Careful designers get the most from brushless DC motors

Jon Titus, Technical Contributor

A brushed-DC motor comprises external permanent magnets and electromagnets wound on a rotating core. Brushes manufactured from graphite and other materials switch, or commutate, electricity to the coils as they rotate to sustain motion. A brushless-DC (BLDC) motor turns this construction inside out and places permanent magnets on the shaft and electromagnets around it. Electronic commutation external to the motor shifts current from coil to coil to cause the shaft to rotate.

Why would a BLDC motor appeal to designers? Paul McGrath, an electrical engineer and east-coast sales manager for Maxon Precision Motors, noted the primary reason: reliability. "By taking the brushes and mechanical commutation out of the motor you have fewer ways for a motor to fail. Often mechanical bearings determine the lifetime of a BLDC motor. Second, a BLDC motor will operate at higher speeds than a brushed motor, and third, the operating environment might dictate a need to eliminate brushes that could cause contamination or arcing."

"Equipment designers also must determine whether or not they need a gear head for their BLDC motor," continued McGrath. "A gear head will experience wear over time and it could fail before an attached BLDC motor. So just substituting a BLDC motor for a brushed-DC motor doesn't inherently increase life or reliability of mechanical equipment. You must look at your system as a whole."

The SpaceX Falcon 9 space vehicle "Dragon," launched on 22 May 2012, depended on Maxon BLDC motors to rotate solar arrays and keep them aligned with the sun as Dragon orbited the earth, open the instrument bay door which contained navigation equipment, and lock in place the fixture that let the International Space Station grab the Dragon capsule. BLDC motors also find use in medical devices, semiconductor-manufacturing apparatus, miniature pumps, and diagnostic instruments.

Brian Chu, marketing manager for the driver and analog interface products at Microchip Technology said, "When engineers look at increasing motor efficiency, they should consider the current rating in addition to a motor's power rating. Current should be the primary parameter for measuring efficiency because the voltage used to drive a BLDC motor tends to remain fixed. The I^2R formula shows how much power your motor and its electronics consume."

"In a BLDC motor controller, integrated-gate bipolar transistors (IGBTs) or field-effect transistors (FETs) switch power to motor coils," said Ward Brown, a staff applications engineer at Microchip. "These transistors dissipate energy when the motor runs. FET manufacturers continue to offer devices with lower resistances, but as you drive higher currents, transistors cause power loss that affects overall efficiency. IGBTs offer a bit better efficiency because they exhibit a constant voltage drop. FETs, on the other hand, dissipate power according to I^2R." (A three-phase BLDC motor requires six power transistors.)

Engineers also must consider what technique they will use to drive a BLDC motor. Many controllers use electronic commutation to drive the coils. That commutation switches the motor current between different phases depending on the shaft angle. You could use pulse-width-modulated (PWM) signals to drive two of three motor coils and leave one coil unpowered. This situation presents an opportunity to read the motor’s back-EMF voltage across the unpowered phase which can then be used for sensorless commutation of the motor. This technique reduces switching losses because the controller turns off one motor phase at any given time. "You can increase system efficiency even further by not using PWM at all," according to Dave Wilson, technical lead for Texas Instruments Motor Solutions Group. "Instead, use 100-percent duty cycle all the time and only switch the inverter transistors at the commutation boundaries. To control the motor’s speed, simply change the DC voltage driving the inverter transistors. This approach reduces the switching losses to almost zero on all phases, and it mitigates high frequency losses inside the motor."

