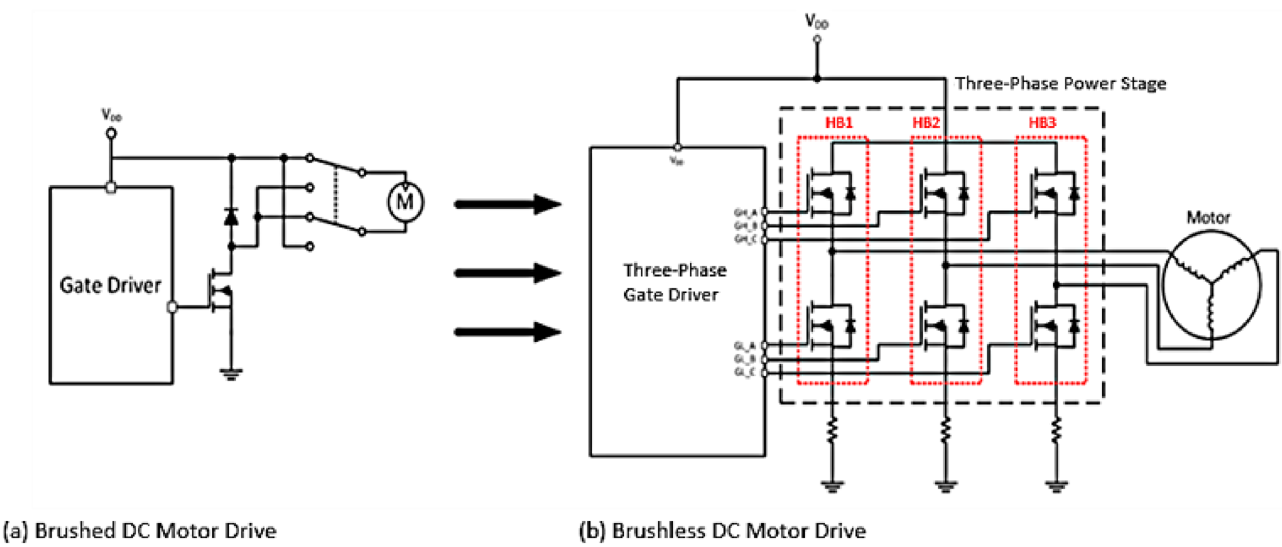
3. Combining a pair of MCUs (a) into a single device (b) is a worthwhile approach to reduce cost and size in a wireless design. (Source: TI blog: "Connectivity helps integrate intelligent motor control on a single MCU")



4. The C2640R2F wireless microcontroller provides both BLE functionality and the power to run a BLDC application. (Source: TI: "CC2640R2F SimpleLink Bluetooth low energy Wireless MCU" PDF)

- *Primary core:* 32-bit ARM Cortex-M3 running at 48 MHz with 128-kB flash memory, 20-kB SRAM, and a cJTAG test and debug interface.
- *Wireless communications:* The RF block contains the RF and digital circuitry to run Bluetooth 4.2 and Bluetooth 5 low-energy communications. It includes a secondary ARM Cortex-M0 core with dedicated RAM and ROM that embeds a Bluetooth controller and host libraries for improved performance.
- *Peripherals:* Its feature set includes GPIOs, timers, a watchdog timer, and an AES encryption block. The MCU also incorporates a unique ultra-low-power sensor controller that can collect analog and digital data from external sensors autonomously while the rest of the system is in sleep mode.
- *Low-power modes:* The C2640R2F consumes very low RF and MCU current during operation. For example, the Cortex-M3 consumes 61 µA/MHz and the Tx circuit uses 9.1 mA at +5-dBm power level. In standby mode, the device consumes 1.1 µA, and only 100 nA in shutdown mode to maximize battery life.

The user can verify that the C2640R2F will support both BLE and BLDC operation using the firmware supplied with the TIDA-01516 reference design discussed below. The firmware package, free to download, includes the Code Composer Studio (CCS) integrated



5. The BLDC requires a more complicated drive circuit than the equivalent brushed dc motor. (Source: TI blog: "Demand for higher power density drives innovative power tool solution," Fig. 1)

development environment (IDE) v7.2, the SmartRF Studio RF measurement platform for Windows, and configuration files for the peripheral devices.