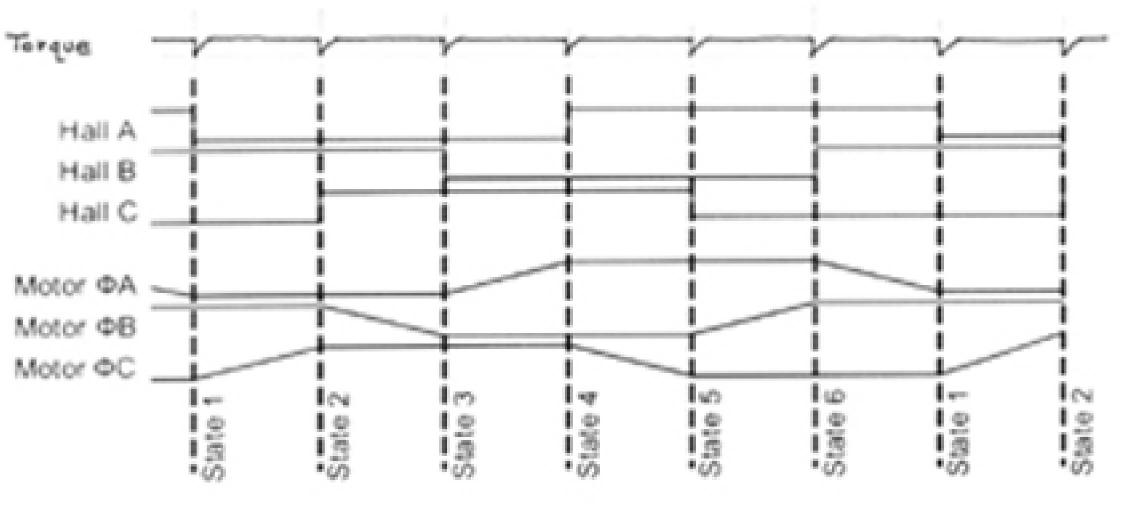

Figure 1. This diagram shows the trapezoidal current waveforms often used to drive a BLDC motor. These signals drive a 6-step motor with Hall-effect sensors spaced 120 degrees apart. Note the torque ripple. Courtesy of Texas Instruments.

Although commutation can result in good performance with most BLDC motors, it can cause torque ripple or slight changes in torque at the commutation boundaries when the current switches from one coil to another. (See Figure 1.) "Even this small torque ripple can be unacceptable in an application such as electric power steering. Vehicle drivers can feel the commutation effect on the steering wheel," added Wilson. In these applications, Wilson suggests engineers consider a technique such as field-oriented control (FOC) that drives the motor with sine waves. "By using field-oriented control, motor coils remain powered at all times and you do not use 100-percent duty cycle as discussed above. FOC can reduce torque ripple and improve dynamic response when compared with traditional commutated drives."

"Trapezoidal control offers the most basic control method when you have a BLDC motor with integrated Hall-effect sensors," said Charlie Ice, Microchip's marketing manager for dsPIC motor-control products. "Advanced algorithms for sinusoidal control or field-oriented control smooth the waveforms of the signals that drive the motor coils. The smoother signals improve motor efficiency under dynamic conditions."

Overall efficiency increases when the drive voltage matches the voltage from the motor, but where does that motor voltage come from? "Keep in mind when you manually spin the rotor of a BLDC motor it becomes a generator, so you could put the signal on a scope and characterize it," explained Ward. "When you apply a voltage to the motor, it spins and creates a voltage--a back EMF--that matches the applied voltage. When your drive circuits match this waveform exactly you get the highest efficiency. Use a trapezoidal-control signal, and you have energy losses at the points where your switching transistors turn on or off. Trapezoidal control is the easiest to implement, but not the most efficient."

To best match controller signals with motor characteristics, an engineer must do his or her own measurements and tests to understand a motor. Get some sample motors and spin them up to see what they can do.

Brushless motors come in two varieties, "sensored" and sensorless. The sensored motors include Hall-effect sensors that respond to the magnets on the motor's core. As a result, the controller can determine the position of the rotor from the sensor signals. Thus when the controller starts the motor it decides which coils to energize to move the rotor clockwise or counterclockwise. BLDC-motor controllers include a microcontroller that will run algorithms that deliver the proper commutating signals to FETs or IGBTs.

Advantages of sensored BLDC motors include good positional control, immediate high torque, and start-up with rotation in the proper direction. Disadvantages usually center on the lifetime of the sensors and extra cost for sensor-connection cables.

The sensorless motors rely on a controller that will measure the back EMF from unenergized coils to determine rotor position. When you start a sensorless BLDC motor with a commercial evaluation or starter kit you will often notice a small rotation of the motor shaft as it starts to rotate. The controller energizes two of three coils and senses the rotor's position based on the back EMF from the unenergized coil. Then the controller can apply the proper signals to the coils to start the motor. You can see this rotor "kick" effect in a YouTube video at: http://www.youtube.com/watch?v=d3fNzl_W4yg [1]. Once a sensorless motor gets started, it works well.