INTEGRATED DRIVER SIMPLIFIES BLDC CONTROL, CUTS COMPONENT COUNT

The designer can then turn his or her attention to the BLDC portion of the system. A BLDC is more efficient than its brushless dc counterpart, but it requires a more complex control design and driver circuit *(Fig. 5)*. In place of the single gate driver and power FET of the brushed motor, the BLDC motor requires six FETs—one for each phase—arranged into three half-bridge pairs.

In addition to the controlling MCU, the other blocks in the BLDC drive system are:

- A three-phase power stage with the required power capability
- Gate drivers to drive the power stage MOSFETs
- A position sensor for accurate motor current commutation

The traditional approach might use six separate power FETs, each one with its own driver, regulators, protection circuitry, and other components.

An integrated gate driver can decrease system size, cost, and complexity by combining multiple functions into a single package. The DRV8323, for example, integrates the functions needed to drive three independent half-bridge circuits consisting of high- and low-side N-channel power FETs. The part includes three pairs of high- and low-side gate drivers, plus a linear regulator and doubler charge pump for their supply voltages. The DRV8323 also integrates three current sense amplifiers and an optional 600-mA buck regulator.

A standard serial peripheral interface (SPI) provides a simple method for configuring the various device settings and reading fault diagnostic information through an external controller. Alternatively, a hardware interface option allows the user to configure the most common settings with fixed external resistors.

The DRV8323 has four different PWM modes for different levels of control. The simplest, 1x PWM mode, allows an MCU to control a three-phase BLDC motor with a single PWM output with the help of the DRV83823's internally stored, six-step block commutation tables. The PWM sets the output frequency and duty cycle of the half bridges and GPIO outputs from the MCU control other functions such as align and stop. Consult the datasheet for more information.

BEAT THE HEAT WITH THERMALLY EFFICIENT POWER BLOCKS

In the tight confines of a handheld power tool, finding room for six power MOSFETs can challenge even the most creative packaging engineer, especially since power transistors traditionally come in bulky packages such as TO-220, DPAK, or D2PAK. It's also difficult to get rid of the heat from the power stage, so the designer must choose devices with the lowest overall losses in thermally efficient packages.

Over several generations of MOSFET technology, designers have successively reduced the major causes of power loss: conduction, switching, body diode, and gate drive. Conduction loss depends on the drain-to-source on-resistance, $R_{DS(ON)}$, and the other losses are due to internal parasitic capacitances.

NexFET is a third-generation macrocell power MOSFET technology from Texas Instruments that offers a low $R_{DS(ON)}$ but reduces parasitic capacitances by about 50% compared to existing TrenchFET devices. Lower capacitances allow the designer to increase the operating frequency and reduce switching losses.

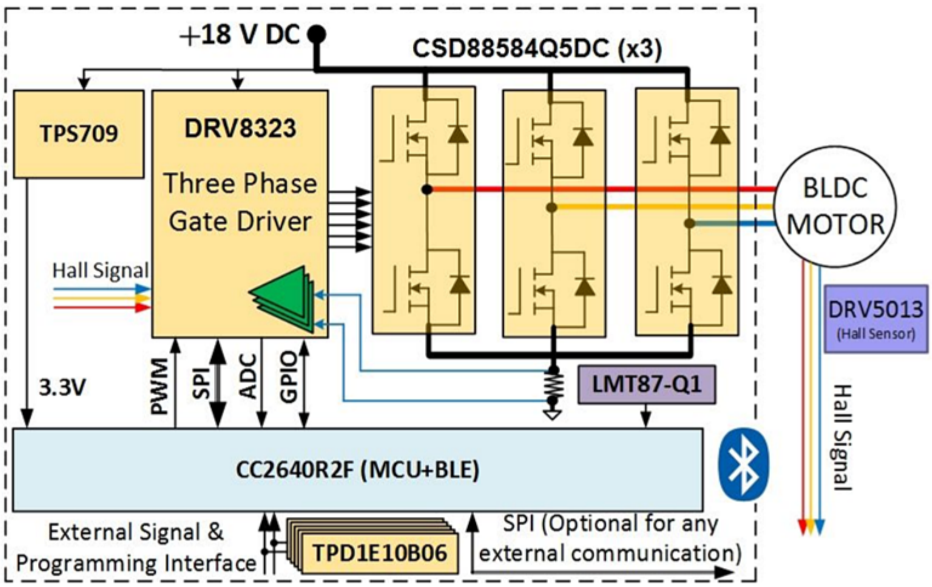
The bare integrated circuit is only part of the equation—reducing package parasitic inductance and capacitance is also key to increasing switching frequency. Multichip modules (MCMs) reduce parasitics by mounting multiple dice next to each other in a single package. Originally, designers were restricted to two dimensions, but new packages are placing components on top of each other in a three-dimensional arrangement.