The sensorless BLDC motors can change direction quickly because they do not experience the hysteresis associated with sensored motors. And sensorless motors do not need extra cables for Hall-effect-sensor signals.

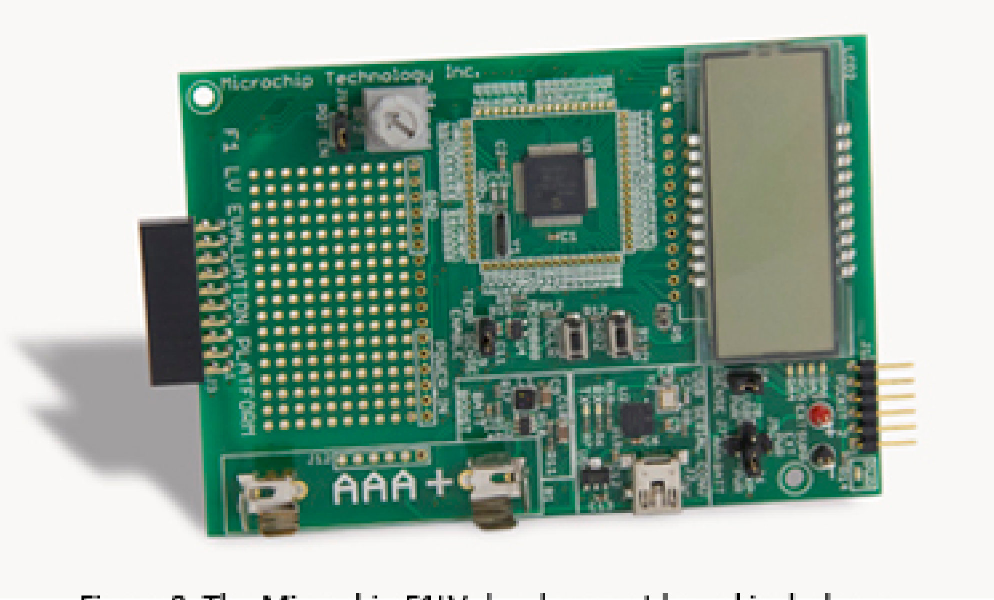

Figure 2. The Microchip F1LV development board includes a PIC16LF1947 MCU, LCD, and an expansion connector for an additional board such as a BLDC driver.

I asked my sources for this article if engineers have misconceptions about BLDC motors. Microchip's Ice responded, "They think using a BLDC motor is easy. They might not understand they must tune everything. There's never an off-the-shelf solution for every BLDC-based application. It takes some tweaking to get things right."

How Do You Get Started?

Texas Instruments, Microchip, and other companies have starter kits, evaluation boards, and development systems available to give engineers a head start with drive electronics, algorithm testing, and programming.

The F1 Low Voltage Evaluation Platform development board (Figure 2) includes a PIC16LF1947 MCU and an MCP1624 chip that can provide power from a single AAA battery. The board lets you create hardware and software for general-purpose or low-power applications for any PIC12F1xxx/PIC16F1xxx MCU. (Part no. DM164130-5, $US 39.99). Microchip sells a separate BLDC motor-driver board and motor that connect directly to the F1 board. Part no. DM164130-2, $US 99.99.

The Texas Instruments DK-LM3S-DRV8312 motor control kit (Figure 3) includes a

32-bit Stellaris LM3S818 microcontroller and DRV8312 motor driver that control a sub-50V, 6.5A 3-phase brushless DC (BLDC) motors. The kit provides a 24-volt BLDC motor. Price: $US 300. http://www.ti.com/tool/dk-lm3s-drv8312?DCMP=drv8312&HQS=stellaris-motor-... [2].

Companies that offer development kits for BLDC-motor control also have application notes, example code, design tools, and application engineers to help you create a controller that meets your design requirements.