Three-dimensional packaging offers electrical and thermal performance benefits if the individual components can accommodate it. The NexFET's vertical current flow makes it ideal for stacking in a half-bridge configuration because the high-side FET source terminal is located directly above the low-side FET drain terminal. This arrangement virtually eliminates resistance and parasitic inductance between the devices and allows for faster switching. In addition, the low-side source terminal is at ground potential and can be soldered directly to the exposed pad of the package for highly efficient heat transfer.

The high-current V_{IN} (high-side FET drain) and V_{SW} connections use clip-bonding technology, which replaces the wire-bond connection with a solid copper bridge. This substantially reduces $R_{DS(ON)}$ and conduction losses compared to wire bonding and provides excellent thermal performance.

The CSD88584Q5DC 40-V Half-Bridge NexFET Power Block is optimized for driving high-current dc motors in power tools. The part utilizes stacked-die technology in a thermally enhanced DualCool 5- × 6-mm package with an exposed metal top. This feature allows for the addition of a heat sink to remove heat through the top of the package and away from the PCB, and provides superior thermal performance at higher currents.

With a 24-V input voltage and maximum junction temperature T_J = 125°C, the CSD88584Q5DC's power loss is only 3.5 W when delivering 35-A output current and switching at 20 kHz. The datasheet contains a discussion of power losses, safe-operating-area (SOA) considerations, as well as a detailed design example.



6. The TIDA-01516 reference design is a 600-W BLDC controller in a small form factor. (Source: TI Designs: TIDA-01516 PDF)

POWER TOOL REFERENCE DESIGN

The TIDA-01516 reference design *(Fig. 6)* combines the devices discussed above into a compact power-tool control application. It's a 600-W BLDC motor drive design and supports 27-A rms continuous winding current without a heat sink in a small-form-factor solution measuring 70 × 45 mm. The design also includes overcurrent and short-circuit protection with MOSFET V_{DS} sensing.

A single CC2640R2F MCU provides BLE connectivity and runs the BLDC control algorithm; a DRV8323 gate driver and three CSD88584Q5DC half-bridge power blocks implement BLDC trapezoidal control. The design operates from a supply of 6 to 21.6 V; a power tool typically uses 18 V from a five-cell Li-ion battery.

The complete design includes an LMT87-Q1 temperature sensor to measure PCB temperature, and TPD1E10B06 ESD protection diodes. A TPS709 150-mA, low-dropout (LDO) regulator converts 18 V down to 3.3 V for the MCU.

The design demonstrates the BLE RX sensitivity of –96 dBm even when the power stage is driving the motor, showing the robustness of RF performance. Full test results are available in the TIDA-01516 design guide.

CONCLUSION

As power tools add capabilities that include Bluetooth connectivity, it becomes more important to integrate the required features into fewer devices to reduce cost and size, while maintaining and even increasing performance. It's also critical to develop thermally and electrically efficient designs to maintain user comfort, boost reliability, and maximize battery life.

Texas Instruments has brought together a range of advanced technologies—wireless MCUs, smart drivers, third-generation power MOSFETs, and three-dimensional packaging—to help solve these design challenges. A BLDC motor control reference design shows these technologies in action.

More information is available on the Appliances and Power Tools Landing Page.