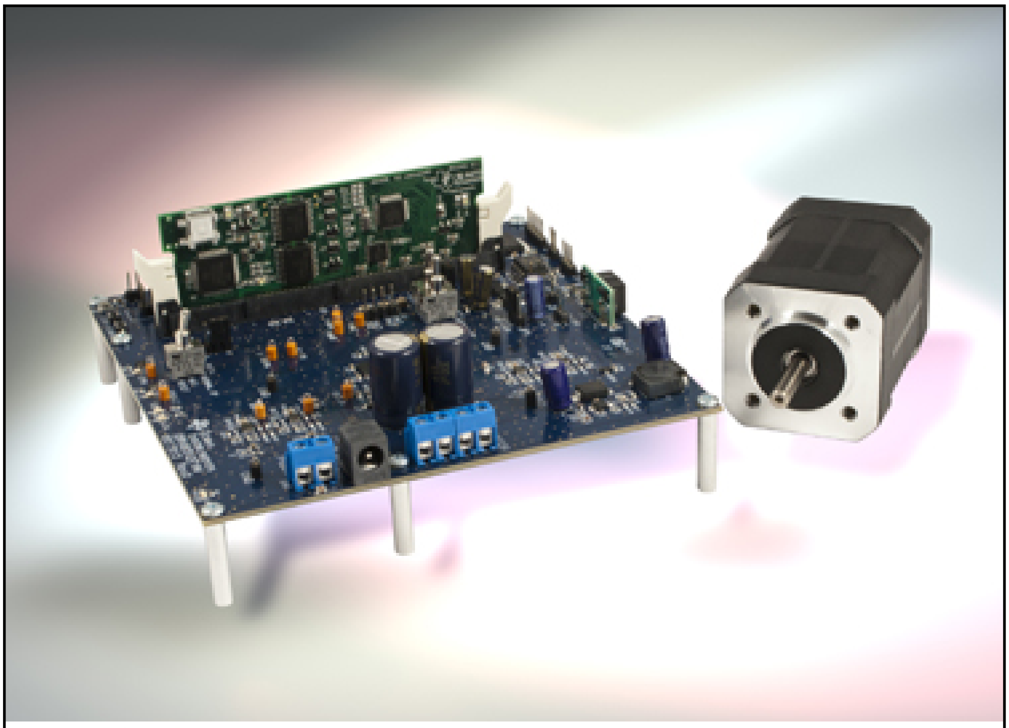

Figure 3. The Texas Instruments DK-LM3S-DRV8312 motor control kit includes a 32-bit Stellaris LM3S818 microcontroller and DRV8312 motor driver for 3-phase BLDC motors used for fans, blowers, pumps, tools and compressors.

For further reading

"Brushless DC (BLDC) Motor Fundamentals," AN885. Microchip, tinyurl.com/nqp73v [3].

Lee, Shiyoung, et al., "A Comparison Study of the Commutation Methods for the Three-Phase Permanent Magnet Brushless DC Motor." http://www.magnelab.com/uploads/4c51d9ba6fe5a.pdf [4].

Maxon Motor USA: www.maxonmotorusa.com/ [5].

Microchip Motor Control and Drive: www.microchip.com/pagehandler/en-us/technology/motorcontrol/ [6].

Texas Instruments Motor Drive & Control: www.ti.com/motor [7].

Texas Instruments Motor Drive & Control Solutions blog: e2e.ti.com/group/motor/b/blog/default.aspx [8].

Texas Motor Control videos: www.ti.com/ww/en/motor_drive_and_control_solutions/motor_control_videos.htm [9].

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Source URL (retrieved on *12/21/2013 - 11:36pm*): http://www.ecnmag.com/articles/2012/08/careful-designers-get-most-brushless-dc-motors?qt-video_of_the_day=0&qt-recent_content=0

Links:
[1] http://www.youtube.com/watch?v=d3fNzl_W4yg
[2] http://www.ti.com/tool/dk-lm3s-drv8312?DCMP=drv8312&HQS=stellaris-motor-pr-lp
[3] http://www.ecnmag.com/tinyurl.com/nqp73v
[4] http://www.magnelab.com/uploads/4c51d9ba6fe5a.pdf
[5] http://www.maxonmotorusa.com/
[6] http://www.microchip.com/pagehandler/en-us/technology/motorcontrol/
